22nd European Conference on Fracture - ECF22

LOADING AND ENVIRONMENT EFFECTS ON STRUCTURAL INTEGRITY

Book of Abstracts

Belgrade, Serbia, 26 - 31 August, 2018

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ECF 21 *Fracture and safety*, Catania, Italy, Jun 20-24, 2016

ECF 20 *Fracture at all scales*, Trondheim, Norway, Jun 30-Jul 4, 2014

ECF 19 *Fracture mechanics for durability, reliability and safety*, Kazan, Russia, Aug 26-31, 2012

ECF 18 *Fracture of materials and structures from micro to macro scale*, Dresden, Germany, Aug 29-Sep 03, 2010

ECF 17 *Multilevel approach to fracture of materials, components and structures*, Brno, Czech Republic, Sep 2-5, 2008

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ECF 15 *Advanced fracture mechanics for life and safety assessments*, Stockholm, Sweden, Aug 11-13, 2004

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ECF 13 *Fracture mechanics: applications and challenges*, San Sebastian, Spain, Sep 6-9, 2000

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ECF 5 *Life assessment of dynamically loaded materials and structures*, Lisbon, Portugal, Sep 17-21, 1984

ECF 4 *Fracture and the role of microstructure*, Leoben, Austria, Sep 22-24, 1982

ECF 3 *Fracture and fatigue*, London, United Kingdom, Sep 8-10, 1980

ECF 2 *2nd European colloquium on fracture*, Darmstadt, Germany, Oct 9-11, 1978

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22nd EUROPEAN CONFERENCE ON FRACTURE

Loading and environment effects on structural integrity

PREFACE

This book contains printed abstracts of the papers presented at the 22nd European Conference on Fracture (ECF 22) – *Loading and Environment Effects on Structural Integrity*, held in Belgrade, Serbia, August 26-31, 2018. Many important topics of Fracture Mechanics and Structural Integrity are covered, including a number of mini-symposia, with many inspiring titles. A total of 563 participants from 47 countries took part in presenting 10 Plenary Lectures, 375 oral presentations and 118 posters.

Proceedings shall be published electronically, in a special edition of Procedia Structural Integrity. High quality papers in their extended form shall be considered for publishing in special issues of ESIS associated journals (WoS), *Engineering Fracture Mechanics*, *Engineering Failure Analysis*, *International Journal of Fatigue* and *Theoretical and Applied Fracture Mechanics*, as well as the DIVK journal *Structural Integrity and Life*, indexed in SCOPUS and ESCI Clarivate Analytics.

The introductory lecture was presented by Prof. James Rice. It has been an honour to witness Prof. James Rice presentation on the J integral, particularly on the occasion of the 50th anniversary of probably the most important paper in Fracture Mechanics history.

ESIS supported two special actions for researchers, and ESIS/Elsevier young scientist award. There were 35 supported researchers, and the best paper awards were presented to young scientists. For the first time, the best paper in *Weldment Fracture Mechanics* was awarded by Dr. Galip Buyuk-yildirim, on the behalf of the Turkish welding community, in the memory of Prof. Stojan Sedmak, who has been the heart and soul of all *Fracture Mechanics* and *Structural Integrity* activities in ex-Yugoslavia and later in Serbia.

The ECF 22 is the first ECF conference held in Serbia. The Serbian DIVK – *Society for Structural Integrity and Life – 'Prof. Dr Stojan Sedmak'* is thankful to the ESIS Council for choosing our country as the ECF 22 venue.

We would like to thank ESIS president Prof. Francesco Iacoviello and former president Prof. Leslie Banks-Sills for their kind support.

Prof. Aleksandar Sedmak, ECF 22 Chairman

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Support

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Analysis of stress corrosion cracking in X80 pipeline steel: An approach from the Theory of Critical Distances

P. González[a,*], S. Cicero[a], J.A. Álvarez[a], B. Arroyo[a]

[a]*LADICIM (Laboratorio de la División de Ciencia e Ingeniería de los Materiales), Universidad de Cantabria. ETS Ingenieros de Caminos, Canales y Puertos, Av/Los Castros 44, Santander 39005, España.*

Abstract

This paper presents an analysis of Stress Corrosion Cracking (SCC) based on the Theory of Critical Distances (TCD). The research is based on an experimental program composed of fracture specimens with notch radius varying from 0 mm (crack-like defect) up to 1 mm, and tensile specimens. A pipeline steel was used in this work (X80). It has been analysed in one hydrogen embrittlement situation. The study has been completed with Finite Elements Simulation analysis. The capacity of the TCD to analyse SCC processes has been proven.

Peer-review under responsibility of the ECF22 organizers.

Keywords: Hydrogen embrittlement; theory of critical distances; notch effect; environmental assisted cracking, stress corrosion cracking.

* Corresponding author. Tel.: +34 622 01 47 75
E-mail address: pablo.glez@unican.es

Embrittlement of RPV metal under long-term irradiation: state-of-the-art and challenges

Sergiy Kotrechko[a,*]

[a]*GV Kurdyumov Institute for Metal Physics of National Academy of Sciences of Ukraine, 36, Academician Vernadsky Blvd., Kyiv, 03142, Ukraine*

Abstract

Long-term irradiation is one of the harshest operating conditions for structural alloys. RPV metals function just in such conditions. To date, the development of both physical models of radiation embrittlement of RPV steels and engineering methods of lifetime prediction is a challenge for the science of materials' strength and structural integrity. That's why, this article reviews two main constituents of above problem, namely: (*i*) micro-mechanisms of radiation embrittlement of RPV metal, and, in particular, "late blooming effect"; (*ii*) development of physics-based engineering methods for prediction of RPV integrity during their long-term operation. In addition to the conventional analysis of micro-mechanisms of radiation hardening, the phenomenon of radiation-induced decrease in brittle strength of irradiated metal is discussed. The existing engineering approaches to prediction of RPV integrity under *thermal-shock load are summarised*. In general, they don't enable to use directly advances of physics of fracture of the irradiated material. A large "gap" exists today between the physics-based models of metal degradation under irradiation and engineering models for assessment of RPV lifetime. It is shown that proposed engineering version of the Local approach to fracture, may be one of the ways to solve this problem. The results of employment of this approach to predict life-time of WWER-1000 RPVs are presented.

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Keywords: RPV integrity, radiation embrittlement, elevated temperatures, Local approach to fracture, RPV lifetime, long-term operation.

* Corresponding author. Tel.:+38-044-424-1352; fax:+38-044-424-2561.
E-mail address: kotr@imp.kiev.ua (S. Kotrechko).

Effect of condensate corrosion on tensile and fatigue properties of brazed AISI 304L stainless steel joints using gold-base filler metal

Anke Schmiedt[a,*], Lars Lingnau[a], Matthias Manka[b], Wolfgang Tillmann[b], Frank Walther[a]

[a]*TU Dortmund University, Department of Materials Test Engineering (WPT), Baroper Str. 303, D-44227 Dortmund, Germany*
[b]*TU Dortmund University, Institute of Materials Engineering (LWT), Leonhard-Euler-Str. 2, D-44227 Dortmund, Germany*

Abstract

As brazed joints have to resist static and cyclic loads in corrosive environments, the effect of a condensate corrosion acc. to VDA 230-214 on the mechanical properties of brazed AISI 304L/BAu-4 joints is investigated. A significant and time-dependent degradation of tensile and fatigue properties is determined over 6 weeks. For an evaluation of local deformations within the small area of the brazing seam, the digital image correlation technique in combination with a triggered image acquisition is used during tensile and fatigue tests. Here, an increasing influence of the gauge length on strain values is identified for increasing stress levels, enhanced by notch-containing surfaces of the pre-corroded brazed joints. Fatigue and corrosion fatigue damage processes are evaluated using scanning electron microscopy.

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Keywords: brazed joints; AISI 304/BAu-4; condensate corrosion; corrosion fatigue; VDA 230-214; digital image correlation

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* Corresponding author. Tel.: +49 231 755 8041; fax: +49 231 755 8029.
E-mail address: anke.schmiedt@tu-dortmund.de

Lifetime assessment of additive manufactured polymer materials by means of the rolling ring test using cyclically loaded notched ring specimens

Ralf Lach[a,*], Andrea Monami[a,b], Sören Grießbach[c], Volker Grießbach[d], Wolfgang Grellmann[a]

[a]*Polymer Service GmbH Merseburg, Eberhard-Leibnitz-Straße 2, 06217 Merseburg, Germany*
[b]*Merseburg University of Applied Sciences, Department of Engineering and Natural Sciences, Eberhard-Leibnitz-Straße 2, 06217 Merseburg, Germany*
[c]*GS-Pro GmbH, Rabensteiner Straße 3, 09224 Chemnitz, Germany*
[d]*VG Kunststofftechnik GmbH, Ludwig-Richter-Straße 38, 09131 Chemnitz, Germany*

Abstract

Compared to other methods of fatigue testing which are in need of expensive testing machines and often highly time-consuming, the developed rolling ring tester is cost-effective, easily to handle and allows relatively fast data acquisition. Within only a few days essential information for fast quality assurance of laser-sintered parts are available such as about the influence of the processing conditions on the lifetime under cyclic loading. The number of cycles at break has been found to increase nearly logarithmically with decreasing deformation of the laser-sintered rolling rings made of polyamide 12. This behavior corresponds to a transition from fully stable fatigue crack growth to mixed stable–unstable crack propagation. Furthermore, the number of cycles at break increases linearly with increasing energy density used during the laser sintering process.

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Keywords: polymer materials; additive manufacturing; cyclic loading; lifetime estimation

* Corresponding author. Tel.: +49 3461 46-2780; fax: +49 3461 46-2592.
E-mail address: ralf.lach@psm-merseburg.de

Hard body impact on glass panes and the fracture energy equilibrium

Stefan Reich [a,*], M. Raghu Sagar Vanapalli[a]

[a]Anhalt University of Applied Sciences, building envelope research group, Bauhausstraße 5, 06846 Dessau, Germany

Abstract

The Griffith theory describes the behavior of brittle materials. For the description of a crack creation, an energy equilibrium is used. At annealed glasses, this equilibrium is reduced to a simple formula containing the mechanical energy in the glass and the surface energy needed for crack creation. The paper deals with the question, whether ball drop test allows the demonstration of the crack creation principles. Furthermore, the specific surface energy is the coefficient that describes the energy needed to create cracks. Therefore it will be discussed whether ball drop tests produce similar specific surface energy values like static tests, e.g. double cantilever of three-point-bending tests. The testing results show a constant surface energy coefficient at different drop height. Nevertheless, the measured coefficient showed a significant difference to statically determined surface energy coefficients. This was explained by the only partly use of the potential energy of the ball drop for the crack creation. The damping of the glass pane, that is supported in a gasket play a significant role in energy absorption. At a ball drop test the energy amount is defined and the energy input cannot be stopped during the experiment. Despite its easy build-up and conduction, the ball drop test seems not to be an appropriate investigation for the fracture mechanism of brittle glass.

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Keywords: Glass, equilibrium; surface energy; brittle fracture; ball drop

* Corresponding author.
E-mail address: stefan.reich@hs-anhalt.de

Damage and fracture of ductile sheet metal: New biaxially loaded specimens for material parameter identification

Steffen Gerke[a,*], Moritz Zistl[a], Marco Schmidt[a], Michael Brünig[a]

[a]*Institut für Mechanik und Statik, Universität der Bundeswehr München, Werner-Heisenberg-Weg 39, D-85577 Neubiberg, Germany*

Abstract

The paper deals with an experimental series of the new biaxial X0-specimen to study the damage and fracture behavior of ductile sheet metal. The specimens have been fabricated from the aluminum alloy EN AW 6082 (AlSiMgMn) and are proportionally loaded with different ratios. Firstly different specimen geometries from the literature for the material parameter determination of sheet metal are discussed and in this context new specimen geometries are motivated and presented. In continuation a corresponding phenomenological continuum damage model is briefly introduced. Main focus is given on experimental results with the biaxial X0-specimen whereas results of new load cases are presented and discussed. The geometry indicates good applicability while advantages and disadvantages are pointed out and finally a perspective to future work is given.

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Keywords: Biaxial experiments; new specimens; ductile damage and fracture; stress state dependence; sheet metals; digital image correlation (DIC); scanning electron microscope (SEM)

* Corresponding author. Tel.: +49-89-6004-3422.
E-mail address: steffen.gerke@unibw.de

Effect of gradient plasticity on crack initiation and propagation in the ductile-brittle transition region of ferritic steel

N.A. Giang[a,*], M. Kuna[a], G. Hütter[a]

[a]*Institute of Mechanics and Fluid Dynamics (IMFD), TU Freiberg, 09599 Freiberg, Germany*

Abstract

Micro-crack initiation in ductile-brittle transition region of ferritic steel is often observed through cracking of carbides near or at ferritic grain boundary. The main reason is that the dislocation pile-up at a grain boundary induces high stresses in the carbide. This mechanism cannot be modelled by classical plasticity. In the present study, the effective gradient plasticity (scalar gradient plasticity) together with cohesive zone models is employed in a unit cell model to adress this mechanism at the microscale.

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Keywords: Ferritic steel; Gradient plasticity; Cell model; Cracking of carbide particle.

* Corresponding author. Tel.: +49-373-139-3313 ; fax: +49-373-139-3455.
E-mail address: Ngoc-Anh.Giang@imfd.tu-freiberg.de

Fracture behavior of rock plate under static and dynamic combined loads

Guiyun Gao[a,*]

[a]Institute of Crustal Dynamics, China Earthquake Administration, Beijing 100085, China

Abstract

It is critical to understand the dynamic fracture and crack propagation of confined rocks in geophysics and geoengineering application, such as earthquake fault rupture and in-situ stress measurement. The objective of this paper is to characterize the dynamic fracture behavior of rock plate especially under uniaxial compression using the DIC method combined with ultra-high speed photography. Using a modified hydraulic pump, the uniaxial compression was exerted at the top and bottom ends of the rock plate. Dynamic crack propagation tests of plate specimen were conducted using split Hopkinson pressure bar (SHPB) and the fracture processes were captured by an ultra-high speed photography. The displacement and strain fields of the dynamic fracture process were calculated using DIC. By setting the virtual digital extensometer, the crack-tip position, crack propagation velocity and the dynamic fracture toughness were obtained. Results show that the fracture toughness increases from 1.39 MPa·m$^{1/2}$ to 2.25 MPa·m$^{1/2}$, and the crack propagation velocity increases from 843.6 m/s to 1148.3 m/s when the incident velocity increases from 8.95m/s to 19.3m/s. The crack propagation velocity is higher than that obtained from small specimen such as NSCB specimen (Gao et al., 2015). Crack propagation velocity in rock plate is higher than that in small specimen such as notched semi-circular bending (NSCB) specimen of rock. There is one main crack path under lower gas pressure, while crack bifurcation occurs under high loading pressure. Crack propagation velocity and crack arrest length decrease with the increase of the hydraulic compressive pressure. If the plate is free of confining stress before dynamic loading, the crack propagation velocity is about 965.0 m/s. The crack propagation velocity decreases with the increase of hydraulic confining stress, and it reduces to about 452.4 m/s at hydraulic pump pressure of 30 MPa or confining stress of 10.6 MPa. Micro cracks could be observed near the crack path and the crack tip when the rock plate subjected to hydraulic compression and dynamic loading. Therefore, DIC method combined with ultra-high speed photography could be used to study the dynamic rock fracture under confining stress, which provides a new method for high speed failure investigation of underground rock that concerned in geophysics and geoengineering application.

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Keywords: Rock plate, combined load, Digital Image Correlation, crack propagation velocity

* Corresponding author. Tel.: +86-15120055150; fax: +86-010-62846130.
E-mail address: gygaopku@163.com

Biaxial experiments on the effect of non-proportional loading paths on damage and fracture behavior of ductile metals

Moritz Zistl[a,*], Steffen Gerke[a], Michael Brünig[a]

[a]*Institut für Mechanik und Statik, Universit¨at der Bundeswehr München, Werner-Heisenberg-Weg 39, 85579 Neubiberg, Germany*

Abstract

The paper deals with a series of new experiments to study the effect of non-proportional loading paths on damage and fracture behavior of ductile metals. In this context, a thermodynamically consistent anisotropic continuum damage model is presented. It takes into account the effect of stress state on damage conditions as well as on the evolution of damage strains. Different branches of the damage criteria corresponding to various ductile damage and fracture mechanisms depending on stress state are considered. The two-dimensionally loaded X0-specimen covering a wide range of stress triaxialities and Lode parameters in the tension and shear stress domains is being used. These tests are driven under different non-proportional loading paths. The formation of strain fields of the specimens is recorded by digital image correlation technique. Furthermore, scanning electron microscope analysis of the fracture surfaces clearly shows various failure modes corresponding to these loading conditions.

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Keywords: Damage and fracture; biaxial experiments; non-proportional loading paths; digital image correlation; scanning electron microscopy

* Corresponding author. Tel.: +49-89-6004-3413 ; fax: +49-89-6004-4549.
E-mail address: moritz.zistl@unibw.de

Applicability of local approaches to assessment of cleavage fracture in complex constraint and load history cases

J. Beswick[a], D. Sarzosa[b], R. Savioli[b], P. James[c], C. Ruggieri[b], A.P. Jivkov[a,*]

[a]*Mechanics and Physics of Solids Research Group, School of Mechanical, Aerospace and Civil Engineering, The University of Manchester, UK*
[b]*Fracture Mechanics and Structural Integrity Research Group, School of Engineering, University of Sao Paulo, Brazil*
[c]*Wood, Warrington, Cheshire, UK*

Abstract

The paper presents results and analysis from an on-going investigation to better understand and quantify the effects of constraint on cleavage fracture under various initial stress and plastic strain conditions. Specifically, new fracture toughness data obtained with three-point bend specimens with crack-to-width ratios 0.4, 0.2 and 0.05 is shown for as-received material and material with 5% initial uniaxial plastic strain. Firstly, analysis with the J-Q approach is used to argue that while pre-strain initial conditions change the fracture toughness, the shape of the failure locus in the J-Q space might remain unaffected. The implication is significant reduction of tests required for assessments taking constraint into account. The potential to use current local approach methods to allow a fracture prediction, which is independent of initial conditions, is then investigated by application of modified Beremin models. It is demonstrated that the local approaches are capable of predicting changes in the apparent toughness across the three constraint levels for the as-received material. It is further shown that accommodation of load history effects, such as the initial plastic strain, requires an advancement of the classical approach, a subject of on-going work.

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Keywords: cleavage fracture; very low constraint; initial plastic strain; two-parameter assessment; local approach

* Corresponding author. *Tel.:* +44-161-306-3765.
E-mail address: andrey.jivkov@manchester.ac.uk

Assessment of fatigue crack growth behavior of cracked specimens repaired by indentation

S.M.J. Razavi[a,*], M.R. Ayatollahi[b], F. Berto[a]

[a]*Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology (NTNU), Richard Birkelands vei 2b, 7491 Trondheim, Norway.*
[b]*School of Mechanical Engineering, Iran University of Science and Technology, Narmak, 16846, Tehran, Iran.*

Abstract

The indentation technique has been widely studied as a technique for fatigue crack growth retardation. However, the majority of the researches are limited only to crack tip indentation technique. The aim of current research is to investigate the effect of three different methods of indentation on the fatigue crack growth life of the pre-cracked specimens. Fatigue tests were performed on a group of specimens repaired by crack tip indentation using various indentation loads and the results were compared with the samples repaired by the double indentation and triple indentation methods. The experimental results revealed that the higher indentation loads results larger domain of compressive residual stress at the vicinity of the crack tip and consequently improve the fatigue crack growth life of the pre-cracked specimen. Additionally, the location of the indentation plays an important role in the efficiency of this method. For the specimens repaired by double and triple indentation methods, indenting ahead of the crack tip led to retardation in more crack growth compared to the other horizontal positions of indentation. The triple indentation technique which was proposed in this research provided higher fatigue crack growth retardation compared to single and double indentation methods.

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Keywords: crack retardation; fatigue crack growth; fatigue damage repair; residual stress

* Corresponding author. Tel.: +47-735-93761.
E-mail address: javad.razavi@ntnu.no

Fatigue strength of notched specimens made of Ti-6Al-4V produced by SLM technique

S.M.J. Razavi[a,*], F. Berto[a]

[a]Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology (NTNU), Trondheim 7491, Norway

Abstract

As an Additive Manufacturing (AM) method, Selective Laser Melting (SLM) allows fabrication of metallic components of any desired geometry with densities greater than 99.5%. This method is usually used for geometrically optimized components with complex geometries including various kinds of notches. Hence, it is important to have a clear information about the fatigue behavior of notched components made by SLM method. This paper evaluates the fatigue behavior of Ti-6Al-4V blunt V-notched and circular notched samples produced by SLM. The fatigue results were then compared with those of the corresponding smooth samples. The fracture surfaces of the tested samples were evaluated using Environmental Scanning Electron Microscopy (ESEM) and the crack initiation points and fracture mechanisms were identified.

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Keywords: Fatigue; notch mechanics; selective laser melting (SLM); semi-circular notch, V notch.

* Corresponding author. Tel.: +47-735-93761.
E-mail address: javad.razavi@ntnu.no

Determination of residual fatigue life of welded structures at bucket-wheel excavators through the use of fracture mechanics

Miodrag Arsić[a,]*, Srđan Bošnjak[b], Nebojša Gnjatović[b], Simon A. Sedmak[c], Dušan Arsić[d], Zoran Savić[a]

[a]*Institute for Materials Testing, 11000 Belgrade, Serbia,*
[b]*Faculty of Mechanical Engineering, 11120 Belgrade, Serbia,*
[c]*Innovation Centre of the Faculty of Mechanical Enginering, 11120, Belgrade, Serbia,*
[d]*Faculty of Engineering,University of Kragujevac, 34000 Kragujevac, Serbia,*

Abstract

This paper presents a methodological approach for the assessment of service life of vital welded structures of a bucket-wheel excavator Sch Rs 650/5x24 ('Thyssen Krupp', Germany) boom, subjected to cyclic loading with a variable amplitude through the use of experimental tests carried out in order to determine operational strength and growth of a fatigue crack. Realized researches and results presented in this paper offer great possibilities for the analyses of behaviour of vital welded structures of the bucket-wheel boom. By the application of the measurement device with 8 channels for registration and processing of electric signals HBM Spider 8 and measurement tapes HBM 6/350xXY31 deformations were measured at vital welded structures of the boom in the area of the bucket-wheel, made of steels St 37.2 and St 52.3 in accordance with standard DIN 17100, or steels S235J2G3 and S355J2G3 in accordance with standard EN 10025-2. The objective of the test is to determine if there is a possibility of occurrence of plastic deformations or initial cracks due to fatigue at vital welded structures. Tests that refer to the growth of the fatigue crack located at the welded joint have been carried out by bending at three points with asymmetric load R = 0.5 ($R = \sigma_{min} / \sigma_{max}$) at the specimen with a single edge notch. Tests were performed through the use of controlled force, ranging between F_{max} and F_{min} at the high-frequency pulsator 'Cracktronic', while obtainment of data regarding the crack growth was carried out through the use of measurement gauge ARM A-10.

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Keywords: bucket-wheel excavator, stress condition, crack, service life

* Corresponding author. Tel.: /
E-mail address: miodrag.arsic@institutims.rs

Effect of hygrothermal environment on the fatigue behaviours of composite laminates

He Yuting[a,*], Feng Yu[a]

[a]*Air Force Engineering University, China*

Abstract

Effect of hygrothermal environment on the fatigue behaviors of composite laminates were investigated in this paper. Absorbing moisture property was analyzed and the micro-damage evolution during the absorbing process was observed. A modified Fick model considering the side absorbing was proposed. Then the static tensile properties after hygrothermal exposure was studied in term of failure strength/strain, stress-strain curves and failure modes, with a comparison with the pristine laminates. Aged specimens have multi-damage fracture and the fracture positions show more uncertainty, which is far different from the pristine laminates. Finally the tension-tension fatigue performances of aged laminates were investigated. The median fatigue life of aged laminates decrease seriously under various stress level. Aged laminates has more serious damage than the virgin specimens at the same fatigue life percentage, which results in the more serious decrease in stiffness of saturated composite laminates.

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Keywords: Hygrothermal, absorbing moisture, damage, stiffness, fatigue life

* Corresponding author. Tel.: /
E-mail address: heyut666@126.com

Identification of crack positions and crack loading quantities from strain gauge data by inverse problem solution

Ramdane Boukellif [a,*], Andreas Ricoeur [a]

[a]Institute of Mechanics, Department of Mechanical Engineering, University of Kassel, 34125 Kassel, Germany

Abstract

A method for the detection of cracks in finite and semi-infinite plane structures is presented. This allows both the identification of crack position parameters such as length, location and inclination angles with respect to a reference coordinate system and the calculation of stress intensity factors (SIFs). The method is based on strains measured at different locations on the surface of a structure and the application of the dislocation technique. Cracks and boundaries are modelled by continuous distributions of dislocation densities. This approach gives a set of singular integral equations with Cauchy kernels, which can be solved using Gauss-Chebyshev numerical quadrature [Erdogan et al. (1973)]. Once knowing the dislocation densities, the strain at an arbitrary point can be calculated. The crack parameters as well as external loads are parameters which are determined by solving the inverse problem with a genetic algorithm. Once knowing loading and crack parameters, the SIFs can be calculated.

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Keywords: Crack detection; distributed dislocations; inverse problem; finite plate; strain gauges

* Corresponding author. Tel.: +49 561 804 2505 ; fax: +49 561 804 2720.
E-mail address: ramdane.boukellif@uni-kassel.de

The effect of negative stress triaxialities on ductile damage and fracture behavior in metal sheets

Marco Schmidt[a,]*, Steffen Gerke[a], Michael Brünig[a]

[a]*Institut für Mechanik und Statik, Universit¨at der Bundeswehr München, Werner-Heisenberg-Weg 39, 85579 Neubiberg, Germany*

Abstract

The paper deals with an anisotropic continuum damage and fracture model and a series of biaxial experiments with focus on negative stress triaxialities. The continuum model is based on the assumption that different damage mechanisms are present and have to be taken into account depending on stress triaxiality and Lode parameter. Therefore, modeling of onset and evaluation of damage are based on a stress-state-dependent damage condition and a stress-state-dependent damage rule. To identify the corresponding parameters biaxial experiments with specimens taken from aluminum sheets have been performed and results of corresponding numerical simulations are discussed in detail. The experimental behavior has been analyzed with a digital image correlation system to compare the strain fields with those obtained by numerical simulations. In addition, fracture modes are detected by scanning electron microscopy. Based on the experimental and numerical results a stress-state-dependent cut-off value for negative stress triaxialities is proposed.

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Keywords: Continuum damage model; ductile metal sheets; stress-state-dependence; experiments; numerical simulations

* Corresponding author. Tel.: +49-89-60043413 ; fax: +49-89-60044549.
E-mail address: m.schmidt@unibw.de

INCEFA-PLUS (increasing safety in NPPs by covering gaps in Environmental Fatigue Assessment)

Isabela Procopio[a,*], Sergio Cicero[a], Kevin Mottershead[b], Matthias Bruchhausen[c], Sam Cuvilliez[d]

[a]*University of Cantabria, Avenida los Castros 44, Santander 39005, Spain*
[b]*Wood, 305 Bridgewater Place, Warrington WA3 6XG, UK*
[c]*European Comission (Joint Research Centre – JRC), Westerduinweg 3, Petten 1755 LE, Netherlands*
[d]*Electricité de France (EDF – DIPNN - DT), 19 rue Bourdeix, CS 80323, 69363 Lyon Cedex 07, France*

Abstract

INCEFA-PLUS is a European Project (funded by the European Commission HORIZON2020 program) that started in July 2015 and lasts five years (until June 2020). The project consists of 16 members from all over Europe and has as its main goal to guarantee safety in operations of Nuclear Power Plants (NPPs) by delivering experimental data to support the development of improved environmental fatigue assessment guidelines. The issues that are being studied (experimentally) are those of common interests to all participants: the effects of mean strain/stress, hold time, strain amplitude and surface finish on the fatigue performance of austenitic stainless steels in the LWR (Light Water Reactor) environment.
Within the framework of the CEN (European Committee for Standardization) workshop FATEDA, the consortium developed a fatigue data format. This data format was used in an online environmental fatigue database, where the experimental data are made available for all participants. Later in the project, it is intended to develop an environmental fatigue assessment procedure on the basis of this data.
The paper will introduce the project and describe phase one (of three) testing, including conditions such as surface finish and hold time. The plans that are being made for phase two testing will be detailed. The materials used in the tests, the surface finish data and some experimental results for phase one will be presented, together with a summary of the INCEFA-PLUS testing protocol. Finally, a review of existing assessment methodologies and a summary of dissemination activities will be provided.

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Keywords: Environmental fatigue, INCEFA-PLUS, light water reactor, nuclear power plants.

* Corresponding author. Tel.: +34-942-200-928
E-mail address: pessoai@unican.es

Application of the PAM method in the milk production sector

Ivana Franjić[a,]*, Dubravka Živoder[a]

[a]*Croatian Agricultural Agency, Croatia*

Abstract

Agricultural production in the Republic of Croatia has followed many problems since the Second World War. At that time the development of agriculture was subordinated to the development of the industry. There were few economic activities that were important for the development of agriculture. These were, above all, guidelines, which served as incentives for a successful future for agriculture, and were sufficient only to prevent the abolition of agricultural production, that is, to ensure sufficient food supply, because by the cessation of the population's employment with agricultural production, would be the end of food production. Family farms face major changes that have long been transformed but due to the fear of something new, this has not happened yet. Based on outdated conceptions and management systems, they are not able to respond to market economy conditions. In order for the economy to adapt, it will have to be seen as an enterprise or a family farm will become the basic organizational form in agricultural production and management in market economy conditions will become an important factor in their business. One of the main goals of agrarian policy is to develop the market structure and adjust the institutional framework in line with market trends. Thus, in 2001, prescribed by the Law on Agriculture and Measures Measured under the Measure of Market Price Policy. Market price policy affects the stability of the domestic market of agricultural products, while strengthening the competitiveness of Croatian agriculture and the implementation of obligations in accordance with international trade agreements. Market price policy consists of the following set of measures: prescribed prices, cash incentives and fees, Measures to encourage sales and consumption, agricultural balancing measures, trade measures. The aim of this paper is to present the calculation of the matrix of political analysis under the name of the PAM method in the milk production sector with the aim of considering the difference between private and economic prices in relation to the costs or inputs traded on domestic inputs and on the basis of calculating the condition of state intervention well thought out or the sector has caused problems. Also, data on the dairy sector in the Republic of Croatia are presented in this paper.

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Keywords: PAM method, agricultural production, agrarian policy, milk production sector.

* Corresponding author. Tel.: /
E-mail address: ifranjic@hpa.hr, dzivoder@hpa.hr

Computer simulation of cleavage fracture surface morphologies in steel plates

Taiko Aikawa[a], Shuji Aihara[a,*] ,Tomoya Kawabata[a], Fuminori Yanagimoto[a], Kazuki Shibanuma[a]

[a]*The University of Tokyo, 7-3-1, Hongo, Bunkyo, Tokyo, 113-8656, Japan*

Abstract

A computer simulation model has been developed to reproduce brittle fracture surface morphologies. Local stress intensity factor along a propagating crack front is calculated considering the fracture surface irregularity and crack front non-straightness. Shear stress exerted at fracture surface steps and crack closure stress by uncracked ligament are also taken into consideration in calculating the local stress intensity factor. The local stress intensity factor is compared with assumed critical value to judge if a crack propagate or arrests at each crack front location. The model was found to reproduce chevron markings and shear-lips, both of which are typical of cleavage fracture in steels. The present model was applied to wide-plate crack arrest test with temperature-gradient. Changes of fracture surface morphologies and arrest crack length were well reproduced by the present model.

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Keywords: Brittle fracture; fracture surface morphology; crack propagation and arrest

* Corresponding author. Tel.: +81-3-5841-6505;
E-mail address: aihara@fract.t.u-tokyo.ac.jp

Simulated running ductile fracture experiment using rubber tube

Yasuyuki Furuta[a], Yuki Nishizono[a], Shuji Aihara[a,]*, Fuminori Yanagimoto[a], Tomoya Kawabata[a], Kazuki Shibanuma[a], Carlos A. Oliveira[b], Armando H. Shinohara[b]

[a]*The University of Tokyo, 7-3-1, Hongo, Bunkyo, Tokyo, 113-8656, Japan*
[b]*Federal University of Pernambuco, Cidade Universitairia, 50740530-Recife, PE, Brazil*

Abstract

Dynamic frack propagation experiment using rubber tubes has been developed which is intended to simulate running ductile fracture in high-pressure gas pipelines. Crack velocity was measured by high-speed camera. It ranged 100 to 500m/s, depending on pressure. The crack velocity decreased more rapidly in helium gas test than in the air test. This result was explained by a comparison of crack propagation velocity and sound velocity of the gas media. The crack opening shape was found similar to that of full-scale burst tests of steel pipes. Also, crack deviation leading to ring-off and crack arrest took place, which was similar to full-scale burst tests. Bi-axial stress state was suggested as a factor controlling the crack deviation.

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Keywords: Dynamic crack propagation; rubber tube; pipelines; crack arrest

* Corresponding author. Tel.: +81-3-5841-6505;
E-mail address: aihara@fract.t.u-tokyo.ac.jp

Investigation on brittle crack propagation and arrest behaviors under high crack driving force in steel

Fuminori Yanagimoto[a,]* , Kazuki Shibanuma[a], Teppei Okawa[b], Katsuyuki Suzuki[c], Shuji Aihara[a]

[a]*Department of Systems Innovation, Graduate School of Engineering, the University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo, Japan*
[b]*Plate & Shape Research Lab., Steel Research Laboratories, Nippon Steel & Sumitomo Metal Coopreration, 20-1 Shintomi, Futtsu-shi, Chiba, Japan*
[c]*Research into Artifacts, Center for Engineering, the University of Tokyo, 5-1-5, Kashiwa-shi, Chiba, Japan*

Abstract

The brittle crack propagation and arrest behaviors under high stress intensity factor conditions have been an unsolved problem in the fracture mechanics. Although a numerical model based on the local fracture stress criterion indicated growth of unbroken shear lips due to SIF increasing was a cause of the problem, such model depended on many assumptions and it lacked experimental discussion on the behaviors. This study carried out brittle crack arrest experiments under high SIF condition using wider specimens. The experiments and finite element analyses of them showed that the unbroken shear lip formation was governed by the effective SIF. The numerical model was modified based on this result and the predictions by the modified model showed better agreement with the experimental results than those by the conventional model.

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Keywords: Brittle crack propagation and arrest behaviour; rapid crack propagation, steel

* Corresponding author. Tel.: +81-3-5841-6505;
E-mail address: yanagimoto@struct.t.u-tokyo.ac.jp

Testing of Brazilian disk specimens with a delamination between a transversely isotropic and a tetragonal composite ply

Mor Mega[a], Leslie Banks-Sills[a,*]

[a]*The Dreszer Fracture Mechanics Laboratory , School of Mechanical Engineering, Tel Aviv University, 6997801 Ramat Aviv, Israel*

Abstract

Fracture toughness tests using the Brazilian disk specimen (BD) were carried out to determine the toughness properties of a delamination between two fiber reinforced composite plies. The upper ply is a transversely isotropic UD fabric with fibers oriented in the 0°-direction and the lower ply is a tetragonal plain balanced weave with fibers oriented in the +45°/ -45° -directions. The composite is manufactured as a wet-layup. With the BD specimen, mixed mode combinations are achieved by changing the loading angle ω, between the load line and the delamination. Eight specimens were tested at four loading angles, two for each angle. Based on the test results, finite element (FE) analyses were carried out in conjunction with two methods, the three-dimensional conservative M-integral and displacement extrapolation (DE) to obtain the stress intensity factors along the delamination front for each specimen resulting from mechanical loads, as well as residual stresses. The two methods were used in order to validate the results. Both methods were extended for this specific interface and made use of the first term of the asymptotic solution of the displacement field. The stress intensity factors were superposed, and the critical interface energy release rates and phase angles were calculated and plotted.

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Keywords: delamination; fracture toughness; interface energy release rate; multidirectional composite; stress intensity factors;

* Corresponding author. Tel.: +972-3-640-8992; fax: +972-3-640-8992.
E-mail address: pellegmor@gmail.com

Application of singular integral equation to crack moving near an inclusion in two-dimensional infinite plate

Masayuki Arai[a], Kazuki Yoshida[b,*]

[a]*Department of Mechanical Engineering, Tokyo University of Science, 6-3-1, Niijyuku, Katsushika-ku, Tokyo 125-8585, Japan*
[b]*Graduate School of Mechanical Engineering, Tokyo University od Science, 6-3-1, Niijyuku, Katsushika-ku, Tokyo 125-8585, Japan*

Abstract

This paper describes application of singular integral equation method to crack moving near an inclusion in two-dimensional infinite plate which is subjected to a tensile loading at infinity. The theoretical formulation is based upon the superposition of the problem of a continuous distribution of edge dislocations spread along the crack locus in an infinite plate with single inclusion and the problem for the same geometry without crack which is subjected to a tensile loading. The superposition leads to simultaneous singular integral equation, and they relate the surface zero-tractions to the dislocation densities along the curved crack locus. The stress intensity factors are derived directly from the crack-tip stress field. Then, the crack tip is automatically moved to a direction as satisfying the restriction that the stress intensity factor K_{II} is zero, which was developed in this study. The direction search is conducted by rotating the tip of virtually incremented crack around the origin crack tip. The search and extension processes are repeated in sequence. In this numerical calculation, the influence of the initial crack locations on crack moving path is discussed.

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Keywords: singular integral equation method, stress intensity factor, crack tip stress field

* Corresponding author. Tel.: +81-3-5876-1823; fax: +81-3-5876-1823.
E-mail address: marai@rs.tus.ac.jp

Cutting resistance of polymeric materials: experimental and theoretical investigation

A. Spagnoli [a,*], R. Brighenti[a] , M. Terzano[a] , F. Artoni[a] , P. Ståhle[b]

[a]Department of Engineering and Architecture, University of Parma, Viale Usberti 181/A, 43124 Parma, Italy
[b]Division of Solid Mechanics, Lund University, SE-221 00 Lund, Sweden

Abstract

In the present paper, an experimental campaign is carried out with reference to the steady state propagation of an existing cut in polymeric plates, ranging from glassy to soft polymers. The steady state propagation is investigated by considering a commercial cutting tool under different insertion velocities of the blade. Full-field finite strain maps are experimentally recorded by means of digital image correlation technique, along with the recording of the insertion force vs displacement curve. It is shown that the cutting resistance is dependent on the fracture toughness of the target material and on the sharpness of the cutting tool. Different scenarios of steady state cut propagation are observed if either a relatively blunt or a relatively sharp blade penetrates in the material. Alternative blade sharpness parameters can be used to discriminate the different conditions of cut propagation observed in the experiments. A theoretical interpretation of the experimental outcomes is provided.
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Keywords: Cutting; soft materials; glassy polymers; large deformations; fracture toughness; blade sharpness.

* Corresponding author. Tel.: +39-0521-905927 ; fax: +39-0521-905924.
E-mail address: spagnoli@unipr.it

Impact of aggressive media on the interlaminar shear strength of innovative glass fiber reinforced polyurea/polysilicate hybrid resins

Mark Kopietz[a,]*, Bernd Wetzel[a]

[a]*Institut für Verbundwerkstoffe GmbH, Erwin-Schrödinger-Str. 58, 67663 Kaiserslautern, Germany*

Abstract

In this work the impact of different media (water, sodium hydroxide (NaOH), and hydrochloric acid (HCl)) especially on the interlaminar shear strength (ILSS) of glass fiber reinforced plastics (GFRP) were explored. The ILSS served as an indicator for the adhesion between fibers and matrix. Furthermore, the media uptake and loss of non-bonded chemicals were determined.
As matrices served phosphate-containing polyurea/polysilicate resin (3P Resins®) as a reference and a recently developed phosphate-free hybrid resin denoted as 2P. Additionally, the 2P hybrid resins were modified by 1 vol% of the nonionic surfactant Efka® WE 3110. It was found that the phosphate-free resin (2P) reaches both, a significantly increased ILSS and fiber/matrix adhesion, and simultaneously, a lower media uptake compared to the 3P. These properties were further enhanced by the presence of the surfactant. Besides, the market established reference resin showed a mass loss indicating the diffusion of unfavorable phosphates from the composite into the media.

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Keywords: Fiber-reinforced plastics, interlaminar shear strength, polyurea/polysilicate hybrid resins, media resistance

* Corresponding author. Tel.: +49 (0)631/2017-147; fax: +49 (0)631/2017-199.
E-mail address: mark.kopietz@ivw.uni-kl.de

Tensile and compression properties of variously arranged porous Ti-6Al-4V additively manufactured structures via SLM

S. Raghavendra[a,*], A. Molinari[a], V. Fontanari[a], V. Luchin[b], G. Zappini[b], M. Benedetti[a], F. Johansson[c], J. Klarin[c]

[a]*Department of Industrial Engineering,University of Trento,Trento 38123,Italy*
[b]*Eurocoating Spa, Pergine Valsugana, Trento 38057, Italy*
[c]*Product Development and Materials Engineering, Jönköping University, Jönköping 55318, Sweden*

Abstract

Additively manufactured porous structures find increasing applications in the biomedical context to produce orthopedic prosthesis and devices. In comparison with traditional bulk metallic implants, they permit to tailor the stiffness of the prosthesis to that of the surrounding bony tissues, thus limiting the onset of stress shielding and resulting implant loosening, and to favor the bone in-growth through the interconnected pores. Mechanical and biological properties of these structures are strongly influenced by the size and spatial arrangement of pores and struts. In the present work irregular and regular cellular as well as fully random porous structures are investigated through tensile and compression uniaxial tests. Specific point of novelty of this work is that, beside classical compressive tests, which are standard characterization methods for porous/cellular materials, tensile tests are carried out. Mechanical tests are complemented with morphological analysis and porosity measurements. An attempt is made to find correlations between cell arrangements, porosity and mechanical properties.
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Keywords: Cellular structures; porosity; strength

* Corresponding author. Tel.: +39-348-381-7779; fax: +0-000-000-0000 .
E-mail address: sunil.raghavendra@unitn.it

TiZrNbTaMo high-entropy alloys designed for orthopedic implants: optimization for mechanical properties

Shao-Ping Wang[a,] Jian Xu[a,]*

[a]*Institute of Metal Research, Chinese Academy of Sciences, China*

Abstract

Combining the high-entropy alloy (HEA) concept with property requirement for orthopedic implants, we proposed an idea to develop new alloys applicable for orthopedic implants, chemically based on biocompatible refractory elements such as Ti, Zr, Nb, Ta and Mo. Using equiatomic TiZrNbTaMo alloy as composition starting point, dependence of microstructure and mechanical properties on Mo concentration are investigated in arc-melted (TiZrNbTa)100-xMox (0δx⩽20) HEAs. The arc-melted (TiZrNbTa)100-xMox alloys structurally consist of two bcc phases. It is shown that with increasing the Mo concentration in the alloys, compressive strength, □y, and Young's modulus, E, increase from 1020 MPa and 115 GPa for the Mo-free quaternary to 1460 MPa and 155 GPa at 20% Mo, respectively. Meanwhile, Mo-concentrated alloys result in deterioration in ductility and toughness, showing a decrease in notch toughness, K_Q, from 29 MPa□m for the Mo-free alloy down to 19 MPa□m at 20% Mo. Moreover, fracture mode at crack tip undergoes a transition from the intergranular to the transgranular. To compromise the strength and toughness, the (TiZrNbTa)90Mo10 exhibits an optimal combination of stiffness (E=137 GPa), compressive yield strength (σ_y=1300 MPa) and fracture toughness (K_Q=20 MPa√m). Suh an alloy is expected to possess improved wear resistance superior to the titanium alloys, and potentially to be used in hard-tissue prosthesis with loading bearing surfaces. Future efforts will focus on the optimization of mechanical properties via processing, and the understanding of corrosion and tribocorrosion behavior in simulated physiological environment.

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Keywords: multicomponent alloy; fracture toughness; strength

* Corresponding author. Tel.: /
E-mail address*:* jianxu@imr.ac.cn

Application of material forces and path independent integrals to the prediction of crack initiation and crack paths

Paul Judt[a,*], Andreas Ricoeur [a]

[a]Institute of Mechanics, University of Kassel, M¨onchebergstraße 7, 34125 Kassel, Germany

Abstract

Next to the shape of a growing crack, it is of importance to predict the initiation of new cracks, especially in structures with stress concentrations due to e.g. holes or notches. In the past, different criteria for crack initiation have been discussed. Furthermore, cracks growing in the vicinity of such stress concentrations in general are deflected and therefore complex crack paths arise. The prediction of crack initiation and the shape of crack paths becomes even more complicated if a material exhibits anisotropic constitutive properties or fracture toughnesses. In this paper, a unified approach of material forces for the prediction of the initiation and growth of a crack is presented. The material or configurational forces as crack driving quantity are strongly related to path-independent integrals, e.g. the J_k -integral. A novel methodology is presented for accurately calculating material forces at cracks employing local numerical data. Material tractions at a round U-notch are investigated and related to crack initiation.

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Keywords: material forces, accuracy, crack initiation, crack paths, fracture toughness anisotropy

* Corresponding author. Tel.: +49-561-804-2852; fax: +49-451-804-2720.
E-mail address: judt@uni-kassel.de

Effect of the geometrical defectiveness on the mechanical properties of SLM biomedical Ti6Al4V lattices

M. Dallago[a,*], F. Zanini[b], S. Carmignato[b], D. Pasini[c], M. Benedetti[a]

[a]*Department of Industrial Engineering, University of Trento, Trento, Italy*
[b]*Department of Management and Engineering, University of Padova, Stradella San Nicola 3, Vicenza, Italy*
[c]*Department of Mechanical Engineering, McGill University, Montreal, Quebec, Canada*

Abstract

Metallic lattice biomaterials can be very complex structures that are often impossible to be fabricated with other manufacturing technologies than additive manufacturing (AM). Residual stresses and geometric defects such as severe notches and distorted struts are inevitably introduced into the printed structures and these can affect the mechanical and biological properties. Micro X-ray Computed Tomography (μCT) has been proven to be a very powerful tool for accurately measuring the mismatch between the as-designed CAD model and the SLM structure. In this work, selective laser melting (SLM) Ti6Al4V lattices were measured using a metrological μCT system to identify and classify the geometrical distortions introduced by the printing process. The μCT measurements have also been used to build Finite Element (FE) models based on beam elements that make possible a quantification of the effect of these defects on the elastic modulus of the lattice by comparison with FE models based on the ideal geometry. Moreover, solid FE models of the junctions between the struts have been built by importing the CT data in Ansys® to calculate the stress concentrations caused by the severe notches.

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Keywords: Cellular materials; Computed tomography; Finite elements; Selective laser melting

* Corresponding author. Tel.: /
E-mail address: michele.dallago@unitn.it

Fracture behaviour and microstructure-mechanics relationship of human aortic aneurysms

Aziz Tokgoz[a,*], Shuo Wang[b], Priya Sastry[c], Chang Sun[b], Nichola Figg[c], Martin R. Bennett[c], Sanjay Sinha[c], Jonathan H. Gillard[b], Michael P. F. Sutcliffe[a], Zhongzhao Teng[b]

[a]*University of Cambridge, Department of Engineering, United Kingdom*
[b]*University of Cambridge, Department of Radiology, United Kingdom*
[c]*University of Cambridge, Department of Medicine, Division of Cardiovascular Medicine , United Kingdom*

Abstract

Aortic aneurysms are amongst the leading vascular diseases that claim millions of lives every year. They cause dilatation of aorta, leading pathological changes in its microstructure and resulting in ruptures and fatal clinical events. Although mechanical properties of the diseased aorta have been studied, literature on its fracture behaviour and microstructure-mechanics relationship does not exist. Objectives of this study are to investigate the fracture behaviour of diseased human aorta and to explore the disease driven changes in microstructural components on its mechanical behaviour.
Methods:
Aortic aneurysm affected aorta regions were collected from eight patients and stored in liquid nitrogen. Tissue pieces were thawed prior to testing and tissue strips were cut from their intima, media and adventitia layers, along both the circumferential and the axial artery directions. Unnotched uniaxial tensile and single edge notched uniaxial tensile tests were performed on all strips and force versus tissue displacement data were collected. Immunohistochemical analysis was used to quantify microstructural components of each tissue.
Results:
Unexpectedly, the failure stress of notched circumferential adventitia strips was found to be significantly (p=0.015) higher and the failure stresses of notched axial adventitia (p=0.083) and axial media (p=0.13) strips marginally higher than their corresponding unnotched counterparts. Bilinear regression analysis revealed strong correlations between increase in collagen and a corresponding decrease in glycosaminoglycan contents of circumferential media (r2=0.86) and axial adventitia (r2=0.81) strips with increases in their tangential moduli at 200 kPa. The same microstructure-mechanics relationship was also observed for the 50 kPa tangential moduli of axial intima (r2=0.87) and circumferential media (r2=0.94) strips.
Discussion:
Differences in original healthy structural organisation, cellular environment and mechanical response of distinct arterial layers could underlie the variations in the relationship between changes in their microstructural components and mechanical behaviour.

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Keywords: Biomaterials; fracture mechanics; microstructure-mechanics relationship; biological tissue; aortic aneurysm; aortic dissection

* Corresponding author. Tel.: /
E-mail address: at684@cam.ac.uk

Prediction of fracture in sandwich-structured composite joints using case-based reasoning approach

Mohammad Reza Khosravani[a,*], Sara Nasiri[b], Kerstin Weinberg[a]

[a]*Chair of Solid Mechanics, University of Siegen, Paul-Bonatz-Str. 9-11, 57068, Germany*
[b]*Department of Electrical Engineering &Computer Science, University of Siegen, H¨olderlinstr. 3, 57076 Siegen, Germany*

Abstract

Repair and replacement of damaged composites are costly and time-consuming processes, therefore a prediction of fracture is highly beneficial, and may enhance structure reliability. In this study, a case-based reasoning (CBR) methodology as a problem- solving method of artificial intelligence is utilized to predict fracture occurrence in adhesively bonded sandwich joints. CBR is an intelligent technique for solving new problems by finding previous similar problems based on the experiences and cases which have similar solutions. In this paper, the experimental data of sandwich joints which experienced static and dynamic loadings under various environmental conditions are analyzed and stored on the case base. The case base of the implemented system is also enriched by numerical simulation results. The developed tool is appropriately designed with the optimized cases which are performed to reach high robustness in the fracture prediction. Furthermore, the case-base updates while using the system by earning from the gathered data as requested problems. Therefore, higher performance in future problems can be achieved. The proposed intelligence system has a general reliability to apply for different types of joints in sandwich-structured composites in order to predict failure load and type of failure. The quality of the obtained results of this research fully demonstrated the usefulness of the proposed intelligent system.

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Keywords: sandwich-structured composites; fracture prediction; case-based reasoning; failure load.

* Corresponding author. Tel.: +49(0271)740-4642 ; fax: +49(0271)740-2241.
E-mail address: mohammadreza.khosravani@uni-siegen.de

Temperature and humidity influence analysis on the behavior of thick composite plates using high order theory

B. Boukert [a,*], A. Benkhedda[a], E.B Adda[b], M. Khodjet-Kesba[a]

[a]*Laboratoire des Sciences Aéronautiques, Institut d'Aéronautique et des études spatiales, Université Blida 1, B.P 270 route de Soumaa, Algerie*
[b]*Laboratoire de Matériaux et Hydrologie, Université de Sidi Bel Abbès,Algerie*

Abstract

The composite materials fields is very important with their wide use in various fields, in aeronautics these materials represent a great potential throught their rigidity and lightness, the aeronautical structures work in variable environmental conditions because of altitude change ,consequently the temperature and the humidity in which the structure is located vary, these parameters generate an internal stresses which influence the behavior of the material, for this the determination of the hygrothermal stress is very important in the engineering phase.
This study investigates the behavior of thick composite laminates using the high order method through hydrothermal stress calculation, the composite laminate is working in a hygrothermal environment, temperature and humidity are used and taken into account for stress calculation, different Simulations are carried out using different values of temperature and concentration, to see the influence of one on the other, other simulations are made by varying the distribution shape of temperature and humidity along the thickness of the laminate, the plate size is also taken into account in the simulations (a/b: ratio of length to width, a/h: ratio length to thickness).

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Keywords: Thick composite plate, High Order, Hygrothermal,

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* Corresponding author. Tel.: +213 552 326 153.
E-mail address: bilanosky@hotmail.fr

Effect of moisture absorption on the elastic properties in cracked composite laminates with transient hygrothermal conditions

M. Khodjet-Kesba[a,*], A. Benkhedda[a], E.A. Adda Bedia[b], B. Boukert[a]

[a]*Laboratoire des sciences aéronautiques, Institut d'aéronautique et des études spatiales,Université de Blida1*
[b]*Laboratoire des Matériaux et Hydrologie, Université de Sidi Bel Abbes*

Abstract

A modified Shear-lag model was used to predict the effect of transverse cracks on the elastic properties degradation for $[\theta_m/90_n]_s$ composite laminates and under different environmental conditions by the variation of temperature and transient moisture concentration distribution in absorption case. Good agreement is obtained by comparing the prediction models and experimental data published by Joffe. Furthermore the cracked angle-ply laminate is submitted to hygrothermal conditions. The transient and non-uniform moisture concentration distribution gives rise to the transient mechanical properties. The obtained results represent well the dependence of the mechanical properties degradation on the cracks density, fibre orientation angle of the outer layers and transient hygrothermal conditions.

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Keywords: Mechanical properties, transverse cracking, Tsai model, shear lag, angle-ply

* Corresponding author. Tel.: +213662788612;
E-mail address: mkhojet@hotmail.fr

Quantification of the fatigue severity of porosity in aluminium alloy 7050-T7451 thick plate

Simon Barter[a,*], Ben Dixon[a]

[a]DST-Group Australia

Abstract

Porosity in aluminium alloy components are well-known initiators of fatigue. This is well understood for many situations where castings are used, what is less well realised is that thick wrought plates of high strength aluminium alloys can also suffer from porosity initiated fatigue cracking. Such plates are used in aircraft components and porosity may be significant due to the lack of sufficient rolling prior to machining. This was particularly the case in the early production F/A-18 aircraft, where in some structural durability tests, some fatigue cracks were observed to initiate from porosity in the main aluminium bulkheads. This demonstrated the potential for porosity to cause fatigue cracking in these components during service. The present study quantifies the fatigue severity of porosity present in the Aluminium Alloy 7050 T7451 thick plate that was used for some F/A-18 components. To this end, over one hundred polished 7050-T7451 coupons were fatigue tested to failure and the fracture surfaces were then examined using quantitative fractography. The data produced by this process were used to determine the effect of the porosity as if it had been a fatigue crack of a size that would have produced the same fatigue crack growth. This metric, denoted as the equivalent pre-crack size of the porosity, defined the fatigue severity for each porosity discontinuity examined here. These equivalent pre-crack sizes were then used to estimate the distribution of porosity fatigue severities in 7050-T7451 thick plate. The use of an equivalent pre-crack size to define fatigue severity facilitates the use of fatigue crack growth prediction models to make deterministic and probabilistic fatigue life predictions for realistic service spectra loading conditions for this discontinuity type. Moreover, it allows the fatigue severity of porosity to be compared to those of other discontinuity types that cause fatigue cracks in other similarly manufactured 7050-T7451 components.

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Keywords: Fatigue crack growth & initiators, quantitative fractography, porosity, prediction

* Corresponding author. Tel.: /
E-mail address: simon.barter@dst.defence.gov.au

Computational evaluation of artery damage in stent deployment

Ran He[a], Liguo Zhao[a,*], Vadim V. Silberschmidt[a], Yang Liu[a], Felix Vogt[b]

[a]*Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Epinal Way, Loughborough, UK*
[b]*University Hospital Aachen, Pauwelsstrasse 30, 52074 Aachen, Germany*

Abstract

This paper aims to evaluate damage in an arterial wall and plaque caused by percutaneous coronary intervention using a finite-element (FE) method. Hyperelastic damage models, verified against experimental results, were used to describe stress-stretch responses of arterial layers and plaque in the lumen; these models are capable to simulate softening behaviour of the tissue due to damage. Abaqus CAE was employed to create the FE models for an artery wall with two constituent layers (media and adventitia), a symmetric uniform plaque, a bioresorbable polymeric stent and a tri-folded expansion balloon. The effect of percutaneous coronary intervention on vessel damage was investigated by simulating the processes of vessel pre-dilation, stent deployment and post-stenting dilation. Energy dissipation density was used to assess the extent of damage in the tissue. Overall, the plaque experienced the most severe damage due to its direct contact with the stent, followed by the media and adventitia layers. Softening of the plaque and the artery due to the pre-dilation-induced damage can facilitate the subsequent stent-deployment process. The plaque and the artery experienced heterogeneous damage behaviour after the stent deployment, caused by non-uniform deformation. The post-stenting dilation was effective to achieve a full expansion of the stent but caused additional damage to the artery. The computational evaluation of the artery damage can be also potentially used to assess the risk of in-stent restenosis after percutaneous coronary intervention.

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Keywords: Artery damage; hyperelastic damage model; finite element; pre/post-dilation; stent deployment

* Corresponding author. Tel.: 0044-1509-227799
E-mail address: L.Zhao@Lboro.ac.uk

Pearlitic ductile cast iron: fatigue crack paths and damaging micromechanisms

V. Di Cocco[a], F. Iacoviello[a,*]

[a]Università di Cassino e del Lazio Meridionale, DICeM, via G. Di Biasio 43, 03043, Cassino, FR, Italy

Abstract

The influence of the graphite nodules morphology (shape, dimension and distribution) on ductile cast irons (DCIs) mechanical properties is experimentally confirmed both in static, quasi static and cyclic loading conditions. According to the most recent results, these graphite elements cannot be merely considered as ''microvoids embedded in a metal matrix'', but their presence implies a modification of the damaging micromechanisms and this modification I s influenced by the metal matrix microstructure.
In this works, the different damaging mechanisms that are active in the graphite nodules in a pearlitic DCI are semi-quantitatively analyzed using light optical microscope observations of the fracture surface profiles.

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Keywords: Pearlitic ductile cast irons; damaging micromechanism; fatigue crack propagation

* Corresponding author. Tel.: +39-07762993681; fax: +39-07762993781.
E-mail address: iacoviello@unicas.it

Prediction of steel weld HAZ Charpy impact property based on stochastic fracture model incorporating microstructural parameters

Michihiro Kunigita[a], Kengo Tanaka[a], Tomoya Kawabata[a], Tadashi Kasuya[a], Yoshiomi Okazaki[b], Masahiro Inomoto[b], Shuji Aihara[a,*]

[a]*The University of Tokyo, 7-3-1, Hongo, Bunkyo, Tokyo, 113-8656, Japan*
[b]*Kobe Steel Ltd., 2222-1, Onoecho Ikeda, Kakogawa, Hyogo, 675-0023, Japan*

Abstract

The present study proposed a model to predict Charpy impact absorbed energy for steel weld HAZ of predominantly upper bainite containing martensite-austenite constituent (MA) as a second phase. Probability distribution of local fracture stress for cleavage crack nucleation is calculated from microstructural parameters. On the other hand, local stress and strain are calculated from dynamic elastic-plastic finite-element analysis. Applying the weakest-link mechanism, probability of cleavage fracture is calculated. Charpy impact tests were conducted for steel simulated HAZ with various cooling rates. As a result, the predicted Charpy absorbed energy transition curves agreed well with the experiment and the model was validated.

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Keywords: toughness; steel; weld heat-affected zone; fracture mechanics; modelling

* Corresponding author.
E-mail address: aihara@fract.t.u-tokyo.ac.jp

Pressurized Thermal Shock analysis of the reactor pressure vessel

Peter Trampus[a,*]

[a]Trampus Consulting & Engineering, Hungary

Abstract

Pressurized Thermal Shock (PTS) is an overcooling transient which causes a thermal shock to the reactor pressure vessel (RPV), while the pressure is either maintained or the system is re-pressurized during the transient. The thermal stress due to the rapid cooling of the vessel wall in combination with the pressure stress results in large tensile stresses nearby the vessel inside surface. Also, a unique ageing phenomenon called irradiation embrittlement, caused by fast neutron bombardment as environmental effect, occurs in the RPV wall reducing the structural material's fracture toughness and shifting the ductile-brittle transition temperature in the direction of higher temperature. In the case if a flaw would exist in an area of the vessel wall near to the inside surface where the material properties degraded due to fast neutron irradiation and a PTS transient would happen, the RPV integrity would be jeopardized.

PTS analysis is a substantial part of the RPV design safety assessment, and it is especially crucial when a plant owner applies license for operation beyond the design life. The presentation describes the methodology and the basic results of the PTS analysis performed for Paks nuclear power plant, Hungary, to support the plant's life extension application. It includes the initiating events selection and the thermal-hydraulic calculations as necessary inputs for the structural analysis. The end-of-life fluence calculations and the RPV surveillance results provided the input for the material characterization (KIc). Temperature and stress field calculations were performed by solving the system of equations of elasticity. Under-cladding crack was postulated for fracture mechanics calculation (KI). Comparison of these two parameters (KI ⩽ KIc), i.e. evaluation of whether the postulated flaw stability criteria was met, gave the result. Then, the allowable critical temperature of brittleness was derived from the criterion and the safe lifetime of the RPV was determined.

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Keywords: pressurized thermal shock; neutron irradiation; fracture toughness; non-destructive evaluation; allowable service life

* Corresponding author. Tel.: /
E-mail address: trampusp@trampus.axelero.net

Experimental investigation of deformation and failure in ductile alloys under shear loading

Ali Ghahremaninezhad[a,*], Khashayar Farzanian[a], Krishnaswamy Ravi-Chandar[b]

[a]*University of Miami, United States*
[b]*The University of Texas at Austin, United States*

Abstract

Conventional ductile fracture models such as the Gurson-Tvergaard-Needleman model has been developed based on the mechanics of void growth due to volumetric strain and subsequent void coalescence leading to fracture. It has now become evident that these models are not capable of capturing fracture in dominant shear deformation scenarios, which arise commonly in the form of shear localizations in polycrystalline metallic materials. In this paper, we report in-situ multiscale examination of deformation and failure mechanisms in Al 6061-T6 under low stress triaxiality levels using modified Arcan specimens. Strains at the grain and subgrain levels were measured in a scanning electron microscope by in-situ tracking of the changes in grain size and morphology, and at the macroscale level with the means of digital image correlation. Strains in the range of 2-2.5 were measured at the grain level without any indication of damage. High strain heterogeneity at the grain was evidenced and quantified, and its relation with grain size and morphology was evaluated. The interaction of matrix grains and particles was monitored and correlated with force data to examine the effect of particle fracture on load carrying capacity and final failure of the material under shear loading.

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Keywords: Ductile fracture; microstructure; Digital Image Correlation

* Corresponding author. Tel.: /
E-mail address: a.ghahremani@miami.edu

Grain size influence on fatigue behaviour in a CuZnAl PE SMA

V. Di Cocco[a,*], F. Iacoviello[a], F. Carlino[a], S. Natali[b]

[a]*University of Cassino and southern Lazio, DICeM, via G. Di Biasio 43, 03043, Cassino, FR, Italy*
[b]*University of Rome "Sapienza", DICMA, Via Eudossiana 18, 00184, Rome, Italy*

Abstract

Due to their capability to recover the initial shape, Shape Memory Alloys (SMAs) are widely used in many applications. Different grades are commercially available and they can be classified considering either their chemical compositions (Cu based, Ni based, Fe based and so on..) or according to their mechanical behaviour. The most used SMAs are the Ni based alloys thanks to their performances both in terms of mechanical resistance and in terms of fatigue resistance, but their costs are quite high. Cu based alloys are good competitors of the Ni based alloys. The recent optimization of their chemical composition improved both the corrosion resistance in aggressive environments and their mechanical performances. In this work, the influence of the grain size on fatigue crack propagation in two Cu-Zn-Al SMAs focusing on the damaging micromechanisms.

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Keywords: Cu-Zn-Al shape memory alloy; grain size; fatigue crack propagation; microstructure; damaging micromechanisms

* Corresponding author. Tel.: +39-07762994334; fax: +39-07762993733.
E-mail address: v.dicocco@unicas.it

Hydrogen embrittlement of steel pipelines during transients

Zahreddine Hafsi[a,b,*], Manoranjan Mishra[b], Sami Elaoud[a]

[a]*Laboratory of Applied Fluids Mechanics Process and Environment Engineering, National Engineering School of Sfax, Sfax, 3038, Tunisia*
[b]*Department of Mathematics, Indian Institute of Technology Ropar, 140001 Rupnagar, Punjab, India*
[b]*Department of Chemical Engineering, Indian Institute of Technology Ropar, 140001 Rupnagar, Punjab, India*

Abstract

Blending hydrogen into natural gas pipelines is a recent alternative adopted for hydrogen transportation as a mixture with natural gas. In this paper, hydrogen embrittlement of steel pipelines originally designed for natural gas transportation is investigated. Solubility, permeation and diffusion phenomena of hydrogen molecules into the crystalline lattice structure of the pipeline material are followed up based on transient evolution of internal pressure applied on the pipeline wall. The transient regime is created through changes of gas demand depending on daily consumptions. As a result, the pressure may reach excessive values that lead to the acceleration of hydrogen solubility and its diffusion through the pipeline wall. Furthermore, permeation is an important parameter to determine the diffusion amount of hydrogen inside the pipeline wall resulting in the embrittlement of the material. The numerical obtained results have shown that using pipelines designed for natural gas conduction to transport hydrogen is a risky choice. Actually, added to overpressure and great fluctuations during transients that may cause fatigue and damage the structure, also the latter pressure evolution is likely to induce the diffusion phenomena of hydrogen molecules into the lattice of the structure leading to brittle the pipe material. The numerical simulation reposes on solving partial differential equations describing transient gas flow in pipelines coupled with the diffusion equation for mass transfer. The model is built using the finite elements based software COMSOL Multiphysics considering different cases of pipe material; API X52 (base metal and nutrided) and API X80 steels. Obtained results allowed tracking the evolution with time of hydrogen concentration through the pipeline internal wall based on the pressure variation due to transient gas flow. Such observation permits to estimate the amount of hydrogen diffused in the metal to avoid leakage of this flammable gas. Thus, precautions may be taken to prevent explosive risks due to hydrogen embrittlement of steel pipelines, among other effects, that can lead to alter safe conditions of gas conduction.

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Keywords: hydrogen flow; transient behaviour, Ficks'law; embrittlement; diffusion, steel pipeline

* Corresponding author. Tel.: /
E-mail address: zahreddine.hafsi@enis.tn

Phase transformation in white etching area in rolling contact fatigue

Shuxin Li[a,]*, Yunshuai Su[a], Siyuan Lu[a]

[a]*School of Mechanical Engineering and Mechanics Ningbo University, China*

Abstract

Rolling contact fatigue (RCF) involves microstructural change in the subsurface of contact. The changed microstructure is generally termed as white etching area (WEA) as it appears white under optical microscope when etching in nital solution. WEA has been acknowledged as one of the primary failure modes in RCF since it causes severe local inhomogeneity of microstructure.

It was reported that WEA consists of nano ferrites as martensite grains and carbides are significantly refined in the WEA. Some carbides are dissolved. In some cases, an amorphous-like structure was occasionally observed in the WEA, indicating that phase transformation may possibly occur. In the current study, two types of WEA were observed in the subsurface. One appears largely sheared morphology with elongated carbides. The other exhibits compact morphology with no carbides observed. We studied the two types by using scanning electron microscopy (SEM), transmission electron microscopy (TEM) and Electron back scattered diffraction (EBSD). The result showed that there is a big difference between these two types of WEA. The first type consists of refined martensites and carbides. It does not involve phase transformation. However, the other type is dominated with an amorphous phase with martensite, austenite and carbides embedded interior. A distinct interface between the matrix and the WEA was present, as shown in Fig.1. In addition to grain refinement down to nanometers, phase transformation including amorphization and austenitization happened in WEAs. The content of austenite was increased from 2% in the matrix to 20% in the WEA. The analysis showed that phase transformation are controlled by plastic deformation mechanism. In view of the above results, WEA was suggested to be categorize into deformed and transformed bands based on whether phase transformation occurs.

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Keywords: Rolling Contact Fatigue (RCF); White etching area (WEA); amorphization; austenitization

* Corresponding author. Tel.: /
E-mail address: li_shuxin@163.com

Effects of pharmaceutical wastes usage as partial replacement of cement on the durability of high-performance concrete

Talah Aissaa[a,]*, Belaid Rachid[a], Fattoum Kharchi[a]

[a]University of sciences and technology, Bp32 BabEzzouar, Algiers 16111, Algeria

Abstract

This paper reports an experimental study of the influence of ash produced from incinerated hospital wastes used as partial substitute for Portland cement (PC) on the mechanical properties and durability of high performance concretes. The analysis of the experimental results on concrete at 10 % content of ash resulting from incineration of pharmaceutical wastes with a fineness modulus of 8000 cm^2/g, in a chloride environment, showed that it contributes positively to the perfection of its mechanical characteristics, its durability with respect to migration of chloride ions and oxygen permeability. On the basis of the experiments performed, it can be concluded that the ash is suitable for formulation of high performance concretes (HPC) and their properties are significantly better compared to the reference concrete (RC). This paper points out the directions for the proper uses of ash of pharmaceutical wastes in concrete.

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Keywords: ash , pharmaceutical wastes,durability,concrete;

* Corresponding author: Talah Aissa. Tel.: +2130247224; fax: +21321247914.
E-mail address:talahay@yahoo.fr

Unified criterion for fatigue endurance modelling under combined loading: static and vibratory

Bhimal Bholah[a,b,]*, Yoann Guilhem[a], Julien Jaravel[a], Sylvie Pommier[a]

[a]Safran HE, France
[b]ENS Paris Saclay, France

Abstract

Rolling contact fatigue (RCF) involves microstructural change in the subsurface of contact. The changed microstructure is generally termed as white etching area (WEA) as it appears white under optical microscope when etching in nital solution. WEA has been acknowledged as one of the primary failure modes in RCF since it causes severe local inhomogeneity of microstructure.
It was reported that WEA consists of nano ferrites as martensite grains and carbides are significantly refined in the WEA. Some carbides are dissolved. In some cases, an amorphous-like structure was occasionally observed in the WEA, indicating that phase transformation may possibly occur. In the current study, two types of WEA were observed in the subsurface. One appears largely sheared morphology with elongated carbides. The other exhibits compact morphology with no carbides observed. We studied the two types by using scanning electron microscopy (SEM), transmission electron microscopy (TEM) and Electron back scattered diffraction (EBSD). The result showed that there is a big difference between these two types of WEA. The first type consists of refined martensites and carbides. It does not involve phase transformation. However, the other type is dominated with an amorphous phase with martensite, austenite and carbides embedded interior. A distinct interface between the matrix and the WEA was present, as shown in Fig.1. In addition to grain refinement down to nanometers, phase transformation including amorphization and austenitization happened in WEAs. The content of austenite was increased from 2% in the matrix to 20% in the WEA. The analysis showed that phase transformation are controlled by plastic deformation mechanism. In view of the above results, WEA was suggested to be categorize into deformed and transformed bands based on whether phase transformation occurs.

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Keywords: Endurance; Short crack; non-propagation criteria; Karhunen Love procedure; non local; multiaxiality

* Corresponding author. Tel.: /
E-mail address: bholahbhimal@gmail.com

Microscopic strain calculations at the onset of coalescence in nodular cast iron

Victor Manuel Trejo Navas[a, *], Ante Buljac[b], François Hild[b], Thilo Morgeneyer[c], Marc Bernacki[a], Pierre-Olivier Bouchard[a]

[a]*Centre de Mise en Forme des matériaux (CEMEF) - MINES ParisTech, PSL Research University, France*
[b]*Laboratoire de Mécanique et Technologie (LMT) - ENS Cachan/CNRS/Université Paris-Saclay, France*
[c]*Centre des Matériaux - MINES ParisTech, PSL Research University, France*

Abstract

At the microscale, ductile materials fail through void nucleation, growth, and coalescence. The understanding of these micromechanisms is crucial for the formulation of macroscale models that can be applied in industrial applications. The present work focuses on void coalescence for a nodular cast iron. The objective of this study is to propose a strain-based coalescence criterion.
The methodology employed is a combination of three techniques: in situ Synchrotron Radiation Computed Laminography, Digital Volume Correlation, and Finite Element simulations. Thanks to this framework, immersed microstructures and realistic boundary conditions can be used in numerical simulations with advanced meshing capabilities.
Equivalent strain values prior to coalescence in the intervoid ligament resulting from Digital Volume Correlation and Finite Element simulations are compared for different pairs of coalescing voids. The limitations given by the spatial resolution of each technique and their complementarity are discussed. After this comparison, the numerical study is generalized to a more numerous group of void pairs in order to obtain more representative data. The obtained results are used to discuss the possibility of establishing a strain-based coalescence criterion while taking into account the occurrence of two coalescence mechanisms, internal necking and void-sheet coalescence.

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Keywords: Ductile fracture; void coalescence; finite element method; micromechanical simulation

* Corresponding author. Tel.: /
E-mail address: victor-manuel.trejo_navas@mines-paristech.fr

Subcritical crack growth in sandstone in aqueous environment with different calcium ion concentration

Yoshitaka Nara[a,*], Hiroyuki Takeda[a]

[a]*Kyoto University, Kyoto-Daigaku-Katsura, Nishikyo-ku, Kyoto 615-8540, Japan*

Abstract

Investigating the time-dependent fracturing in sandstone is crucial to consider the long-term integrity of a sedimentary rock mass surrounding structures. Subcritical crack growth is one of the main causes of the time-dependent fracturing in rock materials. For the long-term integrity, it is essential to investigate subcritical crack growth in rock, which is influenced by the surrounding environmental conditions. Numerous cementitious materials are used to construct various structures such as underground repositories for radioactive waste, underground power plants, etc. In these cases, the calcium ion concentration in the ground water in a rock mass surrounding these structures is high. Therefore, investigation on the subcritical crack growth in rock in water with a high calcium ion concentration is essential. In this study, subcritical crack growth in sandstone is measured in distilled water and calcium hydroxide solution ($Ca(OH)_2$) to investigate the influence of calcium ions on the time-dependent fracturing in rock. Berea sandstone was used as a rock sample. The load-relaxation method of the double-torsion test was used to measure the crack velocity and the stress intensity factor. All measurements have been carried out under controlled temperature and relative humidity. It was shown that the crack velocity in a calcium hydroxide solution is lower than that in distilled water even though the pH was high. In previous researches, it has been considered that the crack velocity in rock increased when the pH was high from the measurements in water and sodium hydroxide solution (NaOH). Therefore, it is considered that calcium ion affects the decrease of the crack velocity. It is concluded that a water environment with a high calcium ion concentration is suitable for the long-term integrity of a sedimentary rock mass.

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Keywords: Subcritical crack growth; double-torsion method; sandstone; water; calciumion

* Corresponding author. Tel.: +81-75-383-3210; fax: +81-75-874-1418.
E-mail address: nara.yoshitaka.2n@kyoto-u.ac.jp

Fracture assessment of an internal surface cracked vessel using the modified Master Curve method

Hessamoddin Moshayedi[a,*], Mastaneh Moattari[a], Iradj Sattari-Far[b]

[a]*Islamic Azad University, Iran*
[b]*Amirkabir University of Technology, Iran*

Abstract

This paper represents the ability of a recently developed methodology for evaluating fracture probability of the Ferritic steel structures which can cause a reduction in the inherent conservatism of the standard Master Curve (SMC) failure assessment method. Due to crack tip geometrical constraint, these structures may experience significant changes in their effective fracture toughness under a given load and temperature whereas the SMC method predicts a certain amount of fracture toughness for them. The conservatism associated with SMC method for low constraint geometries is investigated for a pressurized cylindrical vessel containing an internal semi-elliptical axial crack. A modification of SMC is introduced based on Q parameter as the crack tip constraint. The usability of the modified Master Curve (MMC) approach for structure integrity assessment is studied. It is shown that MMC enables more cost-effective design and accurate analysis of Ferritic components which potentially leading to plant life extension. The comparison of three methodologies including, classical procedure, SMC, and MMC for fracture toughness assessment of the pressure vessel in transition region, demonstrate the capability of the MMC approach in reduction of conservatism in failure assessment.

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Keywords: Fracture toughness; crack tip constraint; modified master curve; failure assessment

* Corresponding author. Tel.: /
E-mail address: h.moshayedi@aut.ac.ir

A comprehensive study of the mechanical properties of woven materials for various types of loading and temperatures

Maria Temerova[a,*]

[a]*Perm National Reserch University, Russia*

Abstract

The structure of the woven material can be designed in such a way as to satisfy the requirements associated with various features of making a composite or using a fabric as a functional structure. In the production of composites, different types of weaving and types of fabrics are used, they differ in weight, thickness, type, linear density of the yarn. To model such materials, knowledge of the mechanical properties of the raw materials, and behavior during deformation is necessary.
Determining the mechanical characteristics of the structural components of the woven composite at each scale level (fiber-thread-cloth) is relevant for a number of reasons. Firstly, the widespread use of woven composite materials in the industry requires solving the problem of optimizing the composition and structure of the woven composite for specific operating conditions, which can not be solved without data on the deformation and strength characteristics of structural components. Secondly, at the present stage of the development of computer technology and technology, direct multiscale modeling is used increasingly in the numerical simulation of concrete assemblies and connections from woven composite materials, for the realization of which constant constants are required, starting with the fiber.
The subject of the study are yarns and woven tapes in the initial and impregnated state. The work includes the study of the behavior of various types of fabrics by the type of interlacing and assignment at elevated and normal temperatures, as well as under different loading effects.

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Keywords: Composite; impregnated fabric; measuring base; mechanical characteristics; raw material.

* Corresponding author. Tel.: /
E-mail address: cem.temerova@gmail.com

Evolution of deformation fields in the regions of defects and concentrators in inelastic deformation and destruction of composite objects

Elena Strungar [a,*], Valery Wildemann[a]

[a]Center of Experimental Mechanics, Perm national research polytechnic university, Russia

Abstract

The bearing capacity of the basic elements of many structures is usually determined by the stress state and strength conditions in the places of concentration, because it is there that first of all comes the ultimate state and destruction. That is why in the field of mechanics of a deformable solid, one of the topical problems is to study the influence of various types of stress concentrators on the behavior of structural elements. The work is focused on the study of the laws of deformation and destruction of bodies with stress concentrators, by which are meant both technological defects and holes of various shapes. In work modern loading systems and means of data recording and non-destructive methods of control are used (contactless three-dimensional video system of deformation fields analysis). The aim of the work is to solve methodological issues and to experimentally study the patterns of deformation and fracture of composite elements with stress concentrators using a non-contact optical video system. The work uses a non-contact optical video system Vic-3D, the mathematical apparatus of which is based on the method of digital image correlation (DIC). The paper presents the main theoretical positions of the DIC method, presents the composition and procedure of the test using Vic-3D. The issues of ensuring the required accuracy when working with a video system are considered and a number of test tests are carried out.
Experimental studies of inhomogeneous displacement and deformation fields in bodies with concentrators by the method of digital image correlation are carried out. An evaluation of the operability of samples of constructively similar elements was made when using a video system. When using composite materials in the industry, there is a need to monitor the state of the structure due to damage and defects. Common defects include defects such as discontinuity: stratification, non-gluing, non-pressing, cracks, air or gas shells. These defects must be eliminated by improving the process or diagnose during operation. In this paper we obtain experimental data on stretching and joint stretching with torsion of samples of layered composite materials with pre-embedded technological defects that correspond to possible non-pressing and non-gluing of layers of material in a given limited area.

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Keywords: Experimental mechanics; composite materials; techniques of tests; digital image correlation; tension tests.

* Corresponding author. Tel.: /
E-mail address: cem.temerova@gmail.com

Mechanical behaviour and fracture of composite sound-absorbing sandwich panels by tension and compression tests at normal and increased operating temperature

Dmitrii Lobanov[a,*]

[a]*Perm National Research Polytechnic University, Russia*

Abstract

At present, composite materials are being widely introduced into aircraft structures — parts and units of airframes and aviation gas turbine power plants. The composite parts of aircraft engines, as a rule, have a rather complex reinforcement scheme, including several layers of a (honeycomb, tubular, or cellular) filler, imbedded elements, composite flanges, etc. During their operation in the structure of a propulsion unit, various defects, including those caused by casual mechanical actions, inevitably arise.
Work present results of experimental research mechanical behaviour and fracture of aircraft composite sound-absorbing sandwich panels by tension and compression tests at normal and increased operating temperature. The tests were carried out at the Center of Experimental Mechanics of Perm National Research Polytechnic University on an Instron 5882 universal electromechanical testing system.

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Keywords: composite materials; mechanical behaviour; tension; compression; sound-absorbing sandwich panels; incresed temperature.

* Corresponding author. Tel.: /
E-mail address: cem.lobanov@gmail.com

Investigations of the hydrogen embrittlement susceptibility of T24 boiler tubing in the context of Stress Corrosion Cracking of its welds

Evy De Bruycker[a,*], Staf Huysmans[b], Frédéric Vanderlinden[a]

[a]ENGIE Laborelec, Rodestraat 125, B1630 Linkebeek, Belgium
[b]SH MatWeld Consult, Sijsjeslaan 6, B2540 Hove, Belgium

Abstract

For the membrane and spiral walls of the new USC boilers, the advanced T24 material was developed. In 2010, however, extensive T24 tube weld cracking during the commissioning phase of several newly built boilers was observed. As the dominant root cause, Hydrogen Induced - Stress Corrosion Cracking was reported.
An investigation into the interaction of the T24 material with hydrogen was launched, in order to compare its hydrogen embrittlement susceptibility with that of the T12 steel commonly used for older boiler evaporators. Both base materials and simulated Heat Affected Zone (HAZ) microstructures were tested. Total and diffusible hydrogen in the materials after electrochemical charging were measured. Thermo Desorption Spectrometry was used to gain insights into the trapping behaviour and the apparent diffusion coefficient at room temperature was determined.
Based on the hardness and the diffusible hydrogen pick-up capacity of the materials, it was concluded that T12 is less susceptible to hydrogen embrittlement than T24, as base material as well as in the HAZ condition and that the HAZ of T24 is more susceptible to hydrogen embrittlement than the base material, both in the as welded and in the Post Weld Heat Treated (PWHT) condition. However, based on the results of this investigation it could not be determined if the T24 HAZ is less susceptible to hydrogen embrittlement after PWHT.

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Keywords: Hydrogen embrittlement; T24; stress corrosion cracking

* Corresponding author. Tel.: +32 2 382 03 04; fax: +32 2 382 02 41.
E-mail address: Evy.DeBruycker@engie.com

Hydrogen diffusion along grain boundaries: atomistic simulations and mechanistic model

Jun Song[a,*], Xiao Zhou[a], William Curtin[b]

[a]*McGill University, Canada*
[b]*Ecole Polytechnique Fédérale de Lausanne, Switzerland*

Abstract

Hydrogen embrittlement (HE) has been a conventional problem in the design of reliable structural materials. Grain boundary (GB), acting as one of the main preferential lattice heterogeneities for hydrogen accumulation and transport, plays a key role in understanding the HE mechanism. However, the kinetics of hydrogen along GBs has been a subject of high contention for decades, with the co-existence of conflicting and even contradictory viewpoints. In this study, combining atomistics with Kinetic Monte Carlo, we performed a comprehensive set of simulations to study hydrogen kinetics along GBs using nickel as a model system. Various symmetric tilt GBs were constructed with key geometric parameters systematically varied. The along-GB diffusion barriers and paths were identified, and diffusivities were computed. We found that hydrogen diffusion can exhibit two distinct types of kinetics depending on the GB characteristics. In light of simulated results, one mechanistic model was proposed to not only clarify the structural origin of the two distinct diffusion behaviors, but also predict the occurrence of and transition between those behaviors as functions of the GB characteristics. Our findings provide critical insights and new knowledge toward fundamental understanding of microstructure-mediated hydrogen kinetics in structural metals.

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Keywords: Hydrogen embrittlement; hydrogen diffusion; grain boundary; microstructure

* Corresponding author. Tel.: /
E-mail address: jun.song2@mcgill.ca

On induced anisotropy of stress-strain relations and fracture resistance in filled elastomers

Konstantin Ustinov[a,*]

[a]*IPMech RAS, Russia*

Abstract

The rubber manifests so many properties appearing illogical and contradictory each other that they give the challenge to put forward a model to describe some of them and not go against any other. Among these properties we need to emphasize the following:

- anisotropy of Mullins effect (reduction of elastic hysteresis is well pronounced for successive loading in the direction of pre-stretching and almost absent in the direction normal to pre-stretching);
- less pronounced Mullins effect under bi-axial stretching than under uniaxial stretching;
- anisotropy of swallowing after uniaxial stretching, with emphasis on reduction of expansion in the direction normal to pre-stretching;
- reinforcement in the direction of pre-stretching and reduction of strength in the direction normal to pre-stretching (especially pronounced in tearing tests).

A model allowing qualitative description of the mentioned phenomena altogether is suggested based on the concept of slippage of molecular chains over the particles of carbon black or strain induced crystals. The basic assumptions of the model is the following:

- elastic moduli in any direction is proportional to the number of molecular chains aligned in this direction (and close directions) and decrease with the chain lengths (according to the classical theory of rubber elasticity);
- sliding of polymer chains over the particles of carbon black or strain induced crystals leads to redistribution of chains lengths, particularly to elongation of the chains aligned along the tension direction;
- the total amount of segments forming the molecular chains conserves during loading; increase in the chain length in the direction of tension is compensated with decrease in the chains number in other directions.

The model was realized in the simplest form of the finite number of chains model with a minimal number of parameters. Illustrative examples are provided.

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Keywords: Rubber elasticity; induced anisotropy; strength anisotropy

* Corresponding author. Tel.: /
E-mail address: ustinov@ipmnet.ru

On mode mixity of interface cracks in composed layers; some analytical solutions

Konstantin Ustinov[a,*]

[a]*IPMech RAS, Russia*

Abstract

The 2-D problem of semi-infinite crack propagating along interface separating two layers of different thicknesses and elastic properties was considered. By applying Laplace transform it was reduced to matrix Riemann problem. In case of satisfying the condition of vanishing the second Dundur's parameter imposed on four elastic constants (two Young's moduli and two Poisson's ratios) the analytical solutions were obtained for two particular cases:

- two layers of equal thickness;
- one of the layers being infinitely thick.

The energy release rates and two modes of stress intensity factors (SIFs) were obtained in terms of three force parameters: the total moment and two components (normal and shear) of the total force of stresses acting on the continuation of the crack line. The available from the literature numerical data (corresponding to vanishing normal component of the total force) are in good agreement with the obtained results. All functions involved are expressed in terms of well converging integrals of elementary functions. For very small and very large ratios of Young's moduli of the layers the simple asymptotics are derived. The obtained results may find applications in problems of delamination and failure of coatings at various scales.

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Keywords: Interface crack; delamination; mode mixity; equivalent boundary conditions; elastic compliance; buckling.

* Corresponding author. Tel.: /
E-mail address: ustinov@ipmnet.ru

Root cause failure analysis of superheated steam tube at a petrochemical plant

Reza Khadem Hosseini[a,*]

[a]*Corrosion Research Group, Research Institute of Petroleum Industry (RIPI), Tehran, Iran*

Abstract

The aim of the present study is to determine root causes of failure in a steam tube at a petrochemical plant. In this order, light microscope and scanning electron microscope (SEM) were carried out observing the microstructures and hardness measurements were used for metallurgical evaluation. In addition, phase composition of deposits were studied by using X-ray diffraction (XRD). Based on the results, "short-term overheating" was recognized as the root cause of steam tube failure. Metallographic studies showed distributed martensite as a brittle phase in ferritic matrix in the microstructure of damaged area, while in the microstructure of non-damaged area only pearlite and ferrite were seen. These findings were confirmed by hardness measurement results as well.

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Keywords: Failure analysis; short-term overheating; steam tube

* Corresponding author. Tel.: +9821 4825 5204
E-mail address: hosseinir@ripi.ir

International Fracture Mechanics Summer Schools in ex-Yugoslavia

Aleksandar Sedmak[a,]*, Blagoj Petrovski[b], Zijah Burzić[c]

[a]University of Belgrade, Serbia
[b]Innovation center of Faculty of Mechanical Engineering, University of Belgrade, Serbia
[c]Military Technical Institute, Belgrade

Abstract

International Fracture Mechanics Summer Schools (IFMASS), founded 38 years ago, back in 1980, have been organized for ten times, the last one (IFMASS 10) held in 2008 in Zlatibor, Serbia. Publishing the monographs after each School enabled to form useful references for introduction of fracture mechanics as an effective tool for structural integrity assessment, but also supporting its theoretical, experimental and numerical development. The first monograph, "Introduction to Fracture Mechanics and Fracture-Safe Design", published in 1981, based on lectures held at IFMASS 1 in 1980 in former Yugoslavia, had been prepared after the request of participants, and also by strong support from the industry. In order to educate as much as possible, several lecture in this monograph has been publish in both Serbian and English. It was an extended request from the industry to organize the next School (IFMASS 2) "Modern Aspects of Design and Construction of Pressure Vessels and Penstocks" and publish the monograph (in Serbian) in 1982. It turned out that IFMASS served not only to educate, but also as a forum to exchange the experience and ideas among the participants and lecturers, many of them invited and attracted from abroad. Next very important event was the joint Yugoslav - USA project "Fracture Mechanics of Weldments", performed by six institutions from former Yugoslavia and the National Institute of Standards and Technology (NIST), Boulder, Colorado, which started in 1982 and ended in 1992. Following already established pattern, IFMASS 3 "Fracture Mechanics of Weldments" was organized 1984, again for education and as a forum, followed by the monograph published the same year. The success of IFMASS was continued through the fourth School "Prospective of Fracture Mechanics Development and Application" in 1986 and the monograph in 1987, leading to the most successful, the fifth one, held under the title "The Application of Fracture Mechanics to Life Estimation of Power Plant Components" in Dubrovnik, 1989. The IFMASS 5 was supported by the "Electricity of Serbia", with impressive number of 145 participants, and lecturers recognized in the power industry world-wide. The monograph under the same title had been published in English by EMAS Publisher from England in 1990, and upon the request from our industry in somewhat reduced version in Serbian in 1991.
With IFMASS 5, the flourishing period in fracture mechanics and structural integrity development was seaced due to unfortunate chain of events in former Yugoslavia. It happened that during IFMASS 6 "Service Cracks in Pressure Vessels and Storage Tanks" in June 1991 these unfortunate events started, making the confusion among the participants from Slovenia. However, even IFMASS 6 was a successful one, though the publishing of the monograph was completed only in 1994. Once again unfortunate circumstances prevented the organization of the next School up to 1997, when again with a strong support of the Industry "GOŠA", IFMASS 7 was held under the title "Experimental and Numerical Methods of Fracture Mechanics in Structural Integrity Assessment". It was difficult time in our country, but IFMASS still saved its importance, attracting 137 participants and 8 foreign contributions out of 25 given lectures. The unfortunate events culminated in 1999 with NATO bombardment, which delayed monograph publishing until 2000. Three years later IFMASS 8 was held under the title "From Fracture Mechanics to Structural Integrity Assessment" in Belg–rade, in 2003, after the Society for Structural Integrity and Life (DIVK) has been established in 2001 and took care about IFMASS. This was also very successful event, followed by the monograph published in 2004. IFMASS 9 was held in 2005 in Golden Sand (Zlatni Pjasci), Varna, Bulgaria. Following already established tradition, organizers decided to publish the monograph "The Cha–llenge of Materials and Weldments" with the subtitle "Structural Integrity and Life Assessments". Finally, after another successful IFMASS 10 in 2008, the monograph on "Fundamentals of fracture mechanics and structural integrity assessment methods" was published. The last three monographs, published in English, are available on ESIS website as free downloadable pdf documents.
Let us say at the end that IFMASS was possible due to gigantic efforts of his establisher and father of Fracture Mechanics in ex-Yugoslavia, Prof. Stojan Sedmak (1929-2014).

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Keywords: Fracture mechanics; summer school; structural integrity

* Corresponding author. Tel.: /
E-mail address: asedmak@mas.bg.ac.rs

An experimental method for a high temperature non-contacting measurements of a deformed specimen

W. Teraud [a,b,*]

[a]Lomonosov Moscow State University, Michurinskiy av. 1, Moscow, 119192, Russia
[b]V.A. Trapeznikov Institute of Control Sciences, Profsouznaya av. 65, Russian Academy of Sciences, Moscow, Russia

Abstract

The aim of paper is a non-touch experimental method for measure parameters of the specimen in a moment of high temperature deformation. The method is consist of a photo camera, a lamp into a furnace, an electronic system send a pulse to take a picture in each 0.1 mm stretching and a computer program for post processing. The specimen geometry was measured remotely, with pictures taken during the experiment.
In a tension test the use of a developed noncontacting measuring system allowed us to see variations in the specimen shape and to estimate the true stress in various cross-sections on the time. In post processing stage we can fix localization time by a theoretical criterion automatically.

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Keywords: measurement; noncontacting; high temperature; experiment; creep

* Corresponding author. Tel.: +7-495-939-5278; fax:+7-495-939-5308
E-mail address: ldrnww@gmail.com

Research on fatigue and dwell-fatigue crack growth in an advanced austenitic stainless steel (Fe-20Cr-25Ni)

Jin Yan[a,*], Suyang Yu[a], Hangyue Li[a], Pual Bowen[a]

[a]*University of Birmingham, United Kingdom*

Abstract

Advanced austenitic stainless steel Alloy709 (Fe-20Cr-25Ni) has been developed as a candidate structural material for the sodium-cooled fast reactor. This new grade has an outstanding cost-effective combination of excellent mechanical properties, corrosion resistance and high temperature creep strength, compared with other austenitic stainless steels. This paper will mainly focus on the study of the fatigue and dwell-fatigue crack growth of the material at temperatures from 550°C to 750°C. The mechanisms at different temperatures and environment (air and vacuum) have been identified. The influence of environment on fatigue crack growth rate has been discussed.
The result shows that the influence of environment on fatigue crack growth rate is very small. And the dwell-fatigue crack growth behaviour is influenced by the crack driving force. When ΔK is more than 40 MPa √ m, the crack growth rate was accelerated obviously when dwell at peak load, the fracture mode is obviously intergranular fracture with micro-voids. While ΔK is less than 40 MPa √ m, the fracture failure mode is transgranular, and the mechanisms change from fatigue striation to ductile cracking at carbides/matrix surface.

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Keywords: Alloy 709; Fatigue and dwell-fatigue; austenitic stainless

* Corresponding author. Tel.: /
E-mail address: JXY497@student.bham.ac.uk

Investigation and modeling of local crack arrest in ferritic-bainitic steels under dynamic loading

Johannes Tlatlik[a,]*, Dieter Siegele[a]

[a]*Fraunhofer Institute for Mechanics of Materials IWM, Wöhlerstr. 11, 79108, Freiburg, Germany*

Abstract

Local crack arrest is usually irrelevant under quasi-static loading conditions in the ductile to brittle transition region. Elevated loading rates, however, allow cleavage fracture due to the dynamic embrittlement also at higher testing temperatures compared to static loading. This behavior is generally accompanied by local crack arrest events. In addition, adiabatic heating processes in the crack tip region increase local temperature as well, which further promotes crack arrest. This complex interaction between crack initiation and crack arrest at elevated loading rates substantially changes macroscopic fracture behavior, whereas its investigation is the core of this work.

An experimental database of dynamic fracture mechanics experiments for the reactor pressure vessel steel 22NiMoCr3-7 is examined in this work that was previously tested at crack tip loading rates of about 103 to 105 MPa√m/s. Recent fractographic examinations and statistics regarding the occurrence and characteristics of local crack arrest incidences are shown for different loading rates and testing temperatures. Furthermore, an existing local probabilistic cleavage fracture model is used to describe macroscopic fracture behavior for the provided experimental database, and also compared to other assessment methods (i.e. Master Curve). The shortcomings in the numerical assessment methods can be linked to the amount of observed local crack arrest incidences, and a micromechanically motivated model modification is proposed to consider the mechanism of local crack arrest. The agreement between experimental results and numerical cleavage fracture assessment can be significantly increased by using the modified model.

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Keywords: cleavage fracture, dynamic fracture mechanics, crack arrest, local approach, finite-element-method

* Corresponding author. Tel.: +49-761-5142-105; fax: +49-761-5142-401.
E-mail address: johannes.tlatlik@iwm.fraunhofer.de

Cohesive zone modeling for three-dimensional elastic-plastic fatigue cracking with significant constraint effects

Huang Yuan[a,*]

[a]*Tsinghua University, China*

Abstract

Damage tolerance assessment is a keen topic in modern industrial product design. Under certain loading conditions fatigue crack growth is elastoplastic and the Paris' law becomes not applicable. In the past decades numerous cohesive zone models were proposed and investigated for predicting elastoplastic fatigue crack growth. However, three-dimensional cracks were not considered properly. The constraint effects to cohesive zone modeling were not explicitly studied so that the three-dimensional crack cannot be analyzed reasonably. Different cyclic cohesive zone models were introduced but lacking in experimental verifications. In the present paper cohesive zone models for three-dimensional crack growth under both monotonic and cyclic loading conditions are critically reviewed and commented. A new cohesive zone model for both monotonic fracture and cyclic fatigue crack growth has been suggested and implemented into a commercial finite element code. The cohesive energy and cohesive traction are assumed to depend on the local stress triaxiaility around the crack front and verified based on fracture and fatigue tests of a series of CT specimens with different thicknesses. The correlation between the stress triaxiality, the cohesive traction as well as the cohesive energy can be determined from fracture mechanics tests with help of detailed finite element computations. The model has been applied to predict rupture and fatigue crack growth in surface cracked round tensile bar and confirm that the stress-triaxiaility-dependent cohesive zone model can describe the elastic-plastic fatigue crack growth properly.

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Keywords: Cohesive zone model, fatigue crack growth, ductile fracture, constraint effects, three-dimensional cracks

* Corresponding author. Tel.: /
E-mail address: yuan.huang@tsinghua.edu.cn

Evolution and characterization of thermal shock damage in oxide/oxide ceramics matrix composites

Huang Yuan[a,*], Zhengmao Yang[b]

[a]*Tsinghua University, China*
[b]*Beijing Institute of Technology, China*

Abstract

The ceramics matrix composites (CMC) has won keen attentions for its high temperature resistance and high specific material strength. However, thermomechanical behavior of the CMC remains an interesting research topic for its application. The material possesses low heat conductivity combined with high temperature resistance and it results in the high sensitivity against thermal shock. Assessment of structural integrity under transient temperature loading conditions is of special importance for such constructions.
In the present paper the oxide/oxide ceramics matrix composite has been studied under different heating and cooling loading conditions. Experiments confirm that the CMC is extremely sensitive to the cooling rate and forms cracks under the sub-surface even after one quench in water. The cracks grow in the parallel direction to the specimen surface. The crack distribution becomes deeper into the material sub-surface with increasing cooling cycles and approaches stable. The macro-scopic stiffness of the specimen sinks with cooling cycles and can be correlated with the crack density. With help of finite element computations the thermal stresses in the thermal shock specimens can be determined and are responsible for the thermal shock damage. It is confirmed that the thermal shock damage grows rapidly for the first shock cycles. With increasing shock cycles, the damage growth rate becomes lower. The thermal shock damage is restricted within the region near the specimen surface. A damage evolution equation is introduced based on continuum damage mechanics principle under correlation with experimental thermal shock tests. The damage model can be applied to predict thermo-mechanical damage in turbine components under both thermal and mechanical loading conditions.

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Keywords: Ceramics matrix composites, thermoshock, fatigue damage, thermomechanical fatigue

* Corresponding author. Tel.: /
E-mail address: yuan.huang@tsinghua.edu.cn

Cyclic plasticity modeling of multi-axial thermo-mechanical fatigue tests with experimental verification on a nickel-based superalloy

Huang Yuan[a,*], Jingyu Sun[a]

[a]*Tsinghua University, China*

Abstract

Turbine components are generally under mechanical and thermal loads. Recent works confirm significant effects of thermomechanical loads to fatigue life assessment. In the present work, extensive experiments are performed for a nickel-based superalloy under both iso-thermal and thermo-mechanical loading conditions to quantify influence of thermal phase angle and loading non-proportionality. Thermo-mechanical and non-proportional loading affect mechanical behavior of metals and change the constitutive modeling. In the present work, extensive experiments are performed for a popular nickel-based superalloy Inconel 718 under both isothermal and thermo-mechanical loading conditions, to investigate the constitutive behavior and computational modeling. Within the frame of the Ohno-Wang cyclic plasticity a modified constitutive model has been suggested to meet the experimental observations, such as cyclic hardening/softening, nonproportional hardening, thermo-mechanical phase effect, nonmasing effect etc. The suggested model agrees with both isothermal as well as thermo-mechanical experiments reasonably. The implicit integration algorithm of the constitutive model is developed and implemented into the commercial finite element code. Comparison between experimental results and computations confirms that the model can predict the cyclic plastic behavior precisely under most different temperatures and loading paths. Based on experimental data a thermomechanical loading parameter is introduced to assess fatigue failure. The thermomechanical fatigue life can be calibrated based on the present concept reasonably.

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Keywords: Cyclic plasticity, multi-axial fatigue, theromechanical fatigue, temperature-gradient mechanical fatigue

* Corresponding author. Tel.: /
E-mail address: yuan.huang@tsinghua.edu.cn

The interlaminar fracture toughness fatigue behavior of fiber metal laminates

Konrad Dadej[a,*], Barbara Surowska[a], Jarosław Bieniaś[a]

[a]*Lublin University of Technology, Poland*

Abstract

The fatigue behavior of interlaminar fracture toughness test in the shearing mode was investigated in cyclically loaded CARALL and GLARE type unidirectional fiber metal laminates. The tests were performed on the basis of End Notched Flexure method. The critical strain energy release rates for the metal-composite adhesive joints were determined based on Enhanced Beam Theory. Fracture opening/shear mode mixity at the crack tip, as well as the fatigue interlaminar crack growth has been determined for nonhomogeneous asymmetrical fiber metal laminates.

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Keywords: fatigue, interlaminar fracture toughness, fiber metal laminates, fatigue crack growth

* Corresponding author. Tel.: /
E-mail address: k.dadej@pollub.pl

Using the Hybrid Metal Extrusion & Bonding (HYB) process for dissimilar joining of AA6082-T6 and S355

Filippo Berto[a,*], Lise Sandnes[a], Filippo Abbatinali[b], Øystein Grong[a,c], Paolo Ferro[b]

[a]Norvegian Unieversity of Science and Technology (NTNU), Department of Mechanical and Industrial Engineering, Richard Birkelands vei 2b, 7491 Trodnheim, Norway
[b]University of Padua, Department of Management and Engineering, Stradella San Nicola 3, 36100 Vicenza, Italy.
[c]HyBond AS, NTNU Aluminum Product innovation center, Richard Birkelands vei 2b, 7491 Trodnheim

Abstract

Hybrid Metal Extrusion & Bonding (HYB) is a new solid state joining technique that uses filler material addition and plastic deformation to create sound joints. The filler material addition makes the HYB process more flexible and less vulnerable to weld defects compared to conventional solid state joining techniques. Moreover, the operational temperature during processing is even lower than that reported for conventional joining techniques, which reduces the width of the heat affected zone (HAZ) significantly as well as residual stresses and contaminants in the weld zone. Here we report the joining of the dissimilar materials aluminum alloy 6082-T6 and structural steel 355. The joint is found to be free from defects like pores and internal cavities and is fully characterized herein from a metallurgical point of view.

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Keywords: Welding; hybrid metal extrusion & bonding (HYB); solid state process; dissimilar metals; intermetallic compounds.

* Corresponding author. Tel.: +47 485 00 575; fax: +47 485 00 576.
E-mail address: Filippo.Berto@ntnu.no

Intermediate self-similar asymptotic presentation of the stress and damage fields in the vicinity of the mixed mode crack tip under creep regime

Stepanova Larisa[a,]*

[a]*Department of Mathematical Modelling in Mechanics, Samara Univeristy, Moskovskoe shosse, 34, Samara 443086 Russia*

Abstract

Higher order asymptotic fields of stress, creep strain rate and damage of a mixed mode I/II creep crack tip are obtained and analyzed on the basis of Continuum Damage Mechanics by employing a similarity variable and similarity solution. In the paper the class of the creep mixed mode crack problems in damaged power law materials under creep-damage coupled formulation for plane strain conditions is considered. With the similarity variable and the self-similar representation of the solution for a power-law creeping material and the classical Kachanov – Rabotnov power-law damage evolution equation the near crack-tip stresses, creep strain rates and damage distributions for plane strain conditions are obtained. The approximate solutions are based on the idea of the existence of the completely damaged zone near the crack tip. The multi-term asymptotic expansions of the stress and damage fields outside the completely damaged zone are found. It is shown that the asymptotical analysis of the near crack-tip fields results in nonlinear eigenvalue problems. The technique permitting to find all the eigenvalues numerically is proposed and numerical solutions to the nonlinear eigenvalue problems arising from the mixed-mode crack problems in a power-law medium under plane strain conditions are obtained. Using the approach developed the eigenvalues different from the eigenvalues corresponding to the Hutchinson-Rice-Rosengren (HRR) problem are found. For new eigenspectra and eigensolutions obtained the geometry of the completely damaged zone in the vicinity of the crack tip is found for all values of the mixity parameter. Effect of the higher order terms of the asymptotic expansions on the near crack tip field description is elucidated. Special attention is paid to angular distributions of the stress and damage fields for mixed mode loading.

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Keywords: Creep crack problem, crack-tip fields, damage field, mixed-mode loading, mixity parameter, similarity .variable, intermediate stress asymptotic behavior, angular distributions of the stresses, totally damaged zone, higher order terms of asymptotic expansions.

* Corresponding author: Stepanova Larisa. Tel.: +7 -846 -334-54-41; fax: +7-846-334-54-41.
E-mail address: stepanovalv@samsu.ru

Crack growth monitoring in corrosion-fatigue tests using back face strain measurement technique

Ali Mehmanparast[a,*], Pietro Albani[a], Victor Igwemezie[a]

[a]*Offshore Renewable Energy Engineering Centre, Cranfield University, Cranfield, MK43 0AL, UK*

Abstract

Corrosion-fatigue crack growth tests are known to be considerably time consuming, particularly due to low loading frequencies which often result in several months of testing. This study focuses on development of a material and load dependent numerical model which correlates back face strains with crack lengths for standard compact tension, C(T), specimen geometry. To validate numerical predictions, calibration fatigue crack growth tests were conducted in air on C(T) specimens made of S355 steel, which is widely employed in offshore wind industry. The results obtained from these tests at different load levels have been compared with those predicted from the numerical model. Characterization of isotropic-kinematic hardening behaviour for the material adopted was carried out using the data available in the literature. The numerical model presented in this work has proven to generate accurate estimates of crack length in corrosion-fatigue tests. This model can be used in future experimental test programmes on S355 steel without needing to obtain experimental correlations between crack length and back face strains from calibration tests performed in air.

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Keywords: Corrosion fatigue crack growth, Offshore wind industry, kinematic hardening, steel S355

* Corresponding author. Tel.: /
E-mail address: a.mehmanparast@cranfield.ac.uk

Application of the equivalent material concept to fracture of U-notched solids under small scale yielding

F.J. Gómez[a,]*, M.A. Martín-Rengel[b], J. Ruiz-Hervías[b], A.R. Torabi[c]

[a]*Advanced Material Simulation, S.L., c/Asturias 3. Bilbao E-48015. Spain*
[b]*Departamento de Ciencia de Materiales, Universidad Politécnica de Madrid, c/Profesor Aranguren s/n Madrid 28040. Spain*
[c]*Fracture Research Laboratory, Faculty of New Sciences and Technologies, University of Tehran, P.O. Box 14395-1561, Tehran, Iran*

Abstract

This paper studies the applicability of the equivalent material concept developed by the author to the fracture of elastoplastic material due to the presence of U-notches. The approach of equivalent material concept consists of simplifying the study of an elastoplastic material reducing it to the linear elastic case with a maximum stress such as in a tensile test the deformation energy is equal to the real material. This idea combined with the cohesive zone model allows to establish a procedure to predict the failure of U-notched elements. The methodology has been successfully applied to five elastoplastic materials, and in all of them, the level of plasticity regarding the load of plastic collapse has been determined. This analysis verifies the proposed methodology and establish some application limits when the failure occurs within small scale yielding

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Keywords: U-notches; failure criteria; cohesive zone model; Equivalent Material Concept.

* Corresponding author. Tel.: +34 629269931.
E-mail address: Javier.gomez@amsimulation.com

Surface modification methods for fatigue properties improvement of laser-beam-welded Ti-6Al-4V butt joints

Fedor Fomin[a,*], Benjamin Klusemann[a,b], Nikolai Kashaev[a]

[a]*Helmholtz-Zentrum Geesthacht, Institute of Materials Research, Materials Mechanics, Max-Planck-Straße 1, 21052 Geesthacht, Germany*
[b]*Leuphana University Lueneburg, Institute of Product and Process Innovation, 21337 Lueneburg, Germany*

Abstract

Surface and internal defects formed upon laser beam welding (LBW) have been recognized as a serious problem because they cause stress concentration leading to premature failure of a welded component. This paper seeks to remedy these weld imperfections by applying various post-weld treatments and analyzing their effect on the high cycle fatigue (HCF) performance of welded joints. High efficiency of laser-based post-processing techniques after welding such as laser surface remelting (LSR) and laser shock peening (LSP) was demonstrated and compared with conventional approaches. The study reveals that welding porosity determines the internal crack initiation of the surface-treated weldments. Influence of process parameters on porosity level and the HCF properties is presented in detail. Based on an extensive experimental study, practical guidelines needed to mitigate the notch effect from defects and to maximize the fatigue performance of the laser-welded Ti-6Al-4V butt joints are given.

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Keywords: Laser beam welding; defects; porosity; high cycle fatigue; laser shock

* Corresponding author. Tel.: +49(4152)87-2529; fax: +49(4152)87-42536.
E-mail address: fedor.fomin@hzg.de

Influence of crack initiation on short crack propagation and cyclic lifetime of AA 7475-T761

Meike Funk[a,]*, Jürgen Bär[a]

[a]*University of the Bundeswehr, Institute for Material Science, 85577 Neubiberg, Germany*

Abstract

The propagation of short cracks covers the main part of the lifetime of cyclic loaded components. Thus, investigations in this field are necessary to enable reliable lifetime predictions.
To investigate the influence of different crack initiation scenarios on the cyclic lifetime, SEN-specimens were fatigued under constant stress amplitude. For additional support of the crack initiation in some specimens a single overload was introduced after 200 cycles, in others the crack initiation was forced by laser cuts in the notch root. In all experiments, the crack length was measured with a high-resolution DC-potential drop method.
This investigation approves and explains the relationship between the cyclic lifetime and the presence of steps on the fracture surface, as a reason of a retarded crack coagulation. The results clearly indicate that the scatter of the cyclic lifetime is determined by the differences in the crack initiation scenarios. Further on, a significant influence of a single overload on the cyclic lifetime can be verified.

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Keywords: fatigue; crack propagation; short crack; crack initiation

* Corresponding author. Tel.: +49-89-6004-2552; fax: +49-89-6004-3055.
E-mail address: meike.funk@unibw.de

Are the mechanical field parameters sufficient to predict uniquely the failure due to the ductile or cleavage mechanisms?

Andrzej Neimitz[a], Jaroslaw Galkiewicz[a,]*

[a]Kielce University of Technology, Aleja Tysiaclecia Panstwa Polskiego 7, 25-314 Kielce, Poland

Abstract

The most often observed failure mechanisms in metallic alloys are divided in two groups: brittle and ductile. Brittle failure mechanism may proceed along grain boundaries (failure due to the creep process or aggressive environment) or along the cleavage planes within the grain. Ductile fracture mechanism is most often the result of voids nucleation–growth–coalescence process or by dislocation slip along slip planes. Tests were performed at three different temperatures: +20°C, –20°C, –50°C, on five different specimens geometries, designed to provide different stress triaxialities, Lode factors as well as critical strains and stresses at the moment of final failure. Numerical analyses were performed after careful calibration of the real stress – logarithmic strains uniaxial curves. Calibration followed modified Bai–Wierzbicki procedure.

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Keywords: triaxiality; Lode angle; fracture mechanisms; stress-strain curve

* Corresponding author. Tel.: +48-41-342-4711; fax: +48-41-342-4295.
E-mail address: jgalka@tu.kielce.pl

A new design concept for prevention of hydrogen-induced mechanical degradation: viewpoints of metastability and high entropy

Motomichi Koyama[a,*], Takeshi Eguchi[a], Kenshiro Ichii[a], Cemal Cem Tasan[b], Kaneaki Tsuzaki[a,c]

[a]*Department of Mechanical Engineering, Kyushu University, Motooka 744, Nishi-ku, Fukuoka, 819-0395 Japan*
[b]*Department of Materials Science and Engineering, Massatusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, USA*
[c]*HYDROGENIOUS, Kyushu University, Motooka 744, Nishiku, Fukuoka, 819-0395 Japan*

Abstract

"How crack growth is prevented" is key to improve both fatigue and monotonic fracture resistances under an influence of hydrogen. Specifically, the key points for the crack growth resistance are hydrogen diffusivity and local ductility. For instance, type 304 austenitic steels show high hydrogen embrittlement susceptibility because of the high hydrogen diffusivity of bcc (α′) martensite. In contrast, metastability in specific austenitic steels enables fcc (γ) to hcp (ε) martensitic transformation, which decreases hydrogen diffusivity and increases strength simultaneously. As a result, even if hydrogen-assisted cracking occurs during monotonic tensile deformation, the ε-martensite acts to arrest micro-damage evolution when the amount of ε-martensite is limited. Thus, the formation of ε-martensite can decrease hydrogen embrittlement susceptibility in austenitic steels. However, a considerable amount of ε-martensite is required when we attempt to have drastic improvements of work hardening capability and strength level with respect to transformation-induced plasticity effect. Since the hcp structure contains a less number of slip systems than fcc and bcc, the less stress accommodation capacity often causes brittle-like failure when the ε-martensite fraction is large. Therefore, ductility of ε-martensite is another key when we maximize the positive effect of ε-martensitic transformation. In fact, ε-martensite in a high entropy alloy was recently found to be extraordinary ductile. Consequently, the metastable high entropy alloys showed low fatigue crack growth rates in a hydrogen atmosphere compared with conventional metastable austenitic steels with α′-martensitic transformation. We here present effects of metastability to ε-phase and configurational entropy on hydrogen-induced mechanical degradation including monotonic tension properties and fatigue crack growth resistance.

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Keywords: hydrogen embrittlement; austenitic steel; martensitic tran

* Corresponding author. Tel.: +81-92-802-3224.
E-mail address: koyama@mech.kyushu-u.ac.jp

Experimental simulation of fatigue crack growth by consecutive notches

Svyatoslav Eleonskiy[a,*], Yury Matvienko[b], Vladimir Pisarev[a]

[a] Central Aero-Hydrodynamics Institute named after Prof. N.E. Zhukovsky (TsAGI), Russia
[b]Mechanical Engineering Research Institute of the Russian Academy of Sciences (IMASH RAN), Russia

Abstract

Modified version of the crack compliance method is employed to describe an evolution of crack mouth opening displacement (CMOD), stress intensity factor (SIF) and T-stress values during low-cyclic fatigue process. The technique resides in modelling of crack propagation by making three successive notches after applying the different number of loading cycles. Rectangular plane specimens of dimensions 180×30×t mm^3 with central open hole of diameter $2r_0$ = 3.0 mm (t = 4 mm) and $2r_0$ = 4.0 mm (t = 5 mm) are the objects of the investigation. Two initial points of the first symmetrical notches belong to the edge of the hole. The direction of all notches coincides with transverse symmetry axis of the specimen. Notches width is Δb = 0.2 mm. The specimens are made from aluminum alloy of 2024 type. Experimental approach employs optical interferometric measurements of local deformation response on small notch length increment. Initial experimental data represent in-plane displacement component values measured by electronic speckle-pattern interferometry at some points located at the notch borders. SIF and T-stress values are calculated by involving of the first four or the first five coefficients of Williams' series. The availability of high-quality interference fringe patterns, which are free from rigid-body motions, indicates the real stress state inherent in the problem considered. Applied regular low-cyclic fatigue loading corresponds to Δσ = 333.3 MPa, R= – 0.33 for t = 4 mm and Δσ = 350 MPa, R = –0.40 for t = 5 mm. Maximal tensile stress for each loading program corresponds to maximal circumferential strain value on the hole edge $\varepsilon_{\varphi max}$ = 0.01. The crack length curves of CMOD, SIF and T-stress profiles are obtained at different stages of cyclic loading. These data provide constructing the dependencies of fracture mechanics parameters for cracks of fixed lengths from the loading cycle number.

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Keywords: Low-cyclic fatigue; crack opening; stress intensity factor; t-stress; speckle interferometry

* Corresponding author. Tel.: /
E-mail address: juzzepka@mail.ru

Defect structure of deformed heterogeneous materials: acoustic emission and X-ray microtomography

Ekaterina Damaskinskaya[a,]*, Ivan Panteleev[b], Dina Gafurova[c], Dmitry Frolov[a]

[a]Ioffe Institute, 26 Politekhnicheskaya, St. Petersburg 194021, Russia
[b]Institute of Continuous Media Mechanics of the Ural Branch of Russian Academy of Sciences, 1 Academician Korolev Street, Perm 614013,Russia
[c]Lomonosov Moscow State University, 1 Leninskiye Gory, Moscow 119991, Russia

Abstract

Laboratory investigations of deformation of heterogeneous brittle materials (rocks) by acoustic emission (AE) and *X*-ray computer microtomography (CT) are presented. The experiments involved loading of cylindrical samples of Westerly granite under the condition of uniaxial compression and recording of AE signals emitted during deformation of samples at different loading-unloading stages. After each unloading of the sample a tomographic survey was performed. All in all, 11 loading-unloading stages and tomographic surveys were carried out. The defect structure evolution is considered in the framework of the concept of self-organized criticality. It has been found that the type of the energy distribution function of AE signals can be used as an indicator of the deformed material state and transition to a critical fracture stage. An exponential function points to a noncritical state of a deformed material, and a power-law function indicates that the defect accumulation has passed to a critical stage. This result is confirmed by *X*-ray microtomographic data.

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Keywords: acoustic emission; X-ray tomography; defect, energy distribution; prediction

* Corresponding author. Tel.: +7-921-754-06-87; fax: +7-812-297-10-17.
E-mail address: Kat.Dama@mail.ioffe.ru

Investigation of pulsating water jet peening on the surface integrity of welded austenitic stainless steel joints

Madhulika Srivastava[a,*], Sergej Hloch[a], Rupam Tripathi[a], Dražan Kozak[b], Somnath Chattopadhyaya[a], Amit Rai Dixit[a], Josef Foldyna[c]

[a] *Indian Institute of technology (Indian School of Mines), India*
[b]*Faculty of Mechanical Engineering at Slavonski Brod, University of J. J. Strossmayer, Osijek, Croatia*
[c]*Institute of Geonics of the Czech Academy of Sciences Ostrava-Poruba, Czech Republic*

Abstract

The study investigates the influence of ultrasonically generated pulsed water jet peening of AISI 304 welded joints on its surface integrity. The tungsten inert gas (TIG welded joints was subjected to the treatment process and the effect of the parameters namely, type of nozzle and traverse speed of the nozzle at a pressure of 20 MPa on the surface characteristics were investigated. The weld joints was treated using flat and circular nozzle of diameter 1 mm and 1.9 mm, respectively. In order to evaluate the effectiveness of pulsating water jet technology as a surface treatment process, the residual stress of the samples was measured before and after the treatment process using x-ray diffraction technique (XRD). An improvement in the residual stress values was observed after the treatment process. The microstructure evolution of the near surface layers of the treated welded joints using optical microscopy (OM) and scanning electron microscopy (SEM) shows the initial and evolved erosion mechanism during the process. The results showed that the slip and twining phenomenon are responsible for causing the plastic deformation of the welded surface and also for the change in the residual stress condition after the treatment process. The improvement in the near surface residual stress of the welded joints shows the potential of using pulsating water jet technology as a surface treatment process.

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Keywords: pulsating water jet; peening; residual stress; welded joints

* Corresponding author. Tel.: /
E-mail address: madhulikamech3003@gmail.com

Environmental effects in biaxially orientated Polymethyl Methacrylate

Sze Ki Ng[a,]*, Muhammad A. Kamaludin[a], John P. Dear[a], Bamber R. Blackman[a]

[a]Department of Mechanical Engineering, Imperial Collge London, London,UK SW7 2AZ

Abstract

Environmental stress cracking (ESC) is commonly found in polymers when submerged in an environment under applied stress. In such conditions, a crack may initiate and propagate from a material defect until it reaches a critical size and causes catastrophic failure. It is known that materials with a denser molecular structure are less prone to ESC, hence amorphous polymers often suffer greatly from this effect. A fracture mechanics approach was employed to investigate the fracture mechanism and crack growth in both air and environment. Two different grades of PMMA (amorphous and biaxially stretched PMMA) were tested in solvents with similar solubility parameters as this is known to hasten crazing. Time for crack initiation and crack speed were obtained and plotted against their corresponding fracture toughness. Thus, the ESC resistance of each material can be compared and component life expectance can also be predicted. To validate the experimental results, scanning electron microscopy (SEM) was used to examine the fracture mechanism of ESC.

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Keywords: environmental stress cracking; biaxially orientated PMMA; fracture mechanics; crazing

* Correpsonding autohor. Tel.: /
E-mail address: sze.ng11@imperial.ac.uk

Optimization of the fracture mechanical properties of additively manufactured EN AW-7075

J.-P. Brüggemann[a,]*, L. Risse[a], G. Kullmer[a], H. A. Richard[a]

[a]*Paderborn University, Institute of applied mechanics*

Abstract

Additive Manufacturing (AM) is a new innovative technique that allows the direct manufacturing of complex products based on their 3D data in a layer technology without tools like molds. In the meantime there are lots of materials available for AM, e.g. plastics or metals. They are used in several areas of application like aerospace, aircraft, medical technology and the automotive industry. In order to fulfil the high requirements of these industrial branches, high-quality products are expected. Selective Laser Melting (SLM) enables the production of finished parts, which can be mechanically and thermally stressed to a very high level. In aerospace, aircraft and automotive industry the lightweight design is of paramount importance. Consequently, in these industries materials with low density and high mechanical properties such as aluminum alloys are used. Therefore, high strength aluminum alloy EN AW-7075 powder, which was not previously used for AM, was produced by gas atomization and processed by SLM.
Initially, several process parameters were varied in order to find the set of process parameters for the best possible result. With this set of parameters samples were produced to examine the fracture mechanical properties. To investigate the influence of the building direction regarding possible anisotropic behavior, specimens were manufactured with starting notches parallel as well as perpendicular to the building direction. For the fracture mechanical examination compact tension specimens, according to ASTM 647-08, were analyzed in order to achieve fatigue crack growth curves. To compare AM products with the conventionally manufactured aluminum alloy EN AW-7075 two different conditions (as-built and heat-treated) were examined.

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Keywords: Additive manufacturing; selective laser melting; aluminium alloy EN AW-7075; mechanical properties; fatigue crack growth behaviour

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* Corresponding author. Tel.: +49-5251-60-4388; fax:+49-5251-60-5322.
E-mail address: brueggemann@fam.upb.de

Fracture mechanical investigations on selective laser melted Ti-6Al-4V

J.-P. Brüggemann[a,*], L. Risse[a], G. Kullmer[a], B. Schramm[a], H. A. Richard[a]

[a]*Paderborn University, Institute of applied mechanics*

Abstract

Additive Manufacturing (AM) techniques such as selective laser melting (SLM) enable material efficient production of individual and complex components in a short period of time. One typical material that is processable by SLM is the titanium alloy Ti-6Al-4V. This alloy is frequently used in medicine technology because of low density, very high strength and biocompatibility. The AM process leads to many advantages like the opportunity to produce complex parts with for instance undercuts or lattice structures. As AM parts are used in various high-quality sectors the material properties are of great interest. Many influencing factors have an impact on the resulting material properties of additively manufactured Ti-6Al-4V products. For a reliable application and a fracture-safe construction the influence of different changes in the production parameters on the material properties have to be known.
As Ti-6Al-4V is already processable and the mechanical and fracture mechanical properties for a defined powder particle size distribution are known, the influence of a varied powder particle size, in this case of a significantly smaller, average particle size is investigated in the scope of this paper. In detail, the mechanical and fracture mechanical behavior under different heat treatments is compared to existing data for the higher average particle size. Because of the resulting residual stresses during the building process a heat treatment is always necessary for a reliable structure. To determine the material properties, tensile tests according to DIN EN 10002-1 were conducted. For the fracture mechanical examinations compact tension specimens, according to ASTM 647-08 standard, were used. Fatigue crack growth curves with an R-ratio of 0.1 were investigated.

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Keywords: Additive manufacturing; selective laser melting; Ti-6Al-4V; particle size distribution; fatigue crack growth behaviour

* Corresponding author. Tel.: +49-5251-60-4388; fax: +49-5251-60-5322.
E-mail address: brueggemann@fam.upb.de

Influence of fracture mechanically graded materials on the crack propagation behaviour in three-dimensional structures

Katharina Dibblee[a,]*, Hans Albert Richard[a], Gunter Kullmer[a]

[a]Institute of Applied Mechanics, University of Paderborn, Germany

Abstract

Due to the constant improvement of technological materials we face new challenges in aspect of crack growth behaviour. It shows different behaviour, depending on whether you use functionally graded materials and structures or if you deal with homogeneous isotropic materials. The crack growth therefore is not only influenced by the actual local stress but also by the local material properties. By accepting this new challenge it is necessary to develop a new fracture criterion which takes both into account.
This paper introduces a new three-dimensional fracture mechanical concept which takes the material parameters into account to calculate crack growth behaviour. The basic principle of this concept is set by the σ_1'-criterion which requires the function of the maximum principle stress along the crack front. By comparing this function with the local materialfunction it is possible to calculate the expected crack kinking according to the TSSR concept. Implementing this new concept into the crack growth program ADAPCRACK3D^{VERSION_KD15} made it possible to simulate the crack growth behaviour in three-dimensional homogeneous isotropic materials as well as in functional graded structures. The influence of fracture mechanically graded material with respect to the crack growth direction, the local crack growth rate and the lifetime of the structures of graded materials can now be realistically calculated. The following paper presents simulation results of structures of fracture mechanically graded materials such as an induction hardened cog wheel. Compact tension specimen and compact tension mixed-mode specimen with various angles of material gradation and combinations of different material properties are examined to emphasise the influence of material gradation on the crack growth. The results of the numerical investigations focused on the crack growth direction as well as the influence on lifetime will be discussed in detail.

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Keywords: crack growth simulation, fracture mechanical graded materials, three-dimensional concept

* Corresponding author. Tel.: +49 5251 605424; fax: +49 5251 605322.
E-mail address: dibblee@fam.upb.de

Crack growth simulation with ADAPCRACK3D in 3D structures under the influence of temperature

T. D. Joy*, J. -P. Brüggemann, G. Kullmer

Institute of Applied Mechanics, Paderborn University, Pohlweg 47-49, Paderborn 33098, Germany

Abstract

Lifetime of components or structures that are under cyclic loading rely upon the growth rate and the path of cracks that are developed during its operation. Thus the prediction of fatigue crack growth reduces the adverse effects which can be caused because of its behavior. Many simulation programs are available to foresee the crack growth and growth rate in structures, thereby determining their lifetime. ADAPCRACK3D is an automatic crack growth simulation program which uses the finite element method to simulate crack growth behavior in structures. FE-Simulations are performed in 3D models of structures to determine the stresses that are developed due to the given loading situations. Thereafter, the software performs fracture mechanical evaluation to determine crack path and the lifetime of components that are under mixed-mode loading. ADAPCRACK3D is generally used for simulating mechanically loaded components. In addition to the stresses that are caused because of mechanical loading, stresses developed due to the change in temperature in components can also have influence on the crack growth behavior.

This paper is an attempt to introduce temperature as a new boundary condition in the software in addition to the mechanical loading conditions that are already available. 3D models of structures are separately created with mechanical and thermal loading conditions. Simulations are conducted to understand the crack growth in models that have only mechanical loading and those having both the mechanical and temperature boundary conditions. The results obtained from both the simulations are evaluated to understand the influence of applying temperature as an additional boundary condition.

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Keywords: Crack growth simulation; ADAPCRACK3D; fatigue crack growth; temperature simulation

* Corresponding author. Tel.: +49-5251-60-5325; fax: +49-5251-60-5322.
E-mail address: joy@fam.upb.de

Working life estimate of the tubular T-joint by application of the LEFM concept

Jelena M. Djoković[a], Ružica R. Nikolić[b,c,*], Branislav Hadzima[b], Dušan Arsić[c], Libor Trško[b]

[a]Technical Faculty of Bor, University of Belgrade, Vojske Jugoslavije 12, 19210 Bor,Serbia
[b]Research Center, University of Žilina, Univerzitna 2415/1, Žilina 010 26, Slovakia;
[c]Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, 34000 Kragujevac, Serbia

Abstract

The crack growth in tubular joints usually occurs along the weld's toe. That is the point where the chord and brace intersect. The semi-elliptical crack appears in this area from the initial flaw that was created during the welding. Sensitivity to fatigue depends on combination of cyclic loading, initial defects, environmental influences and the hot spot stresses, which are result of the walls' bending during the loading of a structure. The principles of the linear elastic fracture mechanics (LEFM) are applied here to crack growth in the tubular T-joint, subjected to axial load, in-plane and anti-plane bending. Influences of the level and type of loading, as well as of the joint's geometrical characteristics, on the fatigue crack propagation and consequently on the working life of the welded joint, are considered. Based on the conducted analysis, which implies a set of assumptions, one can draw sufficiently relevant conclusion on the remaining working life of the tubular T-joint. The assumptions included: the crack shape is semi-elliptical, there is only one crack propagating through the tube wall, the cyclic plastic zone at the crack tip is small with respect to other geometrical variables and the crack grows only if the difference between the stress intensity factor values at maximal and minimal loads is greater than the stress intensity factor necessary for the fatigue crack growth initiation. Results are presented in the form of diagrams from which can be seen that for the same load level the longer working life is achieved for the axial load of the joint than for the in-plane bending, while the values for the anti-plane bending lie between these two limiting results.

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*Keywords:*tubular T- joint; fatigue crack; Paris law; LEFM

* Corresponding author. Tel.: +421415137627.
E-mail address: ruzicarnikolic@yahoo.com

Cruciform welded joints: hot-dip galvanization effect on the fatigue life and local energetic analysis

L. M. Viespoli[a,]*, F. Mutignani[a], H. Remes[b], F. Berto[a]

[a]Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology (NTNU), Norway
[b]Department of Applied Mechanics, Aalto University, Finland

Abstract

Even in a well-controlled technological process, a certain variability in the final product is present and this is very well the case of welded joints, where each single joint is slightly different from the others in terms of fillet dimensions, distortion, notch opening angle and root radius and material properties. When the fatigue life assessment of a welded joint is carried out using the Notch Stress Intensity Factors, their dimensions, so their critical values, vary as a function of the notch opening angle, according to William's solution. This constitutes an adjunct level of complicacy in the implementation of the method, the most explicative case being the inability to use the same material property value in the same joint, this varying from weld toe to weld root. So considered, the local Strain Energy Density, averaged on a critical volume of carefully chosen radius on the base of the class of material and surrounding the notch's tip, has the great advantage of being a scalar value of relatively simple numerical computation, almost independent of mesh refinement and independent of the notch-opening angle. The aim of the paper is to adopt the local SED method to analyze the results of a series of tests executed on fillet welded galvanized and non-galvanized cruciform steel joints. The tests are performed in atmosphere at room temperature. The interest is particularly focused on the influence of the zinc layer on the fatigue life of the joint and on the fitness of the method for its prediction, regardless of coating thickness.

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Keywords: hot dip galvanization; strain energy density; welding; fatigue; structural steel; notch

* Corresponding author. Tel.: +47 459 13 281.
E-mail address: luigimv@stud.ntnu.no

Experimental-numerical analysis of appearance and growth of a crack in hard-faced layers of the hot-work high-strength tool steels

Dušan Arsić[a, *], Vukić Lazić[a], Aleksandar Sedmak[b], Zijah Burzić[c], Bojan Medjo[d], Ružica Nikolić[a, e]

[a]*University of Kragujevac, Faculty of Engineering, Serbia*
[b]*University of Belgrade, Faculty of Mechanical Engineering, Serbia*
[c]*Military Technical Institute, Belgrade, Serbia*
[d]*Faculty of Technology and Metallurgy, Serbia Reserch Center,*
[e]*University of Zilina, Slovakia and Faculty, Slovakia*

Abstract

An analysis of the resistance to crack appearance and growth in different zones of the hard-faced layers of the chromium based hot-work tool steel H11 (AISI) is presented. The analyzed steel is mainly used for manufacturing the highly loaded parts such as forging dies, casting and extrusion dies, as well as for hot rolling and it is aimed for operations at elevated temperatures. It is characterized by the good impact toughness and high tensile strength, which remains stable at elevated temperatures, as well. Experimental investigations included determination of fracture mechanics parameters - energies needed for the crack initiation and growth in different zones of the hard-faced layer (the weld metal, the heat affected zone and the base metal) on the Charpy pendulum, as well as monitoring the crack propagation due to the fatigue load on the SENB samples. For the samples preparation a 15 mm thick plate of the considered steel was hard faced. Results are presented in the form of diagrams of the crack growth per the loading cycle (da/dN).
Besides the experimental investigations, the numerical simulation of determining the fracture mechanics parameters was conducted as well and results obtained by the two methods were compared to each other. Based on obtained results, the most critical zones of the hard-faced layers for the crack appearance were defined. Those results can be used for predicting the behavior of the hard-faced forging dies in exploitation.

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Keywords: Hard facing; Hot-work high strength tool steel; fracture toughness; numerical analysis

* Corresponding author. Tel.: /
E-mail address: dusan.arsic@fink.rs

Experimental investigation of mixed mode fracture of tropical wood material

Odounga Bernard[a,b], Moutou Pitti Rostand[a,c,*], Toussaint Evelyne[a], Grediac Michel[a]

[a]*Universit´e Clermont Auvergne, Institut Pascal, CNRS, F-63000 Clermont-Ferrand, France*
[b]*Universit´e des Sciences et Techniques de Masuku, ´Ecole Polytechnique de Masuku, BP 901, Franceville, Gabon*
[c]*CENAREST, IRT, BP. 14070, Libreville, Gabon*

Abstract

The process of mixed-mode crack growth of three tropical species of the Gabonese forest, namely iroko (Milicia Excelsa), okume (Pierre Aucoumea klaineana), and padouk (Pterocarpus soyauxii) is studied in this paper. Different tests were carried out at room temperature for different thicknesses. A full-field measurement technique, namely the grid method, was used to obtain both the displacement and deformation maps near the crack tip. The mechanical parameters, the specificities of the wood species, the Arcan system and the grid transfer method are described in the paper. For all the samples, the initial crack was oriented along the fiber direction (RL). Fracture tests were performed using modified Mixed Mode Crack Growth (MMCG) specimen. A thickness of the specimens is 20 mm, and a mixed mode ratio corresponding to 15 0 were studied. The force-displacement curves, the crack growth process as well as the opening crack were deduced from grid images treated with the grid method. The experimental critical energy release rate Gc was evaluated by the imposed displacement compliance method. The different results show the predomi- nance of mode 1 compared to mode 2. The proportionality of the initial value of the energy release rate with respect to the density of these species is also highlighted.

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Keywords: Fracture, tropical species, MMCG specimens, grid method.

* Corresponding author: Moutou Pitti Rostand. Tel.: +33 473 407 532 ; fax: +33 473 407 494.
E-mail address: rostand.moutou pitti@uca.fr

Effects of eco-friendly corrosion inhibitors on the behavior of API X65 pipe steel under dynamic loading

Hadj Meliani Mohammed[a,*]

[a]*LPTPM, Hassiba Benbouali university of Chlef, Algeria*

Abstract

Several corrosion inhibitors are used in industry to reduce the corrosive effects of harsh environments on the mechanical properties of steel structures. More recently, eco-friendly (green) inhibitors are being developed to replace synthetic ones with toxic organic molecules. In the present study, Ruta Chalepensi (Fijil) green corrosion inhibitors are utilized with API X65 pipe steel to study their effectiveness in reducing the corrosive effects of HCl acid. Notched specimens are immersed in HCl and HCl with different concentrations of Fijil (3, 5, 10 and 30 vol.%) for 3, 7 and 10 days. Charpy tests are carried out, after each period, on treated and untreated standard specimens to evaluate the response of the material under dynamic loading. The load-displacement curves are found to consist of four zones corresponding to different crack advance events. Immersion in green inhibitor (5 Vol%) for 10 days resulted in improving the fracture toughness of API 5L X65 by 43%.

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Keywords: Corrosion; green inhibitors; failure; fracture mechanics; pipelines; API 5L X65

* Corresponding author. Tel.:/
E-mail address: hadjmeliani@yahoo.fr

The effectiveness of the green inhibitors against corrosion in hydrochloric acid on mechanical properties of API 5l x52 pipe steel

Hadj Meliani Mohammed[a,*], Guy Pluvinage[b]

[a]*LPTPM, Hassiba Benbouali university of Chlef, Algeria*
[b]*LEM3, Lorraine University, France*

Abstract

The impact of environment can cause many types of degradations such as pitting corrosion, stress corrosion cracking and sulphide stress cracking of metal structures. One of the serious problems of oil extracting industry is the corrosion process. Recently there were number of resources failures, caused by internal corrosion, recorded in oil and gas industry, the reports confirmed that the failures were due to the effect of traces Hydrochloric acid. Our objectives are to use the plant extracts, such as corrosion inhibitors on API 5L X52 steel. Indeed, these natural extracts contain many families of natural organic compounds "Green", readily available and renewable. The mechanics tests carried out on this study of anti-corrosive properties of natural products of plant origin will be to given so far promising results on the fracture mechanics properties. The importance of this area of research is mainly related to the fact that natural products can replace toxic organic molecules present condemned by the world directives for environmentally unacceptable.

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Keywords: Corrosion; green inhibitors; failure; fracture mechanics; pipelines; API 5L X65

* Corresponding author. Tel: /
E-mail address: hadjmeliani@yahoo.fr

Failure analysis of gas sweetening tower absorber packing

M. Newishy[a,*], S. A. Khodir[a], H. Abdel-Aleem[a]

[a]*Central metallurgical research and development institute, Egypt*

Abstract

Gas sweetening tower packing was failed in the form of corrosion damage after 3 month from installation. Pieces from the failed packing as well as unused one were received for investigation to establish whether its failure was due to specific material aspects or improper use.
The investigation showed that the packing was 316L stainless steel which failed due to intergranular chloride stress corrosion cracking. The root cause of the failure of the received packing could be mainly attributed to the material residual shear bands after packing sheet manufacturing process. The shear bands were formed due to lack of solution annealing after cold deformation process. Corrosion is mainly controlled by chloride ions and residual stress. It is recommended to use high quality material free from residual stresses by applying solution annealing heat treatment after cold deformation of the packing sheets and removing of the chloride ions by controlling the inlet water.

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Keywords: Gas sweetining, asorber packing, corrosion, stress corrosion cracking, failure analysis

* Corresponding author. Tel.: /
E-mail address: newishymohamed@gmail.com

Flaw interaction under bending, residual stress and thermal shock loading

H. E. Coules[a,*]

[a]*University of Bristol, Bristol, BS9 1TR, United Kingdom*

Abstract

Crack-like surface flaws in pipes, pressure vessels and other structural components sometimes occur near to one another. When this happens, it is often necessary to take the mutual interaction of the flaws into account when performing fracture-mechanics-based fitness-for-service assessment. Integrity assessment procedures including ASME BPVC Section XI, BS 7910 and R6 include interaction criteria which are used during flaw characterisation to ensure that interaction is accounted for conservatively. This paper considers the interaction which occurs when flaws are loaded by a non-uniform through-wall distribution of stress, as may arise due to bending, thermal shock or welding/cladding residual stresses. Using parametric finite element analysis of a large number of crack pairs subjected to different distributions of stress, it is shown that the degree of flaw interaction can be enhanced under non-uniform loading. Therefore, care should be taken when performing integrity assessment using interaction criteria based on uniform tension loading only.

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Keywords: fracture; flaw interaction; structural integrity assessment; weight function; finite element analysis.

* Corresponding author. Tel.: +44 (0)117 3315946.
E-mail address: harry.coules@bristol.ac.uk

Structural analysis and composite material testing for space antenna reflector

Egor Moskvichev[a,*]

[a]*Institute of Computational Technologies SB RAS, Russia*

Abstract

Deployable space antenna reflectors are traditionally represented by a metallized mesh which needs additional tension to ensure desirable accuracy of the reflective surface. But the growing demands on quality of space antennas require new design solutions to increase weight efficiency and surface accuracy of the reflectors. The appropriate design of large aperture reflector was developed jointly by JSC Information Satellite Systems Reshetnev, Reshetnev Siberian State University of Science and Technology and Institute of Computational Technologies SB RAS.
The designed antenna reflector is 4 m diameter and has an umbrella structure with radial spokes. The reflective surface is represented by a thin solid shell which is made of a biaxial carbon fiber woven composite. During space launch the reflector is in a compact transport position while the composite shell is folded between spokes. According to this the material of the reflector must have an appropriate stiffness and strength properties to ensure the shape stability in deployed position after large flexural deformations.
To confirm the required reflector properties the complex structural analysis and composite shell material testing were performed. Experimental studies included the determination of mechanical properties during tension, compression, shear and bending tests. Additional determined properties included density and coefficient of thermal expansion. Based on the experimental results the following studies were carried out by finite element method: estimation of the geometric stability and strength of the reflector considering mechanical and thermal loads; simulation of folding the reflector into transport position.
The results of numerical modeling and experimental studies confirmed that the considered design of the reflector meets the technical requirements. Thus, at the next stage of the research program it is necessary to perform full-scale tests of the reflector prototype to verify the simulation results and folding operation.
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Keywords: space antenna; reflector; structural analysis; composite material; testing.

* Corresponding author. Tel.: /
E-mail address: jugr@icm.krasn.ru

The combined effect of pressure and autofrettage on the 3-D stress intensity factor of an internally cracked spherical pressure vessel

Mordechai Perl[a,]*, Matan Steiner[b]

[a]*Ben-Gurion University of the Negev, Israel*
[b]*Technion - Israel Institute of Technology, Israel*

Abstract

The distributions of the combined 3-D Stress Intensity Factor (SIF), KIN=KIP +KIA, due to both internal pressure and autofrettage along the front of an inner radial lunular or crescentic crack emanating from the bore of an overstrained spherical pressure vessel are evaluated. The 3-D analysis is performed using the finite element (FE) method employing singular elements along the crack front. A novel realistic autofrettage residual stress field incorporating the Bauschinger effect is applied to the vessel. The residual stress field is simulated using an equivalent temperature field in the FE analysis. SIFs for three vessel geometries (R_0/R_i=1.1, 1.2, and 1.7), a wide range of crack depth to wall thickness ratios (a/t=0.01-0.8), various ellipticities (a/c=0.2-1.5), and three levels of autofrettage (ε =50%, 75%, and 100%) are evaluated. In total, about two hundred and seventy different crack configurations are analyzed. A detailed study of the influence of the above parameters on the prevailing SIF is conducted. The results clearly indicate the favorable effect of autofrettage in considerably reducing the prevailing effective stress intensity factor i.e., delaying crack initiation, slowing down crack growth rate, and thus substantially prolonging the total fatigue life of the vessel by up to twenty-five-fold. This favorable effect is found to be governed by σ_y/p - the ratio of the vessel's material initial yield stress to its internal. The higher the ratio is, the more effective autofrettage becomes. Furthermore, the results emphasize the importance of properly evaluating the residual stress field due to autofrettage while at the same time accurately accounting for the Bauschinger effect, including re-yielding, as well as the significance of the three dimensional analysis herein performed.

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Keywords: 3-D Stress intensity factor; spherical pressure vessel; autofrettage

* Corresponding author. Tel.: /
E-mail address: merpr01@bgu.ac.il

Effects of increased span on fracture toughness using non-standard PCVN specimens and implications for the reference temperature, T_0

Vitor Scarabeli Barbosa[a], Claudio Ruggieri[a,*]

[a]*Department of Naval Architecture and Ocean Engineering, University of São Paulo, São Paulo/SP, Brazil*

Abstract

This work addresses an experimental investigation on the effects of increased span on the cleavage fracture behavior for an ASTM A572 high strength, low alloy structural steel using non-standard PCVN configuration. Fracture toughness testing conducted on PCVN specimen configurations with varying specimen span provides the cleavage fracture toughness in terms of the *J*-integral at cleavage instability, J_c. The experimental results show a rather marked effect of increased span on J_c-values which can help to mitigate the effects of constraint loss commonly observed in PCVN specimens. An exploratory application to evaluate the reference temperature, T_0, based on the Master Curve methodology also provides additional support for using non-standard PCVN specimens in routine procedures to assess fracture toughness behavior of ferritic materials.

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Keywords: cleavage fracture behavior; non-standard precracked Charpy specimen; constraint effects; reference temperature; master curve

* Corresponding author. Tel.:+55-11-30915184; fax:+55-11-30915717.
E-mail address: claudio.ruggieri@usp.br

Experimental tests on new titanium alloy interbody cervical cages

Guido La Rosa[a]*, Carmelo Clienti[a], Rosalia Mineo[b]

[a]DICAR, University of Catania, Via S. Sofia 64, 95123 Catania, Italy
[b]MT Ortho s.r.l., Via Fossa Lupo, 95025 Aci S.Antonio, Catania, Italy

Abstract

Degenerative diseases of the spine, when not solvable with clinical treatments or with suitable stabilization systems, can be cured by means of the technique of arthrodesis through the interbody fusion of two or more vertebrae. The paper deals with the tests carried out on commercial and innovative cervical cages, used in the primary stabilization of the vertebrae, able to maintain the right distance and to assure the interbody fusion.
Additive manufacturing (AM) is a powerful new tool offering the necessary competitiveness to the biomedical manufacturing companies, having the possibility to create materials with controlled porosity combined with solid parts, providing to the workpiece excellent capacity in the subsequent phases of osseointegration.
Based on the knowledge developed either in the biomechanics of the spine or in the properties of biocompatibility and osseointegration of titanium alloys, MT Ortho has developed some models of cervical cage made from modern additive printing techniques with titanium alloy.
Three different cervical cage made of different materials were subjected to static compression test: a commercial cervical intervertebral cage in PEEK and two cervical intervertebral cages in Ti alloy produced by the EBM process by MT Ortho.
Tests on the innovative cage produced by EBM have shown encouraging results. From this first preliminary analysis its showed that the mechanical and functional failure of the innovative devices made in melted Ti alloy by EBM is achieved by load values greater than physiological ones of the cervical spine.

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Keywords: Cervical cages; additive manufacturing; EBM Ti alloy; biomechanical tests.

* Corresponding author. Tel.: /
E-mail address: glarosa@dii.unict.it

ECF22 - Loading and Environmental Effects on Structural Integrity

Cracking in paintings due to relative humidity cycles

Joseph D. Wood[a], Cécilia Gauvin[b], Christina R.T. Young[b], Ambrose C. Taylor[a], Daniel S. Balint[a], Maria N. Charalambides[a,]*

[a]*Department of Mechanical Engineering, Imperial College London, London, SW7 2AZ, UK*
[b]*School of Culture & Creative Arts, University of Glasgow, Glasgow, G12 8QQ, UK*

Abstract

A numerical study is performed using the finite element method to consider the effects of low-cycle fatigue, specifically induced through relative humidity cycles on paintings. It has been identified that there are two major crack types in paintings, these being (i) an interfacial crack (delamination) between paint and support and (ii) a through-thickness (channel) crack in the paint layer itself, arresting on the interface. Therefore a 2D plane strain model for each type of crack has been created, which both consist of an alkyd paint modelled using a visco-hyperelastic material model and a primed canvas which is assumed to behave in a linear elastic manner. To account for fatigue damage in both models, cohesive elements located along the interface or through the film thickness respectively, are used and the traction-separation law has been modified to incorporate a fatigue damage parameter. It is possible to expose the models to the same relative humidity cycles, which would typically be seen in museums, enabling the prediction of time to first crack and which crack type is more readily grown in the painting.

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Keywords: finite element; interface fracture; irreversible cohesive zones; low-cycle fatigue; thin films; through-thickness crack; viscoelastic.

* Corresponding author. Tel.: +44 (0)20 7594 7246.
E-mail address: m.charalambides@imperial.ac.uk

Micromechanical modeling of inter-granular localization, damage and fracture

Tuncay Yalçinkaya[a,*], Izzet Özdemir[b], Ali Osman Firat[a], Izzet Tarik Tandoğan[a]

[a]*Department of Aerospace Engineering, Middle East Technical University, Ankara 06800, Turkey*
[b]*Department of Civil Engineering, Izmir Institute of Technology, Urla, Izmir 35430, Turkey*

Abstract

The recent developments in the production of miniaturized devices increases the demand on micro-components where the thickness ranges from tens to hundreds of microns. Various challenges, such as size effect and stress concentrations at the grain boundaries, arise due to the deformation heterogeneity observed at grain scale. Various metallic alloys, e.g. aluminum, exhibit substantial localization and stress concentration at the grain boundaries. In this regard, inter-granular damage evolution, crack initiation and propagation becomes an important failure mechanism at this length scale. Crystal plasticity approach captures intrinsically the heterogeneity developing due to grain orientation mismatch. However, the commonly used local versions do not possess a specific GB model and leads to jumps at the boundaries. Therefore, a more physical treatment of grain boundaries is needed. For this purpose, in this work, the Gurtin GB model (Gurtin (2008)) is incorporated into a strain gradient crystal plasticity framework (Yalcinkaya et al. (2011), Yalcinkaya et al. (2012), Yalcinkaya (2017)), where the intensity of the localization and stress concentration could be modelled considering the effect of grain boundary orientation, the mismatch and the strength of the GB. A zero thickness 12-node interface element for the integration of the grain boundary contribution and a 10-node coupled finite element for the bulk response are developed and implemented in Abaqus software as user element subroutines. 3D grain microstructure is created through Voronoi tessellation and the interface elements are automatically inserted between grains. After obtaining the localization, the mechanical behavior of the GB is modelled through incorporation of a potential based cohesive zone model (see Park et al. (2009), Cerrone et al. (2014)). The numerical examples present the performance of the developed tool for the ntrinsic localization, crack initiation and propagation in micron-sized specimens.

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Keywords: Strain gradient crystal plasticity; cohesive zone modeling, grain boundary modeling, inter-granular fracture.

* Corresponding author. Tel.: +90-312-2104258 ; fax: +90-312-2104250.
E-mail address: yalcinka@metu.edu.tr

Patented inventions of Serbian scientists in the field of seismic reliability of structures and landslide remediation with application

Mirjana D. Jelić[a,b]*

[a]*Patent sector, Intellectual Property Office of the Republic of Serbia, Kneginje Ljubice 5, Belgrade 11000, Serbia*
[b]*University Studies, History and Philosophy of Natural Sciences and Technology, University of Belgrade, Studentski trg 3, Belgrade 11000, Serbia*

Abstract

Having in mind that on the territory of the Republic of Serbia patent protection of domestic inventions has been at the level of 20% of the total number of patents granted by the European Patent Office to inventors from Europe in the past twenty years in the area of seismic reliability of structures and landslide remediation, this work complements research on the continuity in the application of exceptional technical solutions of Serbian scientists in the field of civil engineering, that has been started with the work with title: Common characteristics of main contributions of Roger Boscovich, Milutin Milanković and Branko Žeželj to the development of civil engineering, 2017. Bearing in mind that Žeželj has been active in patent protection of his numerous inventions, during second half of the 20th century, this paper presents systematic overview of patented inventions created in 21st century by Serbian scientists and inventors in the field of seismic safety of structures and landslide remediation, as well as examples of their specific application.

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Keywords: seismic reliability, earthquake, rebuilding landslide, civil engineering, invention, patent

* Corresponding author. Tel.: + 381112025924; fax: + 381113112 377
E-mail address: mjelic@zis.gov.rs; mjelicjm@gmail.com

Fracture toughness for engineering application: There is a need for more suitable testing standards

Hans-Jakob Schindler[a,*]

[a]*Mat-Tec AG, Unterer Graben 27, 8400 winterthur, Switzerland*

Abstract

Fracture toughness testing standards such as ASTM E1820 or ASTM E 1921 ISO 12350 are seldom used in practice. Estimates of K_{Ic} or J_{Ic} by empirical correlations with classical Charpy impact tests are much more popular and often preferred. The reasons for this unsatisfying situation is that the standard procedures of fracture toughness testing are much more demanding than the Charpy test, in terms of costs, test material, test equipment and expertise of the laboratory personal, whereas the much simpler CV-test still delivers useful estimates. However, between standard fracture toughness testing and classical Charpy impact testing there is a wide space for possible new tests that are similarly simple as Charpy tests and similarly informative as a fracture toughness tests. In the present paper, some suggestions for such more practical fracture toughness tests are made.

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Keywords: Fracture toughness testing, test standards, Charpy test,

* Corresponding author. Tel.: +41 52 404 54 44.
E-mail address: schindler@mat-tec.ch

Damages of burner pipes due to the working conditions and its repair welding

Drakče Tanasković[a], Branislav Đorđević[b], Marko Gajin[a], Mihajlo Aranđelović[b], Nemanja Gostović[c,]*

[a]*HBIS Group Serbia Iron & Steel ltd., 11300 Smederevo, Serbia*
[b]*Innovation center of Faculty of Mechanical Engineering, 11120 Belgrade, Serbia*
[c]*Castolin – Messer Tehnogas AD, 11120 Belgrade, Serbia*

Abstract

Repair welding represents the activity that restores the working capability of machine or construction caused by some damage due to working or environmental condition. Damages of burner pipes, part of the facility "Cold Rolling Mill" Steelwork in Smederevo, which appeared on welded joints during the manufacturing of the burner, and its repairing are presented in this paper. The damages occurred on welded joints along the weld as a result of the working conditions that burner was exposed to. Due to high temperatures that can reach up to 850 °C and "explosion" during gas burning, a crack may appear on the inner side of the burner. The base material of the burner pipes is stainless steel X12NiCrSi35-16. Repair welding is preceded by a series of operations, and one of them is the selection of an electrode. It turned out that inadequate selection of the electrode for repair welding had contributed to the occurrence of cracks on welded joints. Selecting a new electrode and examining its characteristics, as well as performing test welding of pipe that is still in exploitation, had confirmed the importance of proper selection of materials for repairing of burner pipes.

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Keywords: burner pipe, repair welding, damages, steel X12NiCrSi35-16

* Corresponding author. Tel.: +381-64-4453840;
E-mail address: brdjordjevic@mas.bg.ac.rs

The influence of oxide deposits on the remaining life and integrity of pressure vessels equipment

Nikola Milovanović[a,]*, Gordana Bakić[b], Branislav Đorđević[a], Aleksandar Sedmak[b]

[a]*Innovation center of Faculty of Mechanical Engineering, 11120 Belgrade, Serbia*
[b]*Faculty of Mechanical Engineering, 11120 Belgrade, Serbia*

Abstract

This paper describes the influence of oxide deposit thickness on the working life and integrity of pressure equipment such as heater pipes, preheaters and other components with cylindrical forms in thermal power plants exposed to internal pressure and boiling gases. Due to the influence of the oxides in the inner side of the pipes, the wall thickness of mentioned components decreases as a result of corrosion-erosion. Within boiler, the thickness of the wall gradually decreases, both from the outer and inner side of the pipes, which leads to increased mechanical stress during service life (i.e. exploitation). Increased stress leads to reduced service life, due to cracking. A model will be presented showing the dependence of thickness increase of the oxide deposit on the time of exploitation and the material, as well as the increase temperature in the pipe walls due to the oxidation on the inner side of the pipe. With temperature increasing on the walls of the pipes, yield stress consequently decreases, leading to the cracking of components.

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Keywords: oxide deposit, integrity, remaining life, pressure vessels equipment

* Corresponding author. Tel.: +381-60-6502541;
E-mail address: nmilovanovic88@gmail.com

Numerical analysis of fatigue crack growth in welded joints with multiple defects

Simon Sedmak[a,*], Radomir Jovičić[a], Branislav Đorđević[a], Mihajlo Aranđelović[a], Filip Vučetić[b]

[a]*Innovation center of Faculty of Mechanical Engineering, 11120 Belgrade, Serbia*
[b]*Faculty of Mechanical Engineering, 11120 Belgrade, Serbia*

Abstract

In the case of welded steel structures (such as pressure equipment), welded joints are often critical location for stress concentrations, due to different mechanical properties and chemical composition compared to the parent material, and due to changes in geometry. In addition, the presence of imperfections (defects) in welded joints can contribute to the increase in local stress, resulting in crack initiation. Recently, standards that are related to acceptable dimensions of various types of defects in welded joints started taking fatigue loading into account as well.
For the purpose of this research, a 3D numerical model was made, of a welded joint with different types of defects (linear misalignment and a crack in the weld metal), based on the previous work, which involved static loading of the same specimen. In this case, fatigue was taken into account, and the simulation was performed using ABAQUS software, as well as Morfeo, an add-on used for determining the fatigue behaviour of structures via XFEM (extended finite element method). The welded joint was made using steel P460NL1 as the parent material, and EPP2NiMo2 wire was used for the weld metal.
An additional model was made, whose defects included a crack and an overhang. Fatigue crack growth analysis was performed for this model as well, and the results for stress intensity factors and stress/strain distribution were compared in order to obtain information about how different defects can affect the integrity of a welded joint.

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Keywords: Fatigue crack growth, extended finite element method, imperfections in welded joints, stress intensity factor

* Corresponding author. Tel.: +381-62-295-496
E-mail address: simon.sedmak@yahoo.com

Experimental setup for determining strain in dental composite veneers subjected to compressive load

Miloš Milošević[a,*], Jovan Cabunac[b], Aleksa Milovanović[a], Nenad Mitrović[c], Goran Mladenović[c], Vesna Miletić[b]

[a]*Innovation center of Faculty of Mechanical Engineering, 11120 Belgrade, Serbia*
[b]*Dental Office dr Jovan Cabunac, Belgrade, Serbia*
[c]*Faculty of Mechanical Engineering, University of Belgrade, Sebia*

Abstract

Veneers are thin dental restorations which cover vestibular, incisal and proximal teeth surfaces. Depending on the design of the preparation, proximal extension of the veneer could be up to the contact point or could cover the entire proximal surfaces of the teeth. This paper shows development of the experimental setup for determining the strain field and failure force of direct composite veneers in upper and lower anterior teeth, subjected to compressive load up to the point of fracture. Extracted teeth were prepared using the turbine diamond conical burrs with a rounded tip of 1.6 mm in diameter and 2^{o} conicity (Burr 6844-Komet Dental, Lemgo, Germany). The preparation was standardized so that the dental tissue was removed 0.8 to 1 mm vestibularly, 0.5 to 0.8 mm proximally and 2 mm incisally. The veneers were made of composite material (nanocomposite Geanial-GC Corp., Tokyo, Japan) using the direct layering technique. Bonding between the material and dental tissue was achieved using an adhesive agent (G bond-GC Corp., Tokyo, Japan).
The prepared specimens, which consisted of a tooth-adhesive-composite system, were immersed in acrylic for easier positioning into the tensile testing machine (Tinius Olsen H10KS). Contactless optical 3D system ARAMIS 2.0 was used for measuring strain in the veneers. In order to simulate the effect of masticatory forces, the prepared specimens were positioned under a 135 degree angle relative to the applied force.
This experimental setup will enable analysis of stress and strain of the tooth-adhesive-veneer system, based on clinically relevant parameters (design of the preparation, material characteristics and angle of the applied force).

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Keywords: dental, composite veneers, strain field, failure force, optical 3D measurement, ARAMIS

* Corresponding author. Tel.: /
E-mail address: mixmilosevic@gmail.com

Influence of temperature and exploitation time on the hardness and micro-structure of characteristic zones of a welded joint in a reactor mantle

Ivica Čamagić[a,*], Simon Sedmak[b], Zijah Burzić[c], Aleksandar Sedmak[d]

[a]*Faculty of Technical Sciences, 7 Kneza Miloša Street, K. Mitrovica*
[b]*Innovation Centre of the Faculty of Mechanical Engineering, 16 Kraljice Marije Street*
[c]*Military Technical Institute, 1 Ratka Resanovića Street, Belgrade*
[d]*Faculty of Mechanical Engineering, University of Belgrade*

Abstract

This paper presents the analysis of the influence of temperature and exploitation time on the cross-sectional hardness and micro-structure changes of characteristic zones of a welded joint made of low-alloyed Cr-Mo steel A-387 Gr. B. Exploited parent metal is a part of a reactor mantle which was working for over 40 years and is in the damage repair stage, i.e. part of its mantle is being replaced with new material. Cross-sectional hardness of a butt-welded joint was measured and macroscopic investigation of the welded joint and microstructural analysis of the parent material, weld metal and the heat affected zone were performed. The comparison of parameters obtained for characteristic zones of a welded joint provides a way to measure the justifiability of the selected welding technology.

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Keywords: Cross-sectional hardness, low-alloyed steels, welded joints, micro-structures

* Corresponding author. Tel.: /
E-mail address: ivica.camagic@pr.ac.rs

Diagnostic of the cause of robot gearbox failure in the paint shop company Magneti Marelli Kragujevac

Taško Maneski[a,*], Vesna Milošević-Mitić[a], Nina Anđelić[a]

[a]*Faculty of Mechanical Engineering, University of Belgrade*

Abstract

The considered construction of the paint shop consists of two parts: main structure with columns and grill (global structure) and substructure for robot supporting (local structure). Diagnostic of the cause of robot gearbox failure in the paint shop company Magneti Marelli Kragujevac required the following activities: static analysis of the global structure deformation using finite element method-FEM; dynamic calculation of its eigen-oscillations using FEM; determination of the transfer function in frequency domain, i.e. dynamic amplification factor for the selected combination of excitation – response; measurement of dynamic displacements and accelerations of the structure, as well as a visual overview of the state of the construction. The basis of the overall diagnosis was related to determination the cause of unfavorable dynamic and resonant behavior of the structure. Calculation was done to determine eigen-oscillations of global structure, i.e. appropriate eigenvectors, which defined the planes and directions of unfavorable dynamic stiffness of the structure. Pulse robot motion, with frequent changes in direction, produces excitation at all frequencies. If the global structure has low eigen-frequencies, it can't accept dynamic inertial forces due to robot motion. It leads to large dynamic deformation and resonant behavior. This property of the structure negatively affected on the work of the robot gearbox. Required measurements aimed to verify dynamic FEM calculation and to confirm resonant behavior of the structure. Experimental values of dynamic displacements and accelerations should indicate if their overrun occur. Based on presented investigation of the failure, reparation and sanation of the substructure was done. So, robot gearbox has been operating successfully.

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Keywords: Diagnostic, robot, sanation

* Corresponding author. Tel: /
E-mail address: tmaneski@mas.bg.ac.rs

Integrity of rails in presence of defects in rail weldments

Milorad Gavrilovski[a], Vaso Manojlović[a], Dejan Momčilović[b,*], Ljubinko Sekulić[c]

[a]*Innovation Center of Faculty of Technology and Metallurgy, Karnegijeva 4, Belgrade*
[b]*Institute for testing of materials IMS, Bulevar vojvode Misica 43, Belgrade*
[c]*JSC Serbian Railways, Nemanjina 6, 11000 Belgrade*

Abstract

Quality of weldments is the major factor that affect on structural integrity on railway tracks. Last decades, the emphasize on quality of weldments increase due to amplifying requirements on speed, traffic frequency and axle loads. Major methods of rail welding are flash butt welding (FW) and aluminothermic welding (AT). Frequency of flaws occurrence is higher during AT welding method, and those flaws can nave significance influence on integrity of rail weldments. Due to the fact that the AT welding us achieving by melting and solidification, i.e. casting it is clear that AT welding have Intrinsically higher level of complexity in term of influencing factors compared to FW welding. The other thing that have significant impact on quality of rail weldments are the training level of welding personnel, which means that the integrity of weldments very complex question. This aim of this paper is to explain the mechanism of crack initiation on typical welding defects.

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Keywords: Welding, aluminothermic, rail integrity, crack initiation

* Corresponding author. Tel: /
E-mail address: dejanmomcilovic@yahoo.com

Geotechnical aspects on seismic retrofit

Željko Žugić[a,]*, Simon Sedmak[a], Boris Folić[a]

[a]University of Belgrade, Innovation Center of the Faculty of Mechanical Engineering, Kraljice Marije 22, Belgrade, Serbia

Abstract

In the paper numerical analysis of foundation of damaged masonry structures using finite element method is presented. Retrofitting of those structures has been performed using technology DC90. By retrofit design, the foundation structure is confined with the foundation collar, connected by anchors and in which the vertical stiffening elements are anchored.
Numerical quantification of benefit of seismic retrofit of building foundation in terms of future excitations was done. Additionally, the soil-structure interaction issue has been addressed.

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Keywords: Seismic retrofit, foundation

* Corresponding author. Tel.: /
E-mail address: zzugic@gmail.com

Permanent ground displacement across earthquake faults, landslides and natural slopes

Željko Žugić[a,*], Mihajlo Aranđelović[a], Boris Folić[a]

[a]*University of Belgrade, Innovation Center of the Faculty of Mechanical Engineering, Kraljice Marije 22, Belgrade, Serbia*

Abstract

Permanent ground displacement analysis methods, as very important aspect of the seismic dynamic analysis is explained in the paper. A methodology for probabilistic hazard assessment of permanent displacement across natural slopes and landslides caused by earthquake rupture is presented, compatible with regions with low to moderate seismicity, as well as comparison with the results of the other authors.
The results show that for the most cases, in terms of displacement of earthquake faults the displacement hazard is small, in contrast to ground shaking hazard. From the other side, slope displacements (rockfalls landslides, mudflows) as side effects may cause huge consequences during the earthquake.

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Keywords: Permanent ground displacement analysis, probabilistic hazard assessment, seismicity

* Corresponding author. Tel.: /
E-mail address: zzugic@gmail.com

Effect of stress ratio on fatigue crack propagation of double T welded joint plate

Abubakr Kreadegh[a,*], Aleksandar Sedmak[a], Aleksandar Grbović[a], Mostafa Abobaker[a]

[a]*Faculty of Mechanical Engineering, Kraljice Marije 22, Belgrade, Serbia*

Abstract

Fatigue cracks frequently grow during a large portion of the cyclically loaded components. Therefore, any parameter that significantly affects the growth of fatigue cracks can have a major effect on the total fatigue behavior of the components. One such parameter is the stress ratio (ratio of the minimum stress to the maximum stress). This paper presents an application of the extended finite element method (XFEM) in the modeling and analysis of simultaneous cracks propagations in friction stir welded double T joint made of 2024-T351 aluminum-alloy plate. This material was selected because of its frequent use in aircraft construction. A FSW numerical tool, based on ABAQUS software, has been developed for modelling and results display.

Tensile fatigue loading of 50 MPa at stress ratios ranging from -1 to 0.5 is applied to evaluate the mechanical properties. Numerical simulations are developed for fatigue life estimation for each crack propagation step and stress intensity factors next to the crack front for each step of crack growth.

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Keywords: Friction stir welding, aluminum alloys, fatigue crack growth, extended finite, element method, fatigue life, stress intensity factor

* Corresponding author. Tel.: /
E-mail address: akredegh@yahoo.com

Crack growth resistance of weldment constituents

Emina Džindo[a,]*, Simon Sedmak[a], Zoran Radaković[a], Ivana Cvetković[a]

[a]*Innovation Center of Faculty of Mechanical Engineering, University of Belgrade, Kraljice Marije 16, 11120 Belgrade, Serbia*

Abstract

The overmatching can affect the occurrence of cold cracks after welding in high-strength low-alloyed steels of 770MPa yield strength class. The welding consumable has been designed in a way to produce WM with slightly lower strength properties compared to BM (undermatching effect). The application of high-strength low-alloyed steel SUMITEN 80P, required a large scope of testing for estimation of behavior of welded joints under different loading conditions, in order to give the reliable estimation of penstock safety.

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Keywords: triaxiality; Crack; HAZ; welded joint

* Corresponding author. Tel.: /
E-mail address: edzindo@mas.bg.ac.rs

Structural integrity assessment from the aspect of fracture mechanics

Mersida Manjgo[a,*], Meri Burzić[b], Katarina Čolić[b], Zijah Burzić[c], Tomaž Vuherer[d]

[a]*University "Džemal Bijedić" Mostar, Faculty of Mechanical Engineering*
[b]*Innovation center of Faculty of Mechanical Engineering, University of Belgrade*
[c]*Military Technical Institute, Belgrade*
[d]*Faculty of Mechanical Engineering, University of Maribor*

Abstract

An increasing diversity of operations, and increasingly different materials as well as different working conditions lead to different constructive solutions. The structure design is the construction preparation which will efficiently fulfill the anticipated exploitation conditions, economically and safely, i.e. there will be no damage resulting in loss of construction functionality during the exploitation. In practice, however, there are fractures that can occur during the construction, assembly, and exploitation. The fracture may be caused by overloading, static fracture, or by dynamic loading, fatigue fracture. During calculation of static structural durability normal and tangential stresses are taken into account, while in the dynamic durability calculation the structure resistance to crack formation and its propagation under the dynamic loading are defined.
The aim of this paper is to demonstrate the possibility of applying fracture mechanics to the assessment of structure integrity. To this end, the basic concepts of linear elastic fracture mechanics will be explained.

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Keywords: PP-polypropylene, J-integral, critical crack tip opening CTOD

* Corresponding author. Tel.: /
E-mail address: mersida.manjgo@unmo.ba

Risk based structural integrity assessment of pressure vessel with cracks in welded joint

Ivana Vučetić[a,*] Aleksandar Sedmak[b], Tamara Golubović[b], Snežana Kirin[a]

[a]Innovation center of Faculty of Mechanical Engineering, University of Belgrade, 11120 Belgrade, Serbia
[b]Faculty of Mechanical Enginnering, University of Belgrade, 11120 Belgrade, Serbia

Abstract

The research is focused on the risk and structural integrity assessment of pressure vessel in Reversed Hydro Power Plant "Bajina Basta" . The risk matrix has been used to assess risk level according to probability and consequence in a more descriptive way, whereas the Failure Assessment Diagramme (FAD) has been used as an alternative engineering approach, both in its simplest form and in more advanced version, taking into account plasticity. Different FADs produced different results indicating importance of plasticity, i.e. capability of material to deform in plastic range without failing at once.

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Keywords: Structural integrity, pressure vessel, welded joint, failure, risk matrix

* Corresponding author. Tel.: /
E-mail address: ivucetic@mas.bg.ac.rs

Using the fracture mechanics parameters in assessment of integrity of rotary equipment

Nikola Milovanović[a,*], Aleksandar Sedmak[b], Branislav Đorđević[a], Simon Sedmak[a]

[a]Innovation center of Faculty of Mechanical Engineering, University of Belgrade, 11120 Belgrade, Serbia
[b] Faculty of Mechanical Enginnering, University of Belgrade, 11120 Belgrade, Serbia

Abstract

In this paper is presented the principle of application of fracture mechanics parameters in determining the integrity of rotary equipment. The behavior of rotary equipment depends on presence of cracks and basically determines the integrity and life of such equipment. The locations of stress concentration (i.e. radius changes) represent a particular problem in rotary equipment, and they are the most suitable places for the occurrence of microcracks i.e. cracks due to fatigue load. This problem is most common in the shaft of relatively large dimensions, for example, turbine shafts in hydropower plants made of high-strength carbon steel with relatively low fracture toughness, and relatively low resistance to crack formation and growth. Having in mind that rotary equipment represents the great risk in the exploitation, whose occasional failures often had severe consequences, it is necessary detail study of their integrity. For this purpose, it is necessary application of parameters of linear-elastic fracture mechanics, such as stress intensity factor, which range defines the rate of crack growth (Parisian law), and its critical value (fracture toughness) determines the critical crack length. The procedures for determining the critical crack length will be described using the fracture mechanics parameters.

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Keywords: Fracture mechanic parameters, integrity assessment, rotary equipment

* Corresponding author. Tel.: /
E-mail address: nmilovanovic88@gmail.com

Microhardness and macrostructures of friction stir welded T-joints

Andrijana Đurđević[a,*], Aleksandar Sedmak[b], Aleksandar Živković[c], Đorđe Đurđević[a], Milan Marković[a], Miodrag Milčić[d]

[a]Tehnikum Taurunum - Collage of Applied Engineering Studies, 11080 Belgrade, Serbia
[b]Faculty of Mechanical Engineering, 11120 Belgrade, Serbia
[c] Goša FOM Company, 11420 Smederevska Palanka, Serbia
[d]Faculty of Mechanical Engineering, 18000 Niš, Serbia

Abstract

The results of research regarding the friction stir welding process of T-joints are presented in this paper. Experimental welding of two and three aluminium plates were performed in order to obtain T-joints. Microhardness measuring and macrostructural examinations of welded T-joints of aluminium alloy are processed. All phases of the welding process are monitored by visual control.

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Keywords: Friction stir welding, aluminium alloy 5754-H111, T-joints, microhardness, macrostructures

* Corresponding author. Tel.: /
E-mail address: andrijana.miler@yahoo.com

Effect of stiffeners on fatigue crack propagation of welded plate

Abubakr Kreadegh[a,*], Aleksandar Sedmak[a], Aleksandar Grbović[a]

[a]*Faculty of Mechanical Engineering, 11120 Belgrade, Serbia*

Abstract

The effects of stiffeners and mesh refinement on the values of stress intensity factor through the thickness of center-cracked plates are presented. The main purpose of this analysis is to model the tensile behavior of a cracked stiffened panel in order to identify special features of that behavior, in particular as concerns bending effects. When a crack is detected at a weld joint, it is necessary to assess the service life remaining until the crack grows and leads to the failure. This paper presents an application of the extended finite element method (XFEM) in the modeling and analysis of simultaneous cracks propagations in friction stir welded joint plate made of 2024-T351 aluminum-alloy plate. This part of the study focuses on the most typical fatigue cracks that start at the weld joint in TMAZ. A FSW numerical tool, based on ABAQUS software, has been developed for modelling and results display. The crack propagation was investigated under uniaxial tensile loading with constant amplitude (50 MPa) and stress ratio of 0 (R=0) at different welded joint plates (without stiffener, one stiffener and two stiffeners).

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Keywords: stiffeners, fatigue crack propagation, welded plate

* Corresponding author. Tel.: /
E-mail address: akredegh@yahoo.com

Influence of activating flux on the mechanical properties of the plasma welded joint of austenitic steel

Luka Grubiša[a], Darko Bajić[b,*], Tomaž Vuherer[c]

[a]*Institute for Development and Research in the Field of Occupational Safety, Podgorica 81000, Montenegro*
[b]*University of Montenegro, Faculty of Mechanical Engineering, Podgorica 81000, Montenegro*
[c]*University of Maribor, Faculty of Mechanical Engineering, Maribor, Slovenia*

Abstract

This paper will present the analyses of influence of application of activating flux on the mechanical properties of the welded joint in plasma welding of austenitic 316L class steel. In addition to standard mechanical tensile test, hardness measurements, Charpy impact test, using elastic-plastic fracture mechanics, the opening of the crack tip at the standard three-point bending tube was determined. SENB testing of the fracture mechanism was performed according to the ASTM standard E1820-15a. The study revealed that the welded A-plasma compounds have very good mechanical properties that confirm the reliability of the weld joints and a high level of quality.

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Keywords: A-plasma, activating flux, mechanical properties, fracture toughness, impact toughness

* Corresponding author. Tel.: /
E-mail address: darko@ac.me

Reverse engineering based integrity assessment of a total hip prosthesis

Milena Babić[a], Ozren Verića[a], Željko Božić[a,]*, Aleksandar Sušić[a]

[a]*University of Zagreb, Faculty of Mech. Eng. And Nav. Arch., I. Lučića 5, 10000 Zagreb, Croatia*

Abstract

The structural strength of a total hip prosthesis was investigated based on a 3D scanning procedure of a hip prosthesis and Finite Element Analysis. 3D scanning was performed by the ATOS 3D scanner, and the CAD model was built using Geomagic Design X software. The obtained CAD model was imported to Finite Element simulation software Abaqus to generate a FEM model. By using the developed FEM model stress and strain distribution in the femoral component were calculated for a typical human walking load case. The analysis was performed for a newly implanted prosthesis and for a case with loosened femoral component of the same hip prosthesis. The analysis results show that in case of loosened femoral component stress concentrations occur at locations where fatigue problems in real cases were observed.

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Keywords: Total hip prosthesis; 3D scanning; stress analysis; reverse engineering

* Corresponding author. Tel.: /
E-mail address: zeljko.bozic@fsb.hr

Modeling of residual stresses in welded stiffened panels

Danijel Barjašić[a], Željko Božić[a,*], Siegfried Schmauder[b]

[a]*University of Zagreb, Faculty of Mech. Eng. And Nav. Arch., I. Lučića 5, 10000 Zagreb, Croatia*
[b]*University of Stuttgart, IMWF, Pfaffenwaldring 32*

Abstract

During the welding process heat is introduced into the base material, and after the cooling residual stresses occur. The typical distribution of residual stresses in a welded stiffened panel is such that tensile stresses occur at the weld site and tensile residual stresses appear between the stiffeners. Using the ANSYS finite element method program, the distribution of the KI stress intensity factors with respect to the crack length in stiffened panel fatigue test specimens was investigated, taking into account welding residual stresses. The total stress intensity factor K_{tot} is determined by the superposition of the value due to applied external load and the residual strain, K_{app} and K_{res}, respectively. Different residual stress distribution patterns such as the rectangular, triangular and Green's distributions were considered. For the considered specimen it was shown that the tensile residual stresses initially increase the K_{tot} value, and then the compressive residual stresses lower the K_{tot} value between adjacent stiffeners. Stress intensity factors due to residual stresses K_{res} have a significant effect on the total value of K_{tot} stress intensity factors. The effect of residual stresses on fatigue crack propagation life was considered. Based on experimentally determined fatigue lives for the considered welded specimens and calculated stress intensity factors Fatigue Crack Growth Rate (FCGR) diagrams were drawn. It was demonstrated that residual stress effects should be taken into account for a proper FCGR assessment of welded stiffened panels.

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Keywords: Fatigue, crack propagation, residual stress, FCGR

* Corresponding author. Tel.: /
E-mail address: zeljko.bozic@fsb.hr

Fracture analysis of pressurized plates damaged with multi-site cracks

Željko Božić[a,]*, Filip Kovačić[a], Siegfried Schmauder[b]

[a]*University of Zagreb, Faculty of Mech. Eng. And Nav. Arch., I. Lučića 5, 10000 Zagreb, Croatia*
[b]*University of Stuttgart, IMWF, Pfaffenwaldring 32*

Abstract

In ship or aircraft structures a crack may initiate at sites of stress concentration, and under service loading further propagate by fatigue mechanisms. Fatigue cracks may grow to a critical size, which can eventually lead to instantaneous failure of the structure under an extreme service load condition. When cracks develop at several adjacent structural members, such as stiffeners, multiple site damage (MSD) is created. In this paper, investigations are performed for the fracture mechanisms of a plate damaged by a single crack or by multiple cracks subjected to lateral pressure, by fracture experiments and the corresponding numerical simulation.
Results of finite element study on fracture behaviour of plate specimens damaged with multiple cracks and subjected to lateral pressure are presented. Considered plate specimens with a single crack or an array of collinear cracks were tested by using a specially designed experimental setup where monotonically increasing lateral pressure load was applied until fracture occurred. Assessed critical pressure loads for considered stiffened panel specimens, based on the critical J-integral and crack tip opening displacement (CTOD) values, were compared with experimentally obtained results and a good agreement was observed.
In the finite element analysis an elastic-plastic fracture mechanics concept (EPFM) was implemented and critical pressures associated with fracture onset in the specimens were assessed based on the critical Jc and δc parameters. The described procedure can be implemented for fracture assessment of real thin walled structures.

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Keywords: Fracture assessment, J-integral, CTOD, multiple cracks

* Corresponding author. Tel.: /
E-mail address: zeljko.bozic@fsb.hr

Design of wing spar cross section for optimum fatigue life

Khalid Eldwaib[a,*], Aleksandar Grbović[a], Gordana Kastratović[b], Mustafa Aldarwish[a]

[a]*Faculty of Mechanical Engineering, University of Belgrade, Kraljice Marije 16, 11120 Belgrade 35, Serbia*
[b]*Faculty of Transport and Traffic Engineering, University of Belgrade, Vojvode Stepe 305 11000 Belgrade, Serbia*

Abstract

Aircraft structure is the most obvious example where functional requirements demand light weight and strong structures. Shape and sizing optimization are being increasingly used nowadays for designing lightweight structural components. The aim of this paper is to present optimization of I-section integral wing spar made of aluminum 2024-T3. The efficient design, based on optimum fatigue life, was achieved using Extended Finite Element Method (XFEM) and its ability to simulate crack growth in complex geometry. The computations were carried out in Morfeo/Crack for Abaqus software which relies on the implementation of XFEM. Shape optimization of the aircraft wing spar beam was conducted by comparing the fatigue crack growth lives for different cross section shapes, but constant cross section area of the spar. The analysis revealed that XFEM is efficient tool for complex three-dimensional configurations optimization where extended fatigue life is one of the most important objectives.

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Keywords: aircraft structure, optimization, Extended Finite Element Method, fatigue life

* Corresponding authot. Tel.: /
E-mail address: kedwaib@yahoo.com

Numerical analysis of fatigue crack growth in hip replacement implant

Aleksa Milovanović[a,*], Katarina Čolić[a], Aleksandar Grbović[b], Simon Sedmak[a], Zorana Golubović[b]

[a]Innovation Center of Faculty of Mechanical Engineering, University of Belgrade, 11120 Belgrade, Serbia
[b]Faculty of Mechanical Engineering, University of Belgrade, Kraljice Marije 16, 11120 Belgrade, Serbia

Abstract

Total hip replacement implants are a substitution of a diseased hip joint and require complete removal in order to restore hip joint functionality. Everyday physical activities produce dynamic load which is exerted onto joint surfaces. Under stated conditions, fatigue represents the most probable mechanism of implant failure. The aim of this paper is to observe structural behaviour from fatigue crack initiation to inevitable structural failure on a selected total hip replacement implant. Tendency to fatigue and its growth besides chosen material highly depends on structural geometry. Locations with the highest stress concentration are the most common place for crack initiation. Observing locations for numerical analysis are sharp edges on the neck area of selected total hip replacement implant. Applied load for this testing is equal to the maximal exerted load on a hip joint. Boundary conditions substitute the bone-implant contact.
Numerical analysis is performed in Abaqus software extension-Morfeo, suitable for XFEM analysis. XFEM generates the mesh on a structure and with each new step in crack growth distributes nods evenly around the crack. Observation of crack growth shows how geometry on a specified total hip replacement implant affects the structural life of a component.

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Keywords: Hip replacement implant, Co-Cr alloy, Extended Finite Element Method (XFEM), fatigue crack

* Corresponding author. Tel.: /
E-mail address: aleksa753@gmail.com

On slightly disordered quasi rate-independent anisotropic viscoplastic FCC-polycrystals

Milan Mićunović[a,*], Ljudmila Kudrjavceva[b]

[a]*Faculty of Technical Sciences, University Of Kragujevac*
[b]*Department of Civil Engineering, State University Of Novi Pazar*

Abstract

Geometry and kinematics of intragranular as well as intergranular plastic deformation of polycrystals are discussed. Elastic strain is covered by the effective medium homogenization method inside a representative volume element (RVE). Evolution equation formed by tensor representation is derived from very simple micro-evolution equation. It has incremental form obtained by Vakulenko's concept of thermodynamic time. The rate dependence takes place by means of stress rate dependent value of the initial yield stress. Following strain geometry is based on constrained micro and free macro rotations in intermediate reference configuration. This leads to the fact that evolution equation for plastic spin of RVE is an outcome of evolution equation for plastic stretching. The theory is applied to slightly disordered fcc-polycrystals. For some characteristic given stress histories (with low, medium and high strain rates) the micro-meso transition is tested and number of active slip systems grains are found and compared with so-called J2-approach.

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Keywords: Polycrystal, representative volume element (RVE), viscoplasticity

* Corresponding author. Tel.: /
E-mail address: milanmicunovic10@gmail.com

High velocity impact response of 3D hybrid woven composites

Ahmed Sohail[a,*], Zheng Xitao[a], Shiekh Muhammad Zakir[a]

[a]*School of Aeronautics, Northwestern Polytechnical University, Xi'an PR China*

Abstract

The aim of this work is to develop an efficient numerical model which can predict the behavior of 3D hybrid woven composites under high velocity impact by utilizing the inbuilt constitutive and damage models within the finite element software. To predict the constitutive and damage behavior of composites during the high velocity impact process, a combination of cohesive contact and continuum shell elements is proposed in finite element (FE) model. Delamination behavior is characterized by introducing the cohesive contact between the two adjacent laminas using the traction separation law, while damage, induced during the impact process in each single layer of composite laminate, is depicted by continuum shell elements with Hashin failure criterion. Connector elements containing the failure behavior are introduced into the model to represent the z-yarns of the 3d woven composite. The proposed FE model reveals good capturing of damage phenomenon during the impact process and indicates good agreement with experimental results, making it a valuable tool for characterizing the impact response of 3D hybrid woven composites under high velocity impacts.

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*Keywords:*3D woven composites; Hybrid; Finite element analysis; Impact behaviour

* Corresponding author. Tel.: /
E-mail address: s.ahmed@mail.nwpu.edu.cn

Structural integrity assessment by using cross-correlated modal identification

Emil Veg[a,*], Aleksandar Sedmak[a], Goran Šiniković[a], Mladen Regodić[a]

[a]*Faculty of Mechanical Engineering, University of Belgrade*

Abstract

Early researches on steel structures integrity were mainly oriented on calculations and conventional experiments. Robust numerical methods of a high accuracy are usually less reliable in estimation of dynamical properties and a true condition of a steel structure. On the other hand, experiments on real structures, being in regular operation, could be very demanding to conduct. Therefore, the implementation and justification of novel methodology in structural integrity analysis is presented here. The main idea is to correlate experimental results with those obtained applying ANSYS software package. Throughout a results cross-correlation and model adjustment the new presentation of the structure is created, involving natural frequency, modal mass, stiffness and damping. By a proper definition of those parameters, and a 3D model of the structure, a preliminary map of measuring points and measuring configuration are set in order to enable structural integrity assessment. Example of application of this procedure is given.

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Keywords: Structural, integrity, assessment

* Corresponding author:
E-mail address: eveg@mas.bg.ac.rs

Model analysis of complex structures' strength – advantages of physical sub-scaled model testing and shortcomings in physical model production

Ana Petrović[a,]*, Taško Maneski[a], Dragan Ignjatović[b], Nataša Trišović[a], Ines Grozdanović[b], Wei Li[c]

[a]*Faculty of Mechanical Engineering, 11120 Belgrade, Serbia*
[b]*Faculty of Mining and Geology, 11120 Belgrade, Serbia*
[c]*Xi'an Jiaotong University, Xi'an, China*

Abstract

The possibilities of testing real constructions strength are often limited, especially in case of large constructions. Testing on the model, instead of the actual construction, results in a great saving of money and time. Sub-scaled model of the construction of the substructure, the slewing platform and the lower part of the pylons of the bucket wheel excavator SchRs630 is made. Numerical calculations (using Finite Element Method) and experimental testing of the model were performed. Experimental testing is performed using classical strain gauge method and Digital Image Correlation Method (Aramis system). Once again, advantages of Digital Image Correlation method compared to classical measurement methods are confirmed. The negative impact of conventional manufacturing methods in some zones is noticed.

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Keywords: Model testing; sub-scaled physical model; finite element method; Digital Image Correlation method.

* Corresponding author. Tel.: /
E-mail address: aspetrovic@mas.bg.ac.rs

Bending fracture of Co-Cr dental bridges, produced by additive technologies: experimental investigation

Tsanka Dikova[a,*]

[a]*Faculty of Dental Medicine, Medical University of Varna, 84 Tsar Osvoboditel Blvd, Varna 9000, Bulgaria*

Abstract

The aim of the present paper is to investigate the fracture during bending test of Co-Cr dental bridges, produced by additive technologies. Three groups of samples (four-part dental bridges from 1-st premolar to 2-nd molar) were produced by conventional casting with handmade wax patterns, casting with 3D printed patterns and selective laser melting (SLM). The bending test was done using *Tira Test 2300 SE/50 kN* machine and especially designed appliance, ensuring loading closest to the actual during masticatory process. The loadings until cracking and fracture were evaluated. The fractured surfaces were investigated by optical microscopy.

It was established that the SLM dental bridges of *Co212-f* alloy are being destroyed in 9.255 kN loading, which is commensurable with that for cracking of the samples, cast from *Biosil-F* alloy – 9.820 kN in conventional casting and 10.171 kN in casting with 3D printed patterns. The destruction of the cast Co-Cr bridges consists of three stages – crack initiation in the most loaded area, its growth and final fracture, while the destruction of the SLM samples suddenly occurs because of a network of cracks in the entire volume. The destruction type of the Co-Cr bridges, produced by SLM and casting, is identical - ductile, but the way that fracture occurs is different due to their structure. The specific layered macrostructure, the fine microstructure with dendritic morphology, the phase composition – the presence of ε-phase and the typical defects of the SLM Co-Cr alloy define the fracture mechanism during bending.

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Keywords: Co-Cr alloys; dental bridges; additive technology; selective laser melting; casting; bedning fracture

* Corresponding author. Tel.: /
E-mail address: tsanka_dikova@abv.bg

Influence of friction and contact area on long term performance of total prostheses

Igor Balać[a,]*, Vladimir Buljak[a], Milorad Milovančević[a]

[a]*Faculty of Mechanical Engineering, University of Belgrade*

Abstract

In dentistry, for purposes of attaching and stabilizing the total prostheses in patients with no teeth, implants of different dimensions are used. In terms of stability, long term performance of total prostheses is crucial for these patients. Retention force (i.e. holding force) might decrease through intensive usage causing prostheses falling down and poor performance as well. Influence of coefficient of friction and contact area on retention force is investigated through numerical methods with the analysis of the prostheses-implant contact. This investigation confirmed that coefficient of friction and contact area have significant influence on retention force as well as long term performance of total prostheses.

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Keywords: Prostheses, numerical methods, implants

* Corresponding author. Tel.: /
E-mail address: ibalac@mas.bg.ac.rs

Stress intensity factor for multiple cracks on curved panels

Gordana Kastratović[a,]*, Mustafa Aldarwish[b], Aleksandar Grbović[b], Nenad Vidanović[a]
Khalid Eldwaib[b]

[a]Faculty of Transport and Traffic Engineering, University of Belgrade, Vojvode Stepe 305 11000 Belgrade, Serbia
[b]Faculty of Mechanical Engineering, University of Belgrade, Kraljice Marije 16, 11120 Belgrade 35, Serbia

Abstract

The aim of this paper is to explore and to demonstrate the capacity, performances and difficulties of stress intensity factors (SIFs) calculations in a case of multiple cracks on curved panels analyzed by means of different computational methods. So-called bulging effect, which is occurring in cracked curved panels, increases the effective stress-intensity factor, making the SIFs assessment in case of multiple cracks more challenging. Here, the stress intensity factors are considered by using two different computational methods: extended finite element method (XFEM) and the approximate method based on superposition, which has been adjusted for curved panel application. The SIFs determination was carried out for aircraft fuselage model: unstiffened panel with three cracked fastener holes, for four different curvature diameters, subjected to uniform internal pressurization. The comparison of the results showed that conducted analyses delivered the data which can be useful in evaluation of crack-growth rate, residual strength and fatigue life of curved aircraft structures with multi-site damage.

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Keywords: Multi-site damage; stress intensity factor; extended finite element method; curved panels

* Corresponding author. Tel.: /
E-mail address: g.kastratovic@sf.bg.ac.rs

Modeling of internal corrosion damage on boiler tubes for integrity analyses

Gordana Bakić[a], Ivana Cvetković[b,*], Miloš Đukić[a], Bratislav Rajičić[a], Aleksandar Maslarević[b], Petar Stanojević[c]

[a]*Faculty of Mechanical Engineering, University of Belgrade*
[b]*Innovation Center of Faculty of Mechanical Enginnering, University of Belgrade*
[c]*Faculty of Security Studies, University of Belgrade*

Abstract

Corrosion is irreversible process of material degradation. Due to the adverse effects on characteristics of the operating material, especially in boiler tubing systems, this is one of the most important problems in the functioning of thermal power plants and it is considered to be the main cause of many outages. The basis and the first step in process of equipment life estimation done by using common methods, and determination of the probability of failure is the calculation of stresses in tubes caused by presence of corrosion damage. In this paper are presented stress analyses attained by deterministic method and finite element method analyses for tubes with internal corrosion damage. Those analyses were performed on a large set of data collected for the first stage of re-heater at 350MW thermal power plant unit, which was in service for app 60000 hours. Comparison of stress analyses results was done and obtained difference was analyzed, as well as implications of obtained results on integrity analyses of corrosion damaged tubes. Influence of gained results on remaining life assessment and probability of failure results were studied as well, since these considerations are important for the risk-based inspection and maintenance programs.

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Keywords: Finite element method analyses, corrosion, remaining life assessment, reliability

* Correpsonding author. Tel.: /
E-mail address: ivanacvetkovic1992@gmail.com

Statistical correlation between the printing angle and stress and strain of 3D printed models

R. Mitrović[a], Ž. Mišković[a,*], M. Ristivojević[a], A. Dimić[a], J. Danko[b], J. Bucha[b], T. Milesich[b]

[a]*University of Belgrade – Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade 11000, Serbia*
[b]*Institute of Transport Technology and Designing, Faculty of Mechanical Engineering, Slovak University of Technology in Bratislava, Slovakia, Nam. Slobody 17, 812 31 Bratislava, Slovakia*

Abstract

In the strides of the most advanced technological achievements, the use of polymers is becoming increasingly evident both in everyday life and in engineering practice. Complex structures made of polymers attract more attention from scientists and researchers, as their application increases in the most diverse fields of science. This phenomenon requires constant improvement of knowledge and technologies for the production of polymeric structures and parts, but it is equally important to establish reliable databases on the behavior of newly-introduced materials under different load conditions. This work is based on the establishment of statistical correlation between parameters of 3D printed models and their mechanical characteristics in conditions of static axial loading.

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Keywords: Rapid prototyping; 3D printing;statistical correlation, stress and strain.

* Correpsonding author. Tel.: /
E-mail address: zmiskovic@mas.bg.ac.rs.

Load spectrums as the basis of fatigue calculation, simulation as a tool and the significance of frequency analyses

Milosav Georgijević[a,*], Dragana Radaković[a], Atila Zelić[a]

[a]Univerzitet u Novom Sadu, FTN, Serbia

Abstract

Fatigue (work life) analysis of machine parts is present in engineering practice, including equipment that could cost millions of euros. It should not be forgotten that inappropriately defined, unclear or suspicious input parameters provide questionable results. Thus, micro-analyses of critical machine parts rely on the macro-analyses of exploitation conditions, which lead to systematic prediction of what function a machines should perform and in what ways during its work life, which could last up to 30 years.

In the case of internal transport and loading, the use of simulations as the contemporary tool for optimization, provides a systematic approach to:

- The design stage, wherein the simulations analyse the following:
  - All of the parameters that affect the number of cycles and exploitation condtions (exploitation fields, loads as variables ranging from zero to maximum values)
  - Load spectrums for previous conditions, which are the basis for defining of representative load spectrums for further calculation
  - Load spectrums for various control system options – operating influence
- The significance of frequency analysis of structures subjected to dynamic loads and load spectrums and
- Desired machine monitoring for the purpose of recording load spectrums as the basis for periodical calculations of expired work life and assessing of the remaining fatigue life.

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Keywords: Machine life calculation, load spectrums, simulations

* Corresponding author. Tel.: /
E-mail address: georgije@uns.ac.rs

Gas cylinder rupture induced by local corrosion damage

Dejan Momčilović[a,*], Ljubica Milović[b], Ivana Atanasovska[c], Zoran Odanović[a]

[a]*Institute for testing of materials IMS, Bulevar vojvode Misica 43*
[b]*Faculty of Technology and Metallurgy, Karnegijeva 4, University of Belgrade*
[c]*Mathematical Institute of the Serbian Academy of Science and Art, Kneza Mihaila 36*

Abstract

Commercial gas cylinders are common type of pressure vessels in many health care and technical facilities. Unexpected failures of gas cylinders occur despite of fact that the design, manufacture route, quality control, transportation, and handling are specified by various standards and regulations, particularly in domain of periodic inspection. A case study of the sudden failure of the 25 years old gas cylinder made of low-alloy steel is presented in this paper. Exploded cylinder was filled with commercial mixture of nitrogen and CO/CO_2. Results of chemical analysis, mechanical testing and microstructure and fracture surface examination of gas cylinder material are given in this paper. Key results from failure analysis revealed micro corrosion pitting as a consequence of undesired traces of moisture. This slow crack initiation combined with gas mixture filling and exhausting cycles, promoted the local damage which could explain the mechanism of failure. In addition, the analysis of gas cylinder material in moment of failure is evaluated by using the critical distance parameter.

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Keywords: Failure analysis, fatigue, stress corrosion cracking, low alloy steel, gas cylinder

[*] Corresponding author. Tel: /
E-mail address: dejanmomcilovic@yahoo.com

Morphology of corrosion fatigue and stress corrosion cracks on low alloy steels

Dejan Momčilović[a,]*, Ivana Atanasovska[b], Ljubica Milović[c], Zoran Odanović[a]

[a]*Institute for testing of materials IMS, Bulevar vojvode Misica 43*
[b]*Mathematical Institute of the Serbian Academy of Science and Art, Kneza Mihaila 36*
[c]*Faculty of Technology and Metallurgy, Karnegijeva 4, University of Belgrade*

Abstract

The fracture surface appearances are slowly changed through decade's side by advantages in technology of steel production. Basic requirements for cleaner steels and lower energy consumption during production induce that newer steels have some different fracture features compared to the old ones. This paper describes morphology of different corrosion fatigue and stress corrosion cracks. The brief failure analysis with key results will be presented for each case mentioned in paper, and emphasize will be on morphology and characteristic features of fracture surfaces. Macro appearance of fatigue cracks will be discussed in detail and characteristic features of stress corrosion fractures will be analyzed. Also, the results from scanning electron microscopy will be presented in this paper.

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Keywords: Corrosion, fatigue, stress corrosion cracking, low alloy steel

* Corresponding author. Tel.: /
E-mail address: dejan.b.momcilovic@gmail.com

Numerical simulation of crack propagation in high-strength low-alloyed welded steel

Elisaveta Doncheva[a,*], Bojan Medjo[b], Bojana Trajanoska[a]

[a]*Faculty of Mechanical Engineering - Skopje, Ss. Cyril and Methodius University in Skopje, R. Macedonia*
[b]*Faculty of Technology and Metallurgy, University of Belgrade, Serbia*

Abstract

The industrial application of high-strength low-alloyed steel (HSLA) in welded structures has increased the demand for understanding fracture behavior and structural integrity assessment of this type of steel and produced welded joints. The aim of this paper is to simulate the experimental evaluation of the fracture mechanics specimens by using the micromechanical model. The investigation is performed on two standard single edge notch bend (SENB) specimens with imposed crack in the central region. Numerical analysis was carried out by using Simulia Abaqus software package on 2D models used to simulate the damage development on the local level. The comparison between numerical and experimental results is presented through measured values of J-integral, load-line displacement v_{LL} and crack growth resistance (J-Δa) curves. This paper shows that numerical simulations are promising in respect to their accuracy. The application of this model enables to decrease the amount of expensive experiments for determination of the load level that causes crack propagation.

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Keywords: high strength steels; welded joints; strength mismatching; finite element method; crack propagation; fracture mechanics

* Corresponding author. Tel.: /
E-mail address: elisaveta_donceva@hotmail.com

Experimental examinations of machinability of ceramic materials during micro processing

Miloš Pjević[a,]*, Mihajlo Popović[a], Ljubodrag Tanović[a], Goran Mladenović[a]

[a]*Faculty of Mechanical Engineering, University of Belgrade*

Abstract

In this paper experimental analyses were conducted in order to determine phenomenon that occurs during micro cutting of brittle material based on the ceramic. In order to investigate interaction between tool and workpiece, diamond tool with tip radius R0.2 was used. Cutting speed of 25 m/s and variable cutting depth were used. Experiments have shown that on the small cutting depths, ductile mode can be achieved. In this region, no evidence of cracks growth in the material was present. Critical penetration depth that represents threshold value of this region was determined. After exceeding critical penetration depth, brittle fracturing occurs. Volume of removed material is much larger then desired one, however smooth surface cannot be achieved. Furthermore, dependence of crack growth from the cutting depth was analyzed. In addition, one of the objectives in this experiment was to determine the changes in the cutting force components (Fn and Ft) in the function of cutting depth. Also, specific cutting energy was determined. Based on the microscopic observation of the machining surfaces, mechanism of micro cutting ceramics was established.

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Keywords: Ceramics, micro cutting, ductile mode, critical penetration depth, specific cutting energy

* Corresponding author. Tel.: /
E-mail address: mpjevic@mas.bg.ac.rs

The influence of welded ribs on the stability of the X table construction

Goran Mladenović[a,*], Marija Đurković[b], Miloš Milošević[c], Marko Milovanović[d], Miloš Pjević[a], Nenad Mitrović[a]

[a]*Faculty of Mechanical Engineering, University of Belgrade*
[b]*Faculty of Forestry, University of Belgrade*
[c]*Innovation Centre of Faculty of Mechanical Engineering. University of Belgrade*
[d]*Deutsches Elektronen-Synchrotron (DESY), Zeuthen*

Abstract

With the upward trend in designer furniture production, this inevitably imposed the need for using CAD/CAE systems in its design and manufacturing. The reason for this is the increased competition in the market, necessitating new products to be released as soon as possible with a lower price tag. This in turn requires manufacturing of a zero prototype which should considerably correspond to the finished product later to be launched onto the market. A research was conducted to determine the applicability of a computer aided product design and calculation system, considering only tables of larger dimensions. The designer's original idea is firstly illustrated by a rough sketch or a CAD model of the table. The following step of the designing process is to analyze the stiffness of a given table, i.e. determining its stress and deformation state. Simultaneously, product manufacturing technology is also considered from a mechanical engineering point of view. Due to products' specificity, they are usually made as a combination of tubular semi-finished products and sheet metal parts with thickness of 4-6mm. For selected table models, CAD models were generated using the Sheet Metal Module of the Autodesk Inventor computer software and Finite Elements Analysis (FEA) performed. Depending on the numbers obtained for stress and deformation state in the stress concentration zones, a modification of the shape is performed to fulfill the stiffness requirements. Static calculations were also carried out in order to determine the dimensions of the table base for the selected area of the worktop made of solid wood; usually oak. Experimental verification of acquired numerical results was conducted after manufacturing of a physical prototype of the table. The results obtained point to a conclusion that the application of CAD/CAE systems is justified in furniture design, particularly because it greatly reduces the time needed for designing good and quality products.

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Keywords: CAD/CAE Systems, manufacturing, designer furniture

* Corresponding author. Tel.: /
E-mail address: gmladenovic@mas.bg.ac.rs

Case study - the Mehmed Pasha Sokolovic Bridge

Vera Vujović[a,*]

[a]DIVK, Belgrade, 11000, Serbia

Abstract

During the research were discussed numerous aspects of management and maintenance of which are based on structural durability, reliability, risk management, integrity and service life with a special reference to the proposal consideration of the Maintenance Design the historic stone bridge (including monitoring). The purpose of researches is designed to assist in developing a basis for decision-making, and the purpose of the case study is to explain the importance of the introduction of advanced system maintenance and monitoring of historical Mehmed Pasha Sokolovic Bridge.

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Keywords: stone bridge; structural durability; integrity; service life; reliability; maintenance design; monitoring

* Corresponding author. Tel.: +381 654 726 776; fax: +0-000-000-0000 .
E-mail address: veravujovic10@gmail.com

Development and testing of the reinforced wooden windows

Uroš Tatić[a,*], Barbara Šubic[a], Aleš Ugovšek[a], Nejc Starman[a], Uros Gantar[b], Jože Lopatič[b]

[a]*M Sora d.d., Trg Svobode 2, Žiri 4226, Slovenia*
[b]*Faculty of Civil Engineering and Geodesy, Jamova cesta 2, Ljubljana 1000, Slovenia*

Abstract

Oversized window systems with extreme heights are becoming increasingly popular at European and global market. Such sizes can cause problems of bending of wooden elements which results in the decrease of main window properties and structural integrity. Double casement wooden windows of the 2 m height, with and without reinforcement, were tested at the pressure load of 2000 Pa in order to define its behaviour and develop numerical simulation. Numerical models were defined as an assembly of individual wooden elements with mutual contact, orthotropic behaviour, simulated dowels constrain and insulated triple glass unit. Simulations have provided insight in to mutual behaviour of all individual elements and have proven that contact between window and the wall represents weak point rather than the integrity of the wooden frame elements as initially assumed. During the next phase special reinforcements used to restrain moments at the contact points were tested both numerically and psychically.

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Keywords: Wood, window, reinforcement, orthotropic, numerical simulation

* Corresponding author. Tel.: /
E-mail address: uros.tatic@m-sora.si

Influence of glued-in reinforcement profiles on the thermal characteristics of wooden window profiles

Barbara Šubic[a,*], Aleš Ugovšek[a], Nejc Starman[a], Uroš Tatić[a], Aljaž Kovačič[b], Gorazd Fajdiga[b]

[a]*M Sora d.d., Trg Svobode 2, Žiri 4226, Slovenia*
[b]*Faculty of Civil Engineering and Geodesy, Jamova cesta 2, Ljubljana 1000, Slovenia*

Abstract

Nowadays wooden windows represent high aesthetic value to modern buildings. There is a strong trend of increasing their dimensions, especially their height, which causes problems considering their stability and load bearing capacity. Aluminium, stainless steel, carbon-fiber reinforced polymer profiles and glass-fiber reinforced polymer profiles, with different geometry and orientation, were used to reinforce wooden window mullion. Since reinforcing materials have usually higher thermal conductivity as wood, their effect on the thermal performance of the window as a whole, was examined in this study. Thermal transmittance of several different reinforced profiles was analyzed to select an optimal solution. It was concluded that reinforcing material does not have significant effect on thermal transmittance of window frame, if reinforcement is not placed through the entire thickness of the window profile. If this is the case, only glass-fiber reinforced polymer, with a maximum of 22 % reinforcing material in window profile, fulfils the standard criteria for low energy buildings. The effect of type and geometry of reinforcing materials have minor effect on thermal transmittance of entire window, but have great impact on the minimal local inside surface temperatures, which can lead to condensation and mould growth.

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*Keywords:*Tthermal transmittance; wooden window; hybrid beams; numerical analysis; aluminium; steel; fibre reinforced polymer

* Corresponding author. Tel.: /
E-mail address: barbara.subic@m-sora.si

Experimental and morphological investigations of fracture behavior of PBT/TPEE

Dani Abdo[a,b,*], Andrew Gleadall[a], Dirk Sprengel[b], Vadim V. Silberschmidt[a]

[a]*Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Loughborough, UK*
[b]*School of Mechanical Engineering, Rheinische Fachhochschule Koeln, Cologne, Germany*

Abstract

Short-fiber-reinforced polymers are widely used in industry. They are light-weight, have excellent mechanical properties and can be processed via injection molding. This allows the mass production of high-quality components with high geometric accuracy. Their superior electrical isolation properties make them a good choice for electrical housings in the automotive sector. Due to the importance and precise nature of applications, in which such products are employed, many studies have investigated the properties of these materials. Polybutylenterephthalat (PBT) with thermoplastic polyester elastomer (TPEE), an impact-enhancing additive, is a typical example. Still, there is a lack of knowledge regarding the effect of TPEE on mechanical and fracture behaviors of short-fiber-reinforced PBT and the effect of its microstructure on the dynamic performance.
To study the characteristics of modified short-fiber-reinforced PBT and to assess the effect of the filament, two types of polymers - standard PBT-GF10 and PBT-GF10 blended with 10% TPEE - were compared. Morphological investigation of fracture surfaces produced in tensile tests at different loading rates was undertaken with scanning electron microscopy (SEM). Further two-dimensional image analysis was completed with the image processing software ImageJ.
The morphological analysis showed that TPE-E generally affected the microstructure of the material. Micrographs of fracture surfaces demonstrated a decrease in the size of area of ductility with increasing loading rate. These results will support the development and design of optimized parts and their processing methods.

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Keywords: Microsctructure; PBT; SEM; fractography; surface morphology

* Corresponding author. Tel.: /
E-mail address: d.abdo@lboro.ac.uk

Neutron diffraction and neutron imaging residual strain measurements on offshore wind monopole weldments

Anaïs Jacob[a,*], Ali Mehmanparast[a], Joe Kelleher[b], Genoveva Burca[b]

[a]*Cranfield University, Bedfordshire MK430AL, UK*
[b]*Rutherford Appleton Laboratory, ISIS-STFC Facility, Chilton, OX11 0QX, UK*

Abstract

Residual stress measurement is of fundamental interest in order to estimate the service life of engineering components and structures subjected to various loading conditions operating in different environments. Destructive and non-destructive techniques are used for the evaluation of residual stresses. Neutron diffraction, as a non-destructive technique, is widely used to measure the elastic strain component of a specific atomic plane from which residual stresses can be calculated. Neutron imaging is an alternative technique which enables residual stresses to be measured through strain mapping of the area of interest. In this study, neutron diffraction measurements were performed in conjunction with neutron imaging to evaluate residual strains in a compact tension, C(T), specimen extracted from a welded plate made of S355 structural steel. Neutron diffraction and imaging are two complementary techniques which have been employed in this work by performing measurements on the Engin-X and newly developed IMAT instruments, respectively, at the Rutherford Appleton Laboratory. Neutron diffraction residual strain measurements in all three directions were conducted within the Heat Affected Zone (HAZ) of the weld area whereas longitudinal residual strains were measured using the neutron imaging technique. A comparison of the neutron diffraction and neutron imaging preliminary results has shown that neutron imaging can provide acceptable measure of residual strains compared to those of obtained from neutron diffraction. The results have been discussed in terms of the possible sources of error encountered in each measurement technique and the accuracy of each technique against the other.

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Keywords: Residual stresses; welded joints; neutron diffraction; neutron imaging.

* Corresponding author. Tel.: /
E-mail address: a.l.jacob@cranfield.ac.uk

Numerical investigation of climate change impacts on European wood species vulnerability

Seif Eddine Hamdi[a,*], Rostand Mouttou Piti[a,b]

[a]Université Clermont Auvergne, CNRS, Institut Pascal, F-63000 Clermont-Ferrand, France
[b]CNAREST, IRT, BP 14070, Libreville, Gabon

Abstract

Moisture levels are considered as a critical environmental impacting factor for wood and its components, as the moisture content (MC) influences virtually all the physical and mechanical properties. Adsorbed moisture is known to cause significant dimensional changes, as well as changes in mechanical properties such as the modulus of elasticity, stress factors and brittleness. In green wood, water droplets moved away from the cell lumens around the crack tip. Drying of wood induces micro-cracking and crack bridging as toughening mechanisms. To quantify the effect of humidity, fracture patterns and properties at various moisture levels are numerically investigated. Finite element simulations were performed on a modified Douglas Mixed-Mode Crack Growth specimen (MMCG). The crack growth process as well as the opening crack under temperature and moisture variations were calculated under various mixed mode ratios, and mixed modes energy release rates were evaluated. The distributed damage patterns in the most stressed regions between the area where concentrated force is applied and the notch plane where the fracture initiates is also taken into account in this study.

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Keywords: Fracture mechanisms; moisture; finite element analysis; numerical modelling; solid wood.

* Corresponding author. Tel.: /
E-mail address: seif-eddine.hamdi@u-bordeaux.fr

Analysis of fatigue damage of aluminium alloy under multiaxial random vibration

Junji Sakamoto[a,]*, Tadahiro Shibutani[a]

[a]*Yokohama National University, 79-5 Tokiwadai, Hodogaya-ku, Yokohama, Kanagawa 240-8501, Japan*

Abstract

Many studies have investigated the fatigue damage of materials under vibration. However, the mechanism of vibration-induced fatigue damage remains unclear, and no method has been established for evaluating the vibration fatigue strength. Therefore, it is important to establish an evaluation method for the vibration fatigue strength of materials to ensure appropriate strength in their design. In this study, we performed experiments to investigate the fracture mechanism of a material under multi-axial random vibration. We selected aluminium alloy A5056 as the test material and employed button-head-type specimens with a notch. The multi-axial random vibration experiments were performed at different acceleration inputs (10, 20, 30, 40, 50, 60, and 70 G_{rms}) within a frequency band of 10–5000 Hz. During the vibration tests, we conducted observations of vibration behaviour. After the vibration tests, we observed the fracture surfaces of the specimens using a scanning electron microscope. The results show that the fatigue fracture was due to the bending resonance mode for the given shape and dimensions of the specimens used in this study. In addition, cracks initiated at different areas on the fracture surface and later propagated; subsequently, the cracks coalesced. Finally, we discussed whether the fatigue life of materials subjected to vibration can be predicted using finite element analysis.

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Keywords: Random vibration, Multi-axis, Fatigue damage, Aluminium alloy

* Corresponding author. Tel.: /
E-mail address: sakamoto-junji-fr@ynu.ac.jp

Experimental and numerical investigation of stress concentration and strength prediction of carbon/epoxy composites

Emre Özaslan[a,b], Bülent Acar[b], Mehmet A. Güler[a,*]

[a]*TOBB Economy and Technology University, Söğütözü, Ankara 06560, Turkey*
[b]*Roketsan Inc. Elmadağ, Ankara 06780, Turkey*

Abstract

Unidirectional composites are very popular structural materials used in aerospace, marine, energy and automotive industries, thanks to their superior material properties. However, the mechanical behavior of composite materials is more complicated than isotropic materials because of their anisotropic nature. Also, stress concentration presence on the structure, like a hole, makes the problem further complicated. Therefore, enormous numbers of tests are required in understanding the mechanical behavior and strength of composites which contain stress concentration. Accurate finite element analysis and analytical models enable us to understand mechanical behavior and predict the strength of composites without enormous number of tests which cost serious time and money. In this study, unidirectional Carbon/Epoxy composite specimens with central circular holes were investigated in terms of stress concentration factor and strength prediction. The composite specimens which had different specimen width (W) to hole diameter (D) ratio were tested to investigate the effect of hole size on the stress concentration and strength. Also, specimens which had same specimen width to hole diameter ratio, but different sizes were tested to investigate the size effect. Finite element analysis were performed to determine the stress concentration factor for all specimen configurations. Also, Point stress criteria (PSC) was used to predict strength of the specimens. For quasi-isotropic laminate, it was found that the stress concentration factor at the hole tip increases approximately %15 as W/D ratio decreased from 6 to 3. Also, it is observed that as W/D ratio quadrupled with constant specimen width the failure strength increases by %62.4. For the specimens which had same width to hole diameter ratio but different (scaled) dimensions, the stress concentration factor at the hole tip was seen to be identical as expected. For these specimens, as W/D ratio doubled the specimen failure strength reduces by %13.2 because of the size effect. For all type of specimens, the PSC method could predict the strength of specimens with maximum %8 error.

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Keywords: Stress concentraiton; composite materials; PSC

* Corresponding author. Tel.: /
E-mail address: mguler@etu.edu.tr

Contribution of date-palm fibres reinforcement to mortar fracture toughness

Andrea Zanichelli[a,*], Andrea Carpinteri[a], Giovanni Fortese[a], Camilla Ronchei[a], Daniela Scorza[a], Sabrina Vantadori[a]

[a]Department of Engineering and Architecture, University of Parma, Parco Area delle Scienze 181/A, 43124 Parma, Italy

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Abstract

The present paper aims to analyse the fracture behaviour of date-palm fibre-reinforced mortar. The vegetable fibres have been valorized over the last few years as a suitable reinforcement of cement-based matrixes used in non-structural applications. As a matter of fact, the desirable characteristics of such fibres (for instance, low environmental impact, biodegradability, low cost and density, and equitable stiffness and toughness) have led many designers to employ vegetable fibres in building composite materials.

To the best knowledge of the authors, there are no studies in the literature related to the fracture behaviour of a cement-based mortar reinforced by a date-palm fibre mesh. In the present paper, the fracture behavior of a cement mortar reinforced by short fibres extracted from date-palm mesh is analysed. An experimental campaign is carried out on single edge-notched specimens, by examining five different values of fibre content. The experimental tests are performed under three-point bending loading and crack mouth opening displacement control. The Modified Two-Parameter Model proposed by the authors is herein adopted in order to compute the fracture toughness. Such a method is able to take into account the possible crack kinking occurring during the stable crack propagation, which is typical of quasi-brittle materials.

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Keywords: Date-palm fibre ; fibre-reinforced mortar ; fracture behaviour ; modified two-parameter model ; performance index .

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* Corresponding author. Tel.: /
E-mail address: andrea.zanichelli1@studenti.unipr.it

Improvement of strength-toughness combination in nanostructured bainite

Avanish Kumar[a], Aparna Singh[a,*]

[a]Department of Metallurgical Engineering and Materials Science, Indian Institute of Technology Bombay, Mumbai, 400076, India

Abstract

The present study makes an effort to improve strength-toughness combination of a high carbon carbide free nanostructured bainite by investigating the effect of content, size and morphology of constituent phases when austempered at 250-350°C. Tension tests showed that the tensile strength increases sharply with refinement of bainitic microstructure with decrease in austempering temperature while retaining significant ductility. However, degradation of toughness was observed with an increase in strength. Processing-microstructure-properties correlations have been formulated in addition to detailed electron microscopy to explain the experimental trends.

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Keywords: Nano-bainite; strength; toughness; phase transformation

* Corresponding author. Tel.: /
E-mail address: aparna_s@iitb.ac.in

Nanoscale wear and fracture of graphene and protection by graphene

Borislav Vasić[a,]*, Radoš Gajić[a], Igor Stanković[b]

[a]*Graphene Laboratory of Center for Solid State Physics and New Materials, Institute of Physics Belgrade, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbia*
[b]*Scientific Computing Laboratory, Center for the Study of Complex Systems, Institute of Physics Belgrade, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbia*

Abstract

Excellent elastic, friction, and wear properties of graphene make it a promising candidate for various protective coatings. Chemical vapour deposition (CVD) is a simple and cost-effective method for the production of large-area graphene necessary for applications. Prerequisite for these technological applications is a good understanding of graphene mechanical properties at nanoscale. Atomic force microscope (AFM) is an appropriate experimental tool for this purpose since it allows not only imaging, but also characterization, scratching and various mechanical manipulations of graphene with a high spatial resolution. At the same time, molecular dynamics (MD) is an excellent numerical method to study graphene mechanics. Here we will cover our recent results on wear and friction of graphene studied by combined AFM measurements and MD simulations.
It will be shown that the graphene wear consists of the following processes: the plastic deformation for lower normal loads, followed by a sudden fracture of graphene for high enough normal load, with subsequent graphene peeling off from the substrate [1]. Wear resistivity of CVD graphene is degraded due to out-of-plane graphene deformations - wrinkles [2]. Wear of free graphene edges with increasing normal load consists of the following processes: small step-edge increase at graphene-substrate interface, elastic deformations of graphene edges, stable wrinkle formation causing plastic deformation of graphene edges, and finally, fracture initiated from graphene edges [3]. As a protective coating, graphene can be used for friction and wear reduction [1] and for the mechanical protection of fragile nanostructures [4]. Finally, we demonstrate use of graphene as a controllable system for testing friction paradigms. It will be shown how complex epitaxial relations between graphene and aromatic molecules determine preferential sliding directions for movement, as well as anisotropic friction during rotations at room temperature experiments [5].

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*Keywords: G*rapheme, atomic force microscopy, wear and fracture

* Corresponding author. Tel.: /
E-mail address: bvasic@ipb.ac.rs

Plastic hinge performance of repaired welded joints in steel structures

Mihaela Iordachescu[a,]*, Andrés Valiente[a], Elena Scutelnicu[b]

[a]*Materials Science Dpt., E.T.S.I. Caminos, Universidad Politécnica de Madrid, Prof. Aranguren St., 28040, Madrid, España*
[b]*Manufacturing Engineering Dpt., Dunarea de Jos University of Galati, 111 Domneasca St., 800201, Romania*

Abstract

Technical codes for the design of steel structures allow repaired welded joints, provided that their performance is the same as that of the as-designed new ones. The paper presents the experimental and analytical work carried out to assess the repairing effects on the bearing and rotation capacities of structural welded configurations, alternatively obtained from an as-designed weld or a repaired one. Precracked compact tensile specimens with the resistant ligament located in the heat affected zone (HAZ) were used and their rotation capacity evaluated by means of a plane stress plastic collapse model as a quantitative criterion to assess by comparison, the effectiveness of the repairing procedure. This permits separation the influences of yielding and ductile fracture resistances in the moment-rotation diagram. The application of the method confirmed the better behaviour of the base metal when comparing it with the HAZs of the tested joints, and shows that joint performance improves by repairing.

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Keywords: Welded joint; heat affected zone; resistant ligament; plastic collapse; capacity of plastic rotation;

* Corresponding author. Tel.: /
E-mail address: mihaela.iordachescu@upm.es

Investigation of heat-treatment-induced pore microstructural variations in cold sprayed titanium

Yuqi Ren[a,*], Peter King[b], Sam Yang[b], Tiqiao Xiao[a]

[a]*Shanghai Institute of Applied Physics, Chinese Academy of Sciences*
[b]*CSIRO, Canbera, Australia*

Abstract

Cold-spray additive manufacture of titanium components has been the subject of considerable interest. However, titanium has limited ductility compared to face-centred cubic (fcc) metals such as copper and aluminium. Consequently, Ti particles do not deform to the same extent upon impact, and some porosity generally remains. To improve the strength and ductility of the sprayed material, a heat treatment procedure is generally employed. From a practical perspective, understanding the nature of the porosity before and after heat treatment is important, since if air or process gas (nitrogen) remains trapped, high-temperature diffusion of oxygen or nitrogen into the bulk can cause embrittlement. Variations to the bulk density will also have an effect on mechanical properties. A change from an open pore network to a closed structure will influence the performance of corrosion- or oxidation-resistant titanium coatings.
Synchrotron-based high-resolution X-ray micro-computed tomography (CT) combined with the data-constrained modelling (DCM) approach for investigation of three-dimensional pore structural variation in a cold-sprayed Ti sample before and after heat treatment [1]. Quantitative analysis indicated that the heat treatment caused morphological changes to the pores and a small decrease in the overall porosity. Interconnectivity between pores was reduced, which has implications for sealing and trapping of contaminant gases in cold-sprayed parts.

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*Keywords:*Ccold spay, titanium, X-ray microtomography, data-constrained modelling

* Corresponding author. Tel.: /
E-mail address: renyuqi@sinap.ac.cn

Meso-scale modelling of mechanical behaviour and damage evolution in normal strength concrete

Jiaming Wanga[a,*], Andrey P. Jivkov[a], Dirk L. Engelberg[b], Q.M. Li[a]

[a]*School of Mechanical, Aerospace and Civil Engineering, University of Manchester, Manchester, UK*
[b]*Corrosion & Protection Centre/Materials Performance Centre, School of Materials, University of Manchester, Manchester, UK*

Abstract

Modelling concrete at the meso-scale has been a topic of intensive research in the last decade, as this approach allows for improved understanding of meso-structure effects on the damage and failure of concrete. The majority of previous works focus on simple stress state, either tension or compression, which does not allow for clarifying the most suitable description of the behaviour of concrete constituents: aggregates, mortar, interfacial transition zones (ITZ) between aggregates and mortar, and entrapped voids. Here all these constituents are represented explicitly and a new combination of their behaviours is explored, applicable to both tension and compression. The work is based on synthetically generated concrete with spherical coarse aggregates and voids randomly packed without overlapping. The meso-structure is meshed and zero-thickness cohesive elements are inserted at ITZs. Aggregates are considered elastic, concrete damage plasticity (CDP) model with both tension and compression hardening is adopted for mortar, and cohesive zone model is used for ITZs. The results presented demonstrate very good agreement with experiments in both tension and compression, in terms of stress-strain curves as well as crack patterns. The proposed development is a promising step towards more realistic representation of concrete behaviour, which is required in practical cases where concrete experiences complex triaxial stress states.

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Keywords: Concrete meso-structure; mortar damage plasticity; cohesive zone ITZ; tension and compression; failure patterns

* Corresponding author. Tel.: /
E-mail address: jiaming.wang@postgrad.manchester.ac.uk

Creep-fatigue behavior analysis in a rotor during a long-term operation

Nailong Zhao[a,]*, Weizhe Wang[a,]*, Richard A. Adjei[a], Yingzheng Liu[a]

[a]*Shanghai Jiao Tong University*

Abstract

With the increasing steam parameters in power plants, much attention should be given to the significant creep and fatigue behavior in ultra-supercritical steam turbines rotors, especially during a long-term operation with gradual variation in the material characteristics. In the present study, the long-term creep-fatigue behavior of an ultra-supercritical critical steam turbine rotor was predicted using a phenomenological lifetime model as a post processing of the finite element method. The temperature and stress distributions of the rotor during the multiple cyclic processes were numerically studied using ABAQUS. The creep-fatigue damage was subsequently computed and discussed, which disclosed that the maximum damage maintained at the inlet zones. The radial temperature gradient had the positive correlation with thermal stress, and the effective stress essentially reflected the tensile/extrusion state of the material, which was affected by the material stiffness variation. By separate damage analysis, the blade groove zones suffered large fatigue damage, while great creep damage mainly appeared at the inlet notch zones. In comparison, the probability of failure due to creep in the long-term operation was much higher than that due to fatigue. Lifetime prediction of the key points was proved to be safe based on the ASME creep-fatigue damage restriction curve.

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Keywords: Rotor, long-term operation, creep-fatigue behavior, damage assessment

* Correpsonding author. Tel.: /
E-mail address: zhaonailong@126.com, wangwz0214@sjtu.edu.cn

Quantifying the deleterious effect of sea water on the fatigue life of welded steel joints using a fracture-mechanics approach

Adam Smith[a,*], Mark Knop[a]

[a]Defence Science and Technology, 506 Lorimer Street, Fishermans Bend, VIC 3207, Australia

Abstract

Numerous studies have been conducted to investigate the deleterious effect of sea water on the fatigue life of welded joints for offshore structures subjected to wave loading (0.15 Hz to 0.5 Hz). In contrast, little research has been conducted to quantify this effect on the fatigue life of marine structures subjected to lower cycle frequencies. In the present study, a fracture-mechanics based approach in conjunction with the finite-element method has been used to model fatigue tests carried out on tee-butt welded joints in aqueous 3.5 wt.% NaCl (an analogue for sea water) under freely corroding conditions and various cycle frequencies (from 1 Hz to < 0.001 Hz) subjected to a constant stress range. This type of analysis can now be carried out because a more comprehensive corrosion-fatigue crack-growth-rate dataset for these low cycle frequencies has recently been published. Fatigue cracking in tee-butt welded joints was successfully modelled, and the results of this modelling, which are consistent with corrosion-fatigue crack-growth rates, indicate that the fatigue life of these tee-butt welded joints can be reduced by up to about 6.7 times in a salt-water environment for very low cycle frequencies (< 0.001 Hz) compared with the fatigue life in air.

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Keywords: fatigue; sea water; steel; tee-butt welds; fatigue-life; fracture-mechanics;

* Corresponding author. Tel.: /
E-mail address: adam.smith@dst.defence.gov.au

Enhancement of tensile properties due to pre-ratcheting of Zircaloy 2 at 400°C

Rupendra Singh Rajpurohit[a,*], N.C. Santhi Srinivas[a], Vakil Singh[a]

[a]*IIT (BHU), Varanasi, India*

Abstract

Asymmetric cyclic loading leads to plastic strain accumulation in a component which is known as ratcheting strain. Ratcheting strain accumulation is a life-limiting factor in mostly piping components. The aim of this investigation was to see the work hardening effect on the Zircaloy-2 at 400°C by pre-ratcheting up to 200 cycles. Stress-controlled fatigue tests were performed at 400°C up to 200 cycles with different combinations of mean stress (σm) and stress amplitude (σa). Tensile properties of these samples were determined at 400°C. There was a marked improvement in the yield strength but less in tensile strength, however, ductility was reduced due to prior ratcheting. The results are discussed in terms of prior work hardening and consequent decrease in the size of dimples on the fracture surfaces due to ratcheting.

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Keywords: Ratcheting strain, pre-ratcheting, tensile testing, mean stress, stress amplitude

* Corresponding author. Tel.: /:
E-mail address: rupendra1986@gmail.com

A local limit load model for *J* prediction via the reference stress method

Yuebao Lei[a,*]

[a]*EDF Energy Nuclear Generation Ltd., Barnett Way, Barnwood, Gloucester, GL4 3RS, UK*

Abstract

A local limit load model is developed for shell/plate type components with surface cracks for determining the local limit load or local reference stress used in *J* prediction via the reference stress *J* scheme for defective components. The model is a plate which contains a rectangular surface crack circumscribing the real surface defect and has the same thickness as the component at the crack location. The model is remotely loaded by the primary stresses of the component at the crack location obtained from elastic uncracked-body stress analysis. The global limit load of this model is used as the local limit load of the defective component. The model is validated using 273 cases of 3-D finite element (FE) *J* results for semi-elliptical surface cracks in plates, cylinders and elbows. The results show that when this local limit load is used in the reference stress *J* prediction scheme, the predicted *J* values are reasonably accurate but conservative, compared with the FE *J* values.

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Keywords: Structural integrity assessment, Reference stress *J* scheme, J-integral, Limit load, Local limit load

* Corresponding author. Tel.: /
E-mail address: yuebao.lei@edf-energy.com

Crack initiation of selected geopolymer mortars with hemp fibers

Hana Simonova[a,*], Barbara Kucharczykova[a], Libor Topolar[a], Zbynek Kersner[a], Ildiko Merta[b], Jelena Dragaš[c], Ivan Ignjatović[c], Miroslav Komljenović[d], Violeta Nikolić[d]

[a]*Brno University of Technology, Faculty of Civil Engineering, Veveri 331/95, 602 00 Brno, Czech Republic*
[b]*Technische Universität Wien, Faculty of Civil Engineering, Adolf-Blamauer-Gasse 1-3, 1030 Vienna, Austria*
[c]*University of Belgrade, Faculty of Civil Engineering, Bulevar kralja Aleksandra 73, 11000 Belgrade, Serbia*
[d]*University of Belgrade, Institute for Multidisciplinary Research, Kneza Višeslava 1, 11030 Belgrade, Serbia*

Abstract

The aim of this paper is to quantify particularly fracture properties of selected types of mortars prepared with an alkali activated binder and hemp fibers. The main attention is focused on evaluation of three-point bending fracture tests of prismatic specimens with an initial central edge notch made of alkali activated fly ash mortars. The load versus crack mouth opening displacement (*F–CMOD*) diagrams were recorded during the fracture tests and subsequently evaluated using the Double-*K* fracture model. This model allows the quantification of two different levels of crack propagation: initiation, which corresponds to the beginning of stable crack growth, and the level of unstable crack propagation. The course of fracture tests was also monitored by acoustic emission method.

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Keywords: Geopolymer, hemp fibre, fracture test, acoustic emission, crack initiation, Double-*K* model.

* Corresponding author. Tel.: /
E-mail address: simonova.h@vutbr.cz

Recent studies of hydrogen embrittlement in structural materials

Dan Eliezer[a,*], Ravit Silverstein[b]

[a]*Department of Material Engineering, Ben-Gurion University of the Negev, Beer-Sheva, Israel*
[b]*Materials Department, University of California, Santa Barbara, California*

Abstract

Mechanical properties of metals and their alloys are most often determined by interstitial atoms. Hydrogen, as one common interstitial element, is often found to degrade the fracture behavior and lead to premature or catastrophic failure in a wide range of materials, known as hydrogen embrittlement. This topic has been studied for more than a century, yet the basic mechanisms of such degradation remain in dispute for many metallic systems. This work attempts to link, experimentally and theoretically, between failure, caused by the presence of hydrogen, and second phases, lattice distortion, and deformation levels.
The connection between hydrogen embrittlement and pathway is established through examination of the evolved microstructural state by hydrogen. Calculations performed by thermal desorption analysis showed the effectiveness of high trapping energy levels in preventing the hydrogen embrittlement phenomena. It was proved that the embrittlement model is highly affected by the trapping mechanisms. These results were confirmed by a diffusion calculation model and a theoretical model that predicts hydrogen trapping mechanisms.

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Keywords: Hydrogen; structure materials; thermal desorption analysis (TDA)

* Corresponding author. Tel.: /:
E-mail address: deliezer@bgu.ac.il

Retardation of the fatigue crack growth in AA2024-T3 through residual stresses induced by laser shock peening

Sergey Chupakhin[a,*], Benjamin Klusemann[a], Norbert Huber[a], Nikolai Kashaev[a]

[a]*Helmholtz-Zentrum Geesthacht*

Abstract

Laser shock peening is a very promising surface modification technique for retardation of fatigue crack growth in metallic structures through generation of deep compressive residual stresses. The hole drilling method is a well-established technique for determining such non-uniform residual stresses. In the light of these two points, the present work aims to optimize the laser shock peening process in regard to high residual stress profiles, their correct measurement by the hole drilling method and demonstration of the retardation of fatigue crack growth through the laser peening treatment. First, the methodology for the correction of hole drilling plasticity effects when measuring residual stresses approaching the material yield strength is established and experimentally validated. The correction methodology utilizes FE modelling and artificial neural networks. This provides a practical way to correct any non-uniform stress profile for a wide range of stress levels and material behaviors typically used in industrial applications. Second, the laser shock peening process is optimized in regard to the generated residual stress profiles using design of experiments techniques. The measured stress profiles are subjected to correction using the neural network methodology. The regression model obtained in the design of experiments study is used for generating the desired residual stresses in the C(T)50 AA2024-T3 specimens for the fatigue crack propagation test. Significant retardation of the fatigue crack growth due to the presence of deep compressive residual stresses is experimentally demonstrated on the laboratory scale. This might lead to the fatigue life extension up to 8 times. It has been found that the integrated residual stress over depth reflects the effect on the fatigue life best. Moreover, the regression model provides the correlation between laser shock peening parameters and fatigue life improvement, which can be used for fatigue life prediction.

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Keywords: Laser shock peening, hole drilling, residual stress, fatigue life extension, AA2024-T3

* Corresponding author. Tel.: /:
E-mail address: sergey.chupakhin@hzg.de

Effect of transversal loading on the fatigue life of cold-drawn duplex stainless steel

Mihaela Iordachescu[a,]*, Maricely de Abreu[a], Andrés Valiente[a]

[a]*Materials Science Dpt., E.T.S.I. Caminos, Universidad Politécnica de Madrid, Prof. Aranguren St., 28040, Madrid, España*

Abstract

The paper gives new insights on failure behavior of high-strength, heavily cold-drawn duplex stainless steel wires when simultaneously subjected to static transverse and longitudinal loadings, with the latter ones being of a fully tensile or cyclic nature. The wires might experience such combined actions when incorporated into strands of pre or post-tensioned cable systems, today used in a wide spectrum of construction applications. The transversal loads are due to the contact forces between the wires, and mainly occur by longitudinal tensioning of strands. In order to reproduce them, the experiments were made with a specially designed device assuring the control of the locally applied transversal compression during the wire loading in simple or cyclic tension. The results concerning the static bi-axial loading did not show significant differences concerning the failure load of duplex stainless steel wires when compared with that of currently used prestressing eutectoid wires: on this basis, an empirical fracture criterion predicting the critical load combinations was formulated. The simultaneous action of transverse compressive loading and fatigue tensile loading of 200 MPa stress range produces a nominally infinite lifetime of lean duplex wires for combinations of the compressive and maximum tensile loads experimentally determined. These combinations could be roughly described as those given by compressive loads or maximum tensile fatigue loads higher than 50% of the tensile bearing capacity of lean duplex wire.

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Keywords: Cold-drawn duplex stainless steel wires; tensile-compression static loading; static compression-tensile fatigue; fatigue life; failure micro and macro-mechanisms;

* Corresponding author. Tel.: /
E-mail address: mihaela.iordachescu@upm.es

Hybrid Metal Extrusion & Bonding (HYB) – a novel solid state joining process for aluminium alloys

Lise Sandnes[a,*], Øystein Grong[a], Filippo Berto[a], Jan Torgersen[a]

[a]*Norwegian University of Science and Technology*

Abstract

Hybrid Metal Extrusion & Bonding (HYB) is a new solid state joining technique mainly developed for aluminium alloys. By the use of filler material addition and plastic deformation, sound joints can be produced at operational temperatures below 400 °C. This makes the HYB process more flexible and less vulnerable to defects associated with conventional solid state joining processes and is a considerable advantage. Thus, it is believed that the HYB process has the potential to compete, or even outperform, conventional joining processes used for aluminium alloys in the future. In the present paper, a more extensive analysis of the HYB joint mechanical properties is conducted, including both hardness measurements, tensile testing and Charpy V-notch testing. The joint is found free from defects like pores and internal cavities, but a soft heat affected zone (HAZ) is still present and reduces the joint load bearing capacity. Moreover, the joint yield strength is found to be 54 % of the base material, with a joint efficiency of 66 %. The HYB joint mechanical properties is found to be slightly better than that reported for comparable gas metal arc welds (GMAW), but it does not fully match that of sound friction stir welds (FSW). Therefore, there is a potential for further optimization of the HYB process to bring it to the forefront of aluminium welding technology. This work is now in progress.

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Keywords: Hybrid metal extrusion & bonding (HYB), solid state joining (SSJ), welding, aluminium, AlMgSi alloys

* Corresponding author. Tel.: /
E-mail address: lise.sandnes@ntnu.no

Experimental investigation and computational modelling of the weaving type influence on the dynamic loading results in a multilayer woven barrier

Anton Beliaev[a,*], Tatiana Beliakova[b], Alexander Inyukhin[a], Liliia Kostyreva[a], Pavel Mossakovsky[a], Petr Chistyakov[a]

[a]*Institute of Mechanics, Lomonosov Moscow State University, Moscow, Russia*
[b]*Lomonosov Moscow State University, Moscow, Russia*

Abstract

The dynamic interaction of multilayer woven barriers of aramid fibers with various forms of impactors is considered, and the processes of energy dissipation are investigated. Experimental investigation of the interface friction coefficients is performed under the conditions of the transverse compression for different weaving types of fabrics. The required range for the compressive loads is estimated by the use of FE-modelling of impact loading of the multi-layer woven barriers. Static and dynamic friction coefficients are determined for all possible combinations of textile-textile interfaces with plain and four types of twill weaving patterns. It is obtained that the interface static friction coefficient for fabrics with various weaving types can differ from the coefficients of the composing layers up to 20%. Moreover, it can also differ from the averaged value of these two coefficients. For the higher values of the transversal compression the experimental equipment is proposed and designed for pulling out a textile layer from a free multilayer structure of fabrics under the conditions of controllable transverse compression loading. The numerical modelling of the load distribution in the tested fabric layer is accomplished which allows us to estimate the irregularity of the transversal pressure in the specimen and to correct the experimental results for friction coefficients. The finite elements models of different complexity for fabrics of five weaving types and for their combinations are constructed. Verification of the models is carried out by full-scale ballistic experiments, and the simulation error is estimated. The influence of the placement of layers with different weaving type in the woven barriers on the impactor velocity after the rupture is analysed numerically. The advantages of the particular combinations of weaving type placement in comparison with the uniform barriers with the same number of layers is shown. The research is carried out using the equipment of the shared research facilities of HPC computing resources at Lomonosov Moscow State University. The work was carried out in accordance with the scientific research plan of the Institute of Mechanics Lomonosov Moscow State University.

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Keywords: Woven fabrics, aramid yarns, interface friction, weaving type influence, impact loading, energy dissipation, transversal compression

* Corresponding author. Tel: /
E-mail address: Belyaev.anton.pav@yandex.ru

Assessment of the cortical bone micromorphology effect on the crack propagation in the bone domain with single osteon

Elena Gulidova[a], Vadim Silberschmidt[b], Sergei Bosiakov[a,]*

[a]*Belarusian State University, Belarusia*
[b]*Loughborough University, United Kingdom*

Abstract

The structural integrity of bone plays an important role in the routine human activities. To understand the mechanism of the bone disruption, it is necessary to develop adequate numerical models that allow to investigate the causes of bone fractures at different hierarchical levels of cortical bone in details, in particularly, at the microscale level. The results of the finite-element modeling of the single dominant crack propagation in a plane domain containing an interstitial matrix with a single osteon surrounded by a cement line are presented in this research paper.
The crack propagation is modeled by using two-dimensional cohesive finite elements with four nodes and triangular solid-state elements. The length of the initial crack on the free boundary of the domain is approximately 46 μm; the position of the initial crack is determined randomly on non-constraint side of the model; the model has been rigidly fixed on the side which is opposite to the boundary with the initial crack. Periodic boundary conditions were established on two other parallel boundaries of the model to control the displacements of the nodes which are located on the boundaries of the domain. This approach makes it possible to use the developed model as a representative element for cortical bone on a microscale level. The shapes of osteon and the surrounding cement line were approximated by ellipses with arbitrary orientation in the interstitial matrix. The shape of the Haversian canal was approximated by a circle. The thickness of the cement line is a constant value and equals to 5 μm.
The effect of the orientation of the elliptical shape of the osteon and cement line, the geometric parameters of the osteon and Haversian canal, and also the material properties of the osteon area, cement line and interstitial matrix on the crack propagation were analyzed.

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Keywords: Cortical bone, osteon, crack propagation, finite-element modeling

* Corresponding author. Tel: /
E-mail address: bosiakov@bsu.by

Characterization of the long crack propagation behaviour in a hardenable aluminium alloy in the very high cycle fatigue regime

F. Bülbül[a,*], H.-J. Christ[a], M. Wicke[b], A. Brückner-Foit[b], T. Kirsten[c], M. Zimmermann[c]

[a]*Institut für Werkstofftechnik, Universität Siegen, D-57068 Siegen, Germany*
[b]*Institut für Werkstofftechnik, Universität Kassel, D-34125 Kassel, Germany*
[c]*Institut für Werkstoffwissenschaft, Technische Universität Dresden, D-01069 Dresden, Germany*

Abstract

In the regime of Very High Cycle Fatigue (VHCF), it appears questionable whether all the well-known stages of fatigue crack propagation occur. Deviations must be expected through the very small dimension of the cyclic plastic zone ahead of the crack tip and, hence, a strong interaction with microstructural features seems very likely. Investigations have shown that "natural" crack initiation often takes place underneath the material surface leading to crack propagation without contact to atmospheric components. In order to reproduce the crack growth behaviour, an ultrasonic fatigue testing system (USFT) equipped with a small vacuum chamber was used for fatigue experiments in vacuum. The tests were carried out on the aluminium alloy EN-AW 6082 in the peak-aged (pa) condition. Micro-notches were prepared in the USFT specimens by means of the Focused-Ion-Beam technique. Systematic measurements in laboratory air in the region of the threshold value of long fatigue crack growth revealed that primary precipitates significantly influence the crack growth behaviour. Depending on the spatial distribution of the primary precipitates, strong crack retardation and localized crack arrest take place even far above the threshold value. In vacuum only shear-stress-controlled VHCF long crack propagation were detected in EN-AW 6082 (pa) due to very pronounced single dislocation slip associated with the secondary precipitates of the aluminium alloy.

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Keywords: Hardenable aluminium alloy; very high cycle fatigue; shear-stress-controlled VHCF long crack propagation; barrier effect

* Corresponding author. Tel: /
E-mail address: fatih.buelbuel@uni-siegen.de

Brazilian disk tests: Circular holes and size effects

A.R. Torabi[a], S. Etesam[a], A. Sapora[b,*], P. Cornetti[b]

[a]*Fracture Research Laboratory, Faculty of New Sciences and Technologies, University of Tehran, P.O. Box 14395-1561, Tehran, Iran*
[b]*Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, 10129 Torino, Italy*

Abstract

Size effects related to circular notched samples imply that the strength of the structure decreases as the hole radius increases. In this framework, Brazilian disk tests are carried out on brittle samples containing a circular hole. By considering two different polymers, namely Polymethyl-methacrylate (PMMA) and General-purpose Polystyrene (GPPS), respectively, five different notch radii were machined and tested for each material, keeping low the hole to disk diameter ratio in order to reproduce an infinite geometry. Under this assumption, analytical relationship for the stress field and the stress intensity factor can be implemented without loss of accuracy. The coupled finite fracture mechanics (FFM) is then applied to catch the recorded failure stresses, allowing a complete description of the experimental size effects. On the contrary, the smallest radius leads to a locally negative eometry, opening the discussion on the stability of crack propagation in circularly notched plates under generic biaxial loadings.

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Keywords: Size effects; circular holes; FFM; negative geometries.

* Corresponding author. Tel.: /:
E-mail address: alberto.sapora@polito.it

Influence of rebar design on mechanical behaviour of Tempcore steel

B. Hortigón[a,*], F. Ancio[a], E.J. Nieto-García[a], M.A. Herrera[a], J.M. Gallardo[b]

[a]*Escuela Politécnica Superior (Universidad de Sevilla), C/ Virgen de Africa,7,41011 Sevilla, España*
[b]*Escuela Técnica Superior de Ingeniería (Universidad de Sevilla), C/ Camino de los Descubrimientos s/n,41092 Sevilla, España*

Abstract

Tensile behaviour of metals beyond the ultimate tensile strength (UTS) must be considered to calculate toughness or absorbed energy till fracture. Structural steels, designed to withstand earthquakes, are the typical material where post necking behaviour can be of paramount importance. This paper deals with the tensile stress-strain behaviour of Tempcore Rebar, a specifically shaped structural steel. Helical, short ribs, formed by rolling, protrude from the cylindrical basic shape of the Rebar. This help in increasing concrete/steel adherence in reinforced structures. On the other hand, those ribs make it difficult to assess strain distribution in the necking area, according to well known theories describing neck profile. New or modified experimental methods, along with new theoretical approaches must be developed to help in studying neck profile evolution and corresponding stresses in rebars. Advances in such methods and theories are presented in this paper along with comparison with Tempcore cylindrical bars necking behaviour. The effect of ribs is clearly identified.

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Keywords: Tempcore, rebar, mechanical behaviour, necking, fracture.

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* Corresponding author. Tel.: /
E-mail address: bhortigon@us.es

A novel micromechanics approach for understanding of fatigue in nodular cast iron

Mehul Lukhi[a,*], Geralf Hütter[a], Meinhard Kuna[a]

[a]TU Bergakademie Freiberg, Institute of Mechanics and Fluid Dynamics, Lampadiusstr. 4, 09599, Freiberg, Germany

Abstract

Nodular cast iron (NCI) experiences failure under static loading in manner of nucleation, growth, and coalescence of voids. Under cyclic loading, materials with elastic-plastic behaviour show an increase in porosity with each cycle which is called void ratchetting. A number of finite element studies in literature proved this mechanism by means of a few cyles with unit cell models. In the present study, low cycle fatigue (LCF) in nodular cast iron is investigated using the cell models for void ratchetting till final failure. The cyclic necking due to plastic strain accumulation is observed as mechanism in the final stage. The proposed methodology uses only input parameters defining the elastic-plastic material behavior and geometrical features of the microstructure. The strain-life curves extracted from the simulations are compared with experimental data collected from the literature. From the comparison, it is confirmed that void ratchetting is the relevant mechanism of LCF in NCI. The effects of material strength, temperature and load sequencing on the fatigue behaviour are studied.

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Keywords: nodular cast iron, void ratchetting; low cycle fatigue; strain-life approach

* Corresponding author. Tel.: /
E-mail address: mehul.lukhi@imfd.tu-freiberg.de

Dynamic interfacial fracture of a thin-layered structure

Tianyu Chen[a], Christopher M. Harvey[a], Simon Wang[a,c], Vadim V. Silberschmidt[b,*]

[a]*Department of Aeronautical and Automotive Engineering, Loughborough University, Lecestershire LE11 3TU, UK*
[b]*Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Leicestershire LE11 3TU, UK*
[c]*School of Mechanical and Equipment Engineering, Hebei University of Engineering, Handan 056038, China*

Abstract

To calculate the dynamic energy release rate of a crack is important for understanding a structure's fracture behavior under transient or varying loads, such as impact and cyclic loads, when the inertial effect can be significant. In this work, a method is proposed to derive an analytic expression for the dynamic energy release rate of a stationary crack under general applied displacement. An asymmetric double cantilever beam with one very thin layer is considered as a special case, with vibration superimposed onto a constant displacement rate applied to the free end. The resulting expression for dynamic energy release rate is verified using the finite-element method (FEM) in conjunction with the virtual crack closure technique. The mode-mixity of the dynamic energy release rate is also calculated. The predicted total dynamic energy release rate and its components, G_I and G_{II}, are both in close agreement with results from FEM simulations.

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Keywords: dynamic energy release rate, inertial effect, modal analysis, dynamic energy release rate partition

* Corresponding author. Tel.: /
E-mail address: v.silberschmidt@lboro.ac.uk

Brittle fracture analysis of Dissimilar Metal Welds between low-alloy steel and stainless steel at low temperatures

Ghassen Ben Salem[a,b,c,*], Stephane Chapuliot[a], Arnaud Blouina[a], Philippe Bompard[b], Clementine Jacquemoud[c]

[a]FRAMATOME, 1 Pl. Jean Millier, 92400 Courbevoie, France
[b]Laboratoire MSSMat, UMR CNRS 8579, CentraleSupelec, 3 Rue Joliot Curie, 91190 Gif-sur-Yvette, France
[c]DEN-Service d´ ´etudes m´ecaniques et thermiques (SEMT), CEA, Universit´e Paris-Saclay, F-91191 Gif-sur-Yvette, France

Abstract

Dissimilar Metal Welds (DMW) between low-alloy steel (A533 steel) and austenitic 316L stainless steel are widely used within the French nuclear power plants where they connect the main components to the primary circuit pipes. In these DMW, the welding process and the post-weld heat-treatment generate a hard thin layer of carburized martensite and austenite in the vicinity of the fusion line (FL), resulting in a heterogeneous microstructure with high mechanical properties gradient, hence potentially, a higher sensitivity to brittle fracture in the hard layer. The present study aims to evaluate the brittle behavior of the DMW at low temperatures and more particularly of the interface between the carburized martensite and austenite (MA interface). Fracture toughness tests were carried out at temperatures between −120 °C and −50 °C, with a precrack tip located on the ferritic side near the FL (i.e., between the ferritic steel and the stainless steel buttering). The analysis of the fracture behavior of the DMW was based on a SEM examination of CT (Compact Tension) specimens fracture surfaces. Coupled with a 2D plane strain numerical simulation of the tests, the results show that the presence of austenite in the fatigue precrack front and subsequent ductile tearing towards FL produced higher solicitations on the hard layer and caused intergranular fracture on the MA interface, resulting in lower toughness values for the specimen. To model the brittle behavior of the MA interface, a stress based criterion was used. Tensile tests on axisymmetric specimen, which were machined to initiate intergranular fracture in the MA interface and tested at −170◦C, were used to define a threshold stress (σ_{th}), below which brittle fracture cannot occur. Then, a criterion to evaluate the brittle fracture risk of the DMW was proposed and applied to the CT specimen.

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Keywords: Dissimilar metal welds; martensite-austenite interface; fusion line; hard layer; intergranular fracture; carbides; threshold stress; notched tensile specimen

* Corresponding author. Tel.: /
E-mail address: ghassen.ben-salem@ecp.fr

Interfacial fracture of 3D-printed bioresorbable polymers

Andrew Gleadall[a,*], Wingho Poon[b], James Allum[a], Alper Ekinci[a], Xiaoxiao Han[a], Vadim V. Silberschmidt[a]

[a]*Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Loughborough, LE11 3TU, UK*
[b]*Department of Materials Science and Engineering, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon 999077, Hong Kong Special Administrative Region, China*

Abstract

A micro specimen for tensile testing was designed with two primary aims: (i) to characterise interface fracture behaviour between fused 3D-printed polymer filaments; and (ii) to minimise material use of high-cost medical-grade polymer since a high number of specimens are required for time-series studies (e.g. polymer degradation).
Polylactide specimens were fabricated on an extrusion 3D-printer as a single-filament-wide wall. The widths of filaments were set individually, with a custom machine-control code, to achieve a higher width in the grip sections of specimens and a narrower width in their gauge section. On average, the interface between filaments was 114 µm narrower than the widest point of the filaments. Each specimen was tested in the build direction to determine the interfacial strength between 3D-printed layers. Optical microscopy was employed to characterise geometry of specimens and fracture surfaces. Samples fractured in the gauge section and the fracture surface demonstrated brittle characteristics.
The specimens utilised an order of magnitude less material than ASTM D638 samples, whilst maintaining repeatability for tensile strength similar to that in other studies. The average strength was 49.4 MPa, which is comparable to data in the literature. Further optimisation of the specimen design and 3D printing strategy could realise greater reductions in material use.

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Keywords: Additive manufacturing; 3D printing; interface; mechanical properties; fracture; micro-tensile; medical polymers

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* Corresponding author. Tel.: /
E-mail address: a.gleadall@lboro.ac.uk

Scatter of fatigue life regarding stress concentration factor

Przemysław Strzelecki[a,*]

[a]*Institute of Mechanical Engineering, University of Science and Technology, 85-789 Bydgoszcz, Poland, PL*

Abstract

The design process of new structural components requires to determine the fatigue life of those components at dynamic loads that change over time. To extend the fatigue life, the shape of the component must maintain the smallest possible stress concentration factor for all its surfaces. Verification calculations use the fatigue characteristics for each structural component (or determined for the material used corrected by the fatigue notch factor) with the probability of failure at 5% or lower. The probability is determined based on the analysis of risk for human life, economic losses, environmental risk etc. The study shows the effects of the shape parameter on the scatter of the test results. The tests were carried out on AW-6063 aluminium alloy, purchased as a 10 mm dia. drawn bar. The rotating bending fatigue tests were carried out on smooth and notched specimens with 1.4, 2 and 2.6 stress concentration factor.

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Keywords: fatigue life, risk, AW-6063 aluminium alloy

* Corresponding author. Tel: /
E-mail address: p.strzelecki@utp.edu.pl

Numerical and analytical model of long tubular bones with anisotropic distribution of elastic properties

Sergei Bosiakov[a,*], Kirill Yurkevich[a], Vadim V. Silberschmidt[b], Anna Ershova[a]

[a]*Belarusian State University, 4 Nezavisimosti Avenue, Minsk 220030, Belarus*
[b]*Loughborough University, Loughborough Leicestershire LE11 3TU, UK*

Abstract

Elastic parameters of a cortical bone tissue at the macrolevel can vary for various bones, as well as in different parts or anatomical quadrants, of the same bone. In this paper, an approach to finite-element modelling of the nonlinear anisotropic and isotropic distribution of elastic properties of tubular bones is proposed. Dependences of the Young's moduli, shear moduli and the Poisson's ratios on the spatial coordinates determining the position of the element in the bone model are used. They were obtained on the basis of experimental data on anisotropic elastic properties of tubular bone. A comparative finite-element analysis of the principal stresses and deformations caused by the action of own weight on the human femur was carried out for nonlinear anisotropic and isotropic distributions of elastic properties. Differences between the levels of maximum principal stresses and deformations for the three cases of elastic properties can reach approximately 10% and 30%, respectively.

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Keywords: Long tubular bone; anisotropic elastic property; numerical and analytical model; principal stresses, deformation

* Corresponding author. Tel.:/:
E-mail address: bosiakov@bsu.by

Local toughness of brittle fracture origins in irradiated pressure vessel steel after fracture toughness tests

Artem Erak[a,*], Evgenia Kuleshova[a], Aleksei Kiselev[a], Andrey Bandura[a], Sergey Bubyakin[a]

[a]*NRC "Kurchatov Institute"*

Abstract

Fracture toughness tests of surveillance-specimens of VVER-1000 pressure vessels are mandatory to validate the life-time prolongation of operating pressure vessels and to verify theirs safe exploitation. To determine the embrittlement mechanisms of pressure vessel steel under irradiation and to establish all fracture stages during three-point-bending tests fractographic researches of tested specimens were carried out. During studies of fracture surfaces types and locations of brittle fracture origins were defined in specimens tested in the initial and irradiated states. To specify mechanisms of irradiation influence on materials local normal stresses at origins were defined. These parameters characterize comparable brittle toughness of different origin types depending on steel state. Determination of such a local characteristic is feasible with application of the calculative-experimental method involving making the finite-element model (for description of stress-strain state of sample with a grown fatigue crack), conducting of fractographic researches (determination of all fracture stages) and numerical description of fracture stages.
Base on the results of investigations: 1) the nucleation time of an initial microcrack at origin were defined after tests of irradiated and non-irradiated surveillance-specimens; 2) values of local normal stress during brittle fracture initiation in the initial and irradiated states (up to fluence 74.4×10^{22} m^{-2}) were calculated; 3) dependences between defined local microstructural parameters of fracture surfaces and calculated fracture macroparameters obtained from mechanical test results.

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Keywords: reactor pressure vessel, fracture toughness tests, SEM fractography, brittle fracture origin, irradiation

* Corresponding author. Tel: /
E-mail address: ad.erak25@gmail.com

Impact of temperature on the fatigue and crack growth behavior of rubbers

Jacopo Schieppati[a,*], Bernd Schrittesser[a], Alfred Wondracek[b], Stefan Robin[b], Armin Holzner[b], Gerald Pinter[c]

[a]*Polymer Competence Center Leoben GmbH, Roseggerstrasse 12, 8700 Leoben, Austria*
[b]*Semperit Technische Produkte Gesellschaft m.b.H., Triester Bundesstrasse 26, 2632 Wimpassing, Austria*
[c]*Department of Polymer Engineering and Science – Material Science and Testing of Plastic, Montanuniversitaet, Otto Glöckel-Strasse 2, 8700 Leoben, Austria*

Abstract

Elasticity and chemical resistance are only two of outstanding properties of elastomers and make them applicable in a broad field of cyclic loaded components. During the cyclic loading, the failure is mainly related to crack growth mechanism. For the description and prediction of the material failure, fracture mechanics concepts represent a valid tool. In the field of elastomer failure under cyclic loading, two main approaches have been developed: (1) the crack nucleation dealing with the lifetime of rubber, due to a specific number of cycles until appearance of a specific crack size and (2) the crack growth approach, devoting the attention to the growth of pre-existing defects. Although both approaches represent effective instruments for fatigue analysis, only little attention has been drawn on the impact of temperature on the failure behavior. Moreover, scientific publications report that temperature influences the fatigue life of rubbers by decreasing the magnitude by four orders. Therefore, a focus on the impact of temperature on the crack growth behavior seems indispensable to rise the knowledge in this field. For the evaluation of the influence of temperature on the fatigue performance, crack growth tests were implemented. For the characterization of the crack growth behavior, pure shear specimens equipped with a camera system to measure the crack growth behavior and the temperature were monitored with contactless thermo-couples to measure the surface temperature during the cyclic loading. Furthermore, the thermal conductivity was measured at different temperatures to allow an accurate evaluation of temperature influence. With the obtained data, a further description of the failure could be provided in order to extend the fracture mechanics approach through the implementation of the temperature effect within different fatigue models for elastomers.

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Keywords: Rubber; fatigue; temperature; crack growth; thermal conductivity.

* Corresponding author. Tel: /
E-mail address: jacopo.schieppati@pccl.at

Toward a non-destructive diagnostic analysis tool of exercises pipelines: models and experiences

Gabriella Bolzon[a,*], Marco Talassi[a]

[a]Department of Civil and Environmental Engineering, Politecnico di Milano, piazza Leonardo da Vinci 32, 20133 Milano, Italy

Abstract

Strategic networks of hydrocarbon pipelines, in long time service, are adversely affected by the action of aggressive chemicals transported with the fluids and dissolved in the environment. Material degradation phenomena are amplified in the presence of hydrogen and water, elements that increase the material brittleness and reduce the safety margins. The risk of failure during operation of these infrastructures can be reduced, if not prevented, by the continuous monitoring of the integrity of the pipe surfaces and by the tracking of the relevant bulk properties. A fast and potentially non-destructive diagnostic tool of material degradation, which may be exploited in this context, is based on the instrumented indentation tests that can be performed on metals at different scales. Preliminary validation studies of the significance of this methodology for the assessment of pipeline integrity have been carried out with the aid of interpretation models of the experiments. The main results of this ongoing activity are illustrated in this contribution.

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Keywords: Diagnostic analysis; non-destructive testing; simulation models; pipelines.

* Corresponding author. Tel.: /
E-mail address: gabriella.bolzon@polimi.it

Deformation behaviour and strain rate sensitivity of Inconel 617 alloy

Visweswara Rao[a,*], N.C. Santhi Srinivas[a], Vakil Singh[a]

[a]*Indian Institute of Technology (BHU)-Varanasi, India*

Abstract

The strain rate sensitivity of Inconel 617 alloy that is used for high temperature applications such as heat exchange in gas cooled reactors and steam generator super heater and reheater parts, is determined over a range of temperature from Room temperature to 900°C, using two different methods. In method one, tensile tests were done at three different strain rates $5\cdot10^{-4}$ s^{-1}, $5\cdot10^{-3}$ s^{-1} and $1\cdot10^{-2}$ s^{-1} at series of temperatures and in method two strain rate jump tests were used to determine strain rate sensitivity. The relationship of the temperature dependence of the strain rate sensitivity to the tensile curves of both methods is determined, method 1 found more appropriate to correlate with DSA region for this alloy. Negative strain rate sensitivity is found in the DSA region for this alloy (400-800°C). Serrations were observed in engineering stress strain diagram in the temperature range of 300 to 700°C at three strain rates. Work hardening parameters were determined using Ludwigson's equation to describe the tensile true stress strain curves as this curve deviating from Hollomon equation, and correlated the results with strain rate sensitivity with respect to temperature.

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Keywords: Rate sensitivity, Inconel 617, DSA, Ludwigson equation

* Corresponding author. Tel.: /
E-mail address: cvrao.rs.met15@itbhu.ac.in

Effect of hydrogen on the motion of dislocations during nanoindentation

Jianying He[a,*], Kai Zhao[a], Zhiliang Zhang[a]

[a]*Norwegian University of Science and Technology, Trondheim, Norway*

Abstract

Hydrogen-induced softening of metallic materials is studied from a perspective of collective behavior of dislocations. Based on dislocation density, a hydrogen-informed expanding cavity model is developed to describe the dynamic evolution of load-displacement curve obtained from nanoindentation tests. Large-scale molecular dynamics simulations on the mechanical behavior of FCC Ni with and without hydrogen (H) are performed to calibrate the proposed continuum model. The results show that the H-induced decrease of pop-in load is caused by that the energy barrier for dislocation nucleation is lowered by the solute drag of the H atmosphere formed around dislocations. No obvious reduction of pop-in load is observed with increasing H concentration. It is found that the power-law exponent of the self-organized criticality of dislocations increases due to the insertion of H atoms. Dislocation analysis shows that H can reduce the probability of the generation of dislocation pile-up.

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Keywords: Hydrogen embrittlement, dislocation, nanoindentation, molecular dynamics

* Corresponding author. Tel.: /
E-mail address: jianying.he@ntnu.no

Controlled fracture of brittle solid materials based on wave dynamics

Koji Uenishi[a,b,]*, Shintaro Sakaguchi[b], Naoyuki Shigeno[b], Hiroshi Yamachi[c], Junichiro Nakamori[c]

[a]*Department of Advanced Energy, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, 277-8561 Chiba, Japan*
[b]*Department of Aeronautics and Astronautics, The University of Tokyo, 7-3-1 Hongo, Bunkyo, 113-8656 Tokyo, Japan*
[c]*Sumitomo Mitsui Construction Co., Ltd., 518-1 Komagi, Nagareyama, 270-0132 Chiba, Japan*

Abstract

It is critically important to establish controllable fracturing techniques for safer and more effective operation in disintegration (or partial removal) of complex structures made of solid materials. Therefore, we have been developing more precise methods for controlled dynamic fracture of brittle solid materials based on the theory of wave dynamics that takes into account the influence of wave propagation and interaction with inhomogeneities such as free surfaces, interfaces and e.g. reinforcing steel bars in concrete. For this aim, instead of explosives, using more easily handleable electric discharge impulses, we have experimentally investigated optimal geometrical and dynamic loading conditions for fracture of a given structure in the field. Comprehensive experimental observations with a high-speed digital video camera and computations by our fully three-dimensional finite difference simulator have indicated that crack development in brittle solid materials may be governed by the combination of direct waves from blast holes (energy sources) and reflected / diffracted ones. Here, we show especially that sets of blast holes surrounded or sandwiched by empty dummy holes may indeed control the dynamics of waves (and thus main crack propagation and final disintegration pattern) in rectangular concrete structures, even when all blast holes are simultaneously pressurized and waves are radiated from all energy sources concurrently. The technique mentioned in this work may be employed to actualize not only crack extension in a desired direction but also rather precisely controlled dynamic fracture of (parts of) brittle solid materials.

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Keywords: Controlled dynamic fracture; Wave interaction; Mechanism of fracture

* Corresponding author. Tel.: /
E-mail address: uenishi@k.u-tokyo.ac.jp

Free vibration of functionally graded materials plates resting on elastic foundation

Nebab Mokhtar[a,*], Hassen Ait Atmane[a]

[a]University Hassiba BenBouali of Chlef, Chlef, Algeria

Abstract

In this works, the free vibration of functionally graded materials plates on an elastic foundation was investigated, based on the theory of first order shear deformation with different shear factors. The position of the neutral surface for the FG plate is determined. The Winkler-Pasternak model of one or two parameters describe the elastic foundation. The material properties of the functionally graded plate are supposed to vary according to the distribution of the power law of the volume fraction of the constituents. The motion equations are derived using the Hamilton principle. The accuracy of the present solutions is verified by comparing the results obtained with the solutions found in literature.

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Keywords: Free vibration, FGM plates, shear factors, elastic foundation

* Corresponding author. Tel.: /
E-mail address: m.nebab@univ-chlef.dz

Analysis of fracture behavior of exploded metal cylinders with varied charge

Xinlong Dong[a,]*, Xinlu Yu[b], Yingqian Fu[b]

[a]*Faculty of Mechanical Engineering and Mechanics, Ningbo University, China*
[b]*Beijing Institute of Technology, Beijing, China*

Abstract

Explosively driven fragmentation of ductile metals cylinders is a highly complex phenomenon. The previous works shown that several failure modes in the fragment cross-section could be occurs, including radial fracture, internal micro cracks, shear-lip fracture, which are related to the characteristics of the impulsive loadings, the dynamic behavior of the materials, the geometry of the shell structures, etc. In this study, TA2 titanium alloy tubular are explosively expanded to fragmentation with varied charge. Fractographic and metallographic examination are carried out on the analysis of the fragmentations, to identify the mode of fracture. The experimental results show that, under the higher explosion pressure, the cracking of the cylinder is initialed from the middle region of specimen wall thickness and then propagates to the inner or outer surface. At lower detonation pressure, the cracks start from the inner surface, and extend indirection of 45° or 135° to the radial. The fracture mechanism is different. Furthermore, the deformation and fracture behavior of different loaded cylinders are discussed numerically. Finite element analysis demonstrated that the localization at middle of the tuber wall was arose the secondary plastic due to effect of reflection wave when the tube loaded by the explosive shock, the equivalent plastic strain in the middle of the wall is always larger than that of the inner and outer surface. If the shock pressure is higher, it would lead to damages and micro-crack initiation at the localization of specimen thickness and extends to the inner and outer surfaces along the 45° or 135° to radial direction. While at lower pressure, fracture initiation from the inner surface of specimen and propagate to the outer wall at directions of 45° or 135°, different from higher pressure, the failure occur at the stage of tube free expansion of metal. Both failure mode is different. The tendency of finite element analysis is in good agreement with the experiments.

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Keywords: Metal cylinder, internal blast, finite element

* Corresponding author. Tel.: /
E-mail address: dongxinlong@nbu.edu.cn

Influence of substrate stiffness and of PVD parameters on the microstructure and tension fracture characteristics of TiN thin films

Felipe C. da Silva[a], Matheus A. Tunes[b], Julio C. Sagás[c], Cláudio G. Schön[a,*]

[a] *Department of Metallurgical and Materials Engineering, Escola Politécnica da Universidade de São Paulo, Av.Prof.Mello Moraes, 2463, 05508-900, São Paulo, Brazil*

[b] *Electron Microscopy and Materials Analysis (EMMA), UK National Ion Beam Centre, University of Huddersfield, Queensgate, HD1 3DH, United Kingdom*

[c] *Laboratory of Plasmas, Films and Surfaces, Universidade do Estado de Santa Catarina, Rua Paulo Malschitzki, 200, 89219-710, Joinville, Brazil*

Abstract

Titanium nitride is widely used as wear resistant coating thin films in industrial parts. Mechanically they correspond to nanometric 2D ceramic systems which are bound to a much thicker metallic substrate. Under uniaxial tension these films respond by forming a periodic array of cracks. The separation between the cracks is primarily defined by the strength and stiffness of the film. Secondary factors, as the elastic properties of the substrate, or the microstructure and/or induction of residual stresses during processing may also have and effect. In the present work PVD TiN films were deposited by triode magnetron sputtering in Brass and Aluminum substrates. The deposition characteristics of the films were varied by changing the bias potential and the nitrogen supply during deposition (constant or variable). Tension fractures were observed in situ using a traveling microscope and under nanoindentation/scratching tests. Energy Filtered TEM was used to access the nitrogen levels across film thickness. The results were correlated with the film residual stress levels obtained in the different deposition conditions.

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Keywords: Titanium nitride; PVD; bias; N_2 flow rate; fracture.

* Corresponding author. Tel.: /
E-mail address: schoen@usp.br

Update on the interaction between microstructure and stress state in duplex stainless steels

Eduardo Maeda[a], Cláudio Schon[a,]*

[a]*University of São Paulo, São Paulo, Brazil*

Abstract

In a recent work by one of the authors (A. Gallifa Terricabras, C. G. Schon, Mater, Sci. Eng. A, 717C, 2018, 20-25) a plastic anisotropy observed in the necking region of tensile samples made of duplex stainless steels was traced back to the underlying microstructure morphology. The present work continues this investigation by performing interrupted tensile tests in samples produced from rolled plates of different thicknesses of a lean duplex stainless steel. It turns out that the interaction between the underlying microstructure and the plastic flow in the necking zone is more complex than first assumed. The lamellar microstructure, which remains stable in the homogeneously deformed portion of the sample, is completely destroyed already in the initial stages of neck development. The necking zone present complex strain heterogeneities, in particular, dual phase shear bands across the volume of the neck. Surprisingly, the lamellar microstructure reforms close to the final fracture, in the region dominated by the plane strain state. This microstructural development is discussed in terms of the material flux inside the necking zone of the specimens.

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Keywords: Duplex stainless steels, tensile test, plastic anisotropy, microstructure

* Corresponding author. Tel.: /
E-mail address: schoen@usp.br

Nonlinear deformation and failure analysis of laminated composites

Evgeny Lomakin[a,b,*], Boris Fedulov[b]

[a]*Lomonosov Moscow State University, 1 Leninskie Gory, Moscow, 119991 Russia,*
[b]*Moscow Aviation Institute, Aircraft Design Center, 4 Volokolamskoe Road, Moscow,125993 Russia,*

Abstract

An approach to the characterization of different types of nonlinearity in the behavior of composite materials is proposed. One of them is concerned usually observed in experimental studies the dependence of deformation properties of composite materials on the type of external forces. Another type of nonlinearity lies in the fact that the shear stress-strain curves are nonlinear, though they are linear ones when the load is applied along the reinforcement. To describe these effects, the additional matrix is introduced into the proposed constitutive relations. There are different mechanisms of deformation of these materials, which are dependent on the type of reinforcement, matrix properties, loading conditions, directions of loads with respect to reinforcement and some others. These mechanisms and their interactions determine the stress-strain behavior of materials that influence the damage evolution and fracture properties of composite materials. To describe the damage accumulation process, the system of general failure model assumptions is formulated that include the choice of first ply failure criterion, constitutive relations for damaged materials with the use of corresponding damage parameters, the dependence of first ply failure criterion and elastic properties on the damage rate parameters and others. Some particular models are considered taking into account different types of nonlinearities, Lomakin et al. (1981, 2007, 2014, 2015 and 2017). This approach is verified using complex loading experiments. The theoretical dependencies obtained on the base of proposed models are compared with the results of experimental studies and good correspondence of them is shown. The proposed approach to the formulations of constitutive models from simple to more complex ones allows to describe adequately the behavior of composite materials under different loading conditions with the necessary precision.

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Keywords: Failure analysis, laminate composite, nonlinear effects

* Corresponding author. Tel.: /
E-mail address: lomakin@mech.math.msu.su

Dynamic fragmentation of ice spheres: Two specific fracture patterns

Koji Uenishi[a,b], Tomoya Yoshida[b,*], Ioan R. Ionescu[c], Kojiro Suzuki[a,b]

[a]*Department of Advanced Energy, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, 277-8561 Chiba, Japan*
[b]*Department of Aeronautics and Astronautics, The University of Tokyo, 7-3-1 Hongo, Bunkyo, 113-8656 Tokyo, Japan*
[c]*Galilee Institute, University Paris 13, 99 Avenue Jean-Baptiste Clément, 93430 Villetaneuse, France*

Abstract

Although ice materials are commonly found not only in our daily life on the earth but also in space, e.g. in the rings of Saturn, their fracture mechanisms, especially those in a dynamic range, have not been fully clarified. In our previous investigation, therefore, collision of a brittle ice sphere (diameter 25, 50 or 60 mm) that is free falling against a fixed plate of ice or polycarbonate has been experimentally observed using high-speed digital video cameras at a frame rate of up to 150,000 frames per second. It has been recognized that there exist basically only two specific fracture patterns generated by this dynamic impact: (i) “Top”-type fracture, normally at a relatively smaller impact speed, where only the bottom surface areas of a sphere are fragmented into small pieces by the impact at bottom and a relatively large top-shaped portion is left unbroken; and (ii) “orange segments”-type in which rather flat fracture planes extend approximately along the central axis of the sphere and split the sphere into three or four larger segments of comparable size. Preliminary comparison of the experimental findings with linear elastic wave fields obtained numerically by three-dimensional finite difference calculations suggests two distinct spatiotemporal scales: (1) The “top” fracture pattern is induced by the propagation of surface waves with relatively shorter wavelengths from the bottom along the free surface of the sphere, quickly producing fracture only near the bottom; (2) In the “orange segments” -type fracture, a longer contact time makes largely stressed regions enlarge more slowly and widely (quasi-statically-like) and larger fracture planes develop along the axis of the sphere. The above speculations seem to be supported by recent computations adopting the Discontinuous Galerkin (DG) method that treat more rigorously the mechanics of dynamic contact between the sphere and plate.

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Keywords: Ice; mechanics of dynamic contact; wave interaction

* Corresponding author. Tel.: /
E-mail address: yoshida@dyn.t.u-tokyo.ac.jp

Applied problems of fracture mechanics, resource and safety of technical systems

Vladimir Moskvichev[a,*]

[a]*Institute of Computational Technologies SB RAS, Krasnoyarsk Branch Office*

Abstract

The main trends in the development of complex technical systems are considered, including problems of technogenic safety, structural materials science, reliability and risk analysis. On the basis of statistical data on the causes of failures of technical systems (TS) of various applications and technological equipment in the "man-machine-environment" system, three groups of limit states (LS) are formulated:

- normative types of limit states (strength under static, dynamic and cyclic loading, plastic deformation, stability loss);
- limit states of technical systems with defects (brittle, quasi-brittle and ductile fracture, initiation and propagation of fatigue and corrosion-mechanical cracks);
- limit states of emergency situations (loss of load bearing capacity by 50…90%, of service life by 1…2 order, formation of secondary fracture factors).

For the analysis of these limiting states, the criterial correlation of fracture mechanics and reliability theory is given; the results of experimental determination of the characteristics of the mechanics of elastoplastic fracture of steels and aluminum alloys have been proposed.

Computational and experimental methods and algorithms for the analysis of elastoplastic fracture of TS elements and resource design of welded structures by the criteria of fracture mechanics have been developed. Based on methods of fracture mechanics, reliability theory and risk analysis, a number of applied problems have been solved:

- evaluation of reliability functions and risk of welded joints of the VVR-1000 reactor;
- determination of the critical and allowable size of defects of boron-aluminum elements of truss structures of space vehicles;
- computational and experimental justification of the strength and reliability of metal-composite high-pressure tanks for electric propulsion engines of heavy-class satellites;
- verification calculations of load bearing capacity of truss constructions of starting rocket and space complex;
- examination of the causes of accidents of the hydroelectric unit of the Sayano–Shushenskaya hydroelectric power station.

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Keywords: fracture mechanics, resource, safety of technical systems, reliability theory, risk analysis

* Corresponding author. Tel.: /
E-mail address: efedorova@sfu-kras.ru

Fatigue testing at 1000 Hz testing frequency

Markus Berchtold[a,*], Ingbert Klopfer[a]

[a]*RUMUL Russenberger Prüfmaschinen AG Switzerland*

Abstract

In 2014 RUMUL could present a new resonant fatigue testing machine, with a testing frequency of 1000Hz. The dynamic load of maximum 50kN peak-peak is produced with an electromagnetic system. Similar to established resonant systems which run on testing frequencies from about 40 up to 250H. The static portion of the load is provided by a mechanical spindle, the maximum load of the system is +/- 50kN. Any load ratio can be selected. Flat and round specimen types that are normally used in fatigue testing can be used. The new testing machine offers new possibilities for investigations of material properties in the very high cycle fatigue (VHCF) regime. Compared to other systems used in the field of VHCF testing the RUMUL GIGAFORTE provides several advantages. The size of the machine is smaller and energy consumption less compared to a servo hydraulic system. The actually tested material volume is larger than the material volume that is tested on ultrasonic systems. The testing frequency of 1000Hz allows normally continuous testing, without stopping for cooling down the specimen.
In the past three years the new testing machine was intensively used for example at the laboratory of the Fraunhofer institute IWS Dresden in Germany. Effects of the 1000Hz testing frequency on the fatigue behaviour of the material were observed. This talk shows some example of heating up of the specimen related to the 1000Hz testing frequency and highlights some of the found frequency related effects on fatigue strength.

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Keywords: New resonant fatigue testing machine; giga cycle (VHCF); frequency effects

* Corresponding author. Tel.: /
E-mail address: mberchtold@rumul.ch

Numerical modelling of flexural fatigue behavior of lightweight laminated cementitious composites

Asad Hanif[a,]*, Pavithra Parthasarathy[a], Zeyu Lu[b], Muhammad Usman[c], Zongjin Li[b]

[a]*The Hong Kong University of Science and Technology*
[b]*Institute of Applied Physics and Materials Engineering, University of Macau (UM), Taipa, Macau, S.A.R, China*
[c]*School of Civil and Environmental Engineering, National University of Science and Technology, Islamabad Pakistan*

Abstract

In this paper, numerical modelling of flexural fatigue behavior of lightweight laminated cementitious composites (LCCs) is done to predict the corresponding failure fatigue lives. LCCs were developed by incorporating fly ash cenosphere (FAC) as lightweight filler material (in various weight fractions of 40 %, 50 %, and 60 %), and PVA fibers as discontinuous reinforcement in the matrix, while galvanized iron (GI) welded wire mesh and fiber glass (FG) as primary continuous reinforcement. Both single and double layer reinforced LCC composites were cast. The developed composites were tested for static flexural strength as well as flexural fatigue strength under three – point flexural loading. The fatigue lives, thus, determined at various stress levels and stress ratios were used to develop S-N relationships, and equations were proposed to predict the flexural fatigue strength of LCCs. The results suggested that the probabilistic distribution of fatigue life of ferrocement can be modeled by two-parameter Weibull distribution. Thus, the Weibull distribution was further employed to incorporate the failure probabilities into the fatigue life of LCC. The fatigue lives corresponding to different failure probabilities have been calculated and the data so obtained have been used to generate Pf-S-N diagrams. The obtained results were further validated by ProFatigue and artificial neural networks (ANN) modelling, for probabilistic assessment of experimental fatigue data sets. It is found that FAC is useful in producing structural lightweight LCC elements with enhanced ductility and improved flexural fatigue characteristics. Moreover, theoretical modelling by ProFatigue and ANN elucidates two-parameter Weibull distribution model.

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Keywords: Flexural fatigue, laminated composites, fly ash cenosphere, cement-based composite, theoretical modelling

* Corresponding author. Tel.: /
E-mail address: asadhanif193@gmail.com

Hydrogen effects on the formation of nickel based superalloys cutting and wear products

Balitskii Alexander[a,*], Valerii Kolesnikov[a]

[a]Karpenko Physicomechanical Institute, Ukrainian National Academy of Science, Lviv, Ukraine

Abstract

The life cycle of advanced gas turbine structural elements consists of the manufacture (including mechanical processing) and their subsequent operation (for example under friction conditions). One of the key process is applocation of lubricant cooling liquids (LCL) for the machining of turbine parts: high speed cutting (HSC), high performance cutting (HPM) and high dynamic cutting (HDC). They are intended for lubrication of friction surfaces, cooling of a cutting tool and machined workpieces by HSC, facilitating the process of metal deformation, timely removal the chip from cutting area and tools of wear during HDC, as well as for the temporary corrosion protection of equipments after HPM. Due to this LCL has increases the stability of the cutting tool, improves the quality of the products, reduces the cutting power and the required power. The high degree of steels and alloys alloying has a great influence on their processing due to the formation on the basis of alloying elements the dispersed phases, solidifying the solid solution of the alloy, or of such solid component structures as nitrides, carbides, intermetallic compounds, which intensively wear out cutting tools. It is known that nickel alloys are difficult for mechanical treatmeny. One of the reasons is their tendency to slander, and a slight deformation leads to a strong strengthening of the metal. The effect of LCL on the formation of chips for high-strength nickel superalloys has investigated. The high nickel content leads to increased of viscosity and the formation of long chips, which worsen the processing conditions. But the application of LCL has affect the morphology of chips due to the hydrogen effects. It has been established that LCL application has reduces surface roughness (in comparison with dry cutting) by 20 times. LCL application containing the different substances changes, like the chip morphology and surface roughness. The observed hydrogen concentration is closely correlated with the roughness of the surface. The maximum detected hydrogen concentration (12 ppm) in the chips coincides with an increase in surface roughness compared with concentrations corresponding to the application of LCL with sunflower oil. It has established that in the conditions of LCL application hydrogen has enters to chips material and involved in changing the mechanisms of alloys destruction. It is clear that the morphology of wear products should be addressed to identify fracture processes, such as friction.

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Keywords: Nickel based superalloys, cutting products, wear products, steels, hydrogen, alloys destruction, wear, cutting, hydrogen concentration

* Corresponding author. Tel.: /
E-mail address: abalitskii@hotmail.com

Damage tolerance in biological and metallic materials

Robert Ritchie[a,]*

[a]*University of California, Berkeley, Unites States of America*

Abstract

The ability of a material to undergo limited deformation is a critical aspect of conferring toughness as this feature enables the local dissipation of high stresses which would otherwise cause fracture. The mechanisms of such deformation can be widely diverse. Although plasticity from dislocation motion in crystalline materials is most documented, inelastic deformation can also occur via in situ phase transformations in certain metals and ceramics, sliding of mineralized collagen fibrils in tooth dentin and bone, rotation of such fibrils in skin, frictional motion between mineral “platelets” in seashells, and even by mechanisms that also lead to fracture such as shear banding in glasses and microcracking in geological materials and bone. Resistance to fracture (toughness) is thus a compromise - a combination of two, often mutually exclusive, properties of strength and deformability. It can also be considered as a mutual competition between intrinsic damage processes that operate ahead of the tip of a crack to promote its advance and extrinsic crack-tip shielding mechanisms that act mostly behind the crack tip to locally diminish crack-tip stresses and strains. Here we examine the interplay between strength and ductility and between intrinsic and extrinsic mechanisms in developing toughness in a range of biological and natural materials, including bone, skin and fish scales, and in certain advanced, multiple-element, metallic alloys, including bulk-metallic glasses, where the atomic origins of their damage-tolerance can be found in their short-range order, and high-entropy alloys, some of which represent the toughest metallic materials on record.

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Keywords: Strength, toughness, plasticity, fracture, skin, bone, bulk-metallic glasses, high-entropy alloys

* Corresponding author. Tel.: /
E-mail address: roritchie@lbl.gov

Trapping states of hydrogen and hydrogen embrittlement of high strength steels

Kenichi Takai[a,]*, Hiroshi Suzuki[a]

[a]*Sophia University, Tokyo, Japan*

Abstract

To clarify the function of hydrogen in embrittlement of high strength steels, determination of hydrogen trapping sites, dynamic behaviour of hydrogen during deformation and strain-induced lattice defects enhanced by hydrogen are important. In the present paper, the determination of hydrogen trapping sites in iron and steels using thermal desorption spectrometry heated from lower temperature (L-TDS), the interaction between dislocations and hydrogen, evaluation of strain-induced lattice defects associated with hydrogen such as vacancies and its clusters, and their relevance to hydrogen embrittlement are discussed. For the determination of hydrogen trapping sites, L-TDS makes it possible to separate hydrogen desorption peaks corresponding to various lattice defects such as dislocations, grain boundaries and vacancies in iron and steels. For the interaction between dislocations and hydrogen, hydrogen desorption seldom increases under elastic deformation. In contrast, it increases rapidly after the proof stress when plastic deformation begins, reaches its maximum, and then decreases gradually with increasing applied strain. This desorption behaviour is probably closely related to moving dislocations during plastic deformation and depends on the dislocation type such as edge or screw dislocations and dislocation mobility. For the evaluation of strain-induced lattice defects associated with hydrogen, subjecting plastic strain in the presence of hydrogen increases the amount of lattice defects corresponding to vacancies. In contrast, the presence of hydrogen has no effects on the formation of lattice defects under subjecting elastic stress. These findings indicate that the lattice defects enhanced by hydrogen affect the fracture in plastic region with hydrogen.

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Keywords: Hydrogen, hydrogen embrittlement, thermal desorption spectrometry, dislocation, vacancy, high strength steel

* Corresponding author. Tel.: /
E-mail address: takai@me.sophia.ac.jp

Statistical regularities of the parameter scatter of the crack growth rate equation in service life estimation

Natalia Chernyakova[a,*]

[a]Institute of Computational Technologies of SB RAS (ICT SB RAS), Kemerevo, Russia

Abstract

The influence of parameter scatter of fatigue crack growth rate model on calculation of service life of structural elements was studied using statistical modeling approach. A modified multiparametric model of fatigue crack growth was used for the case of two-frequency loading. The effect of the scattering of the model parameters on the crack growth rate was estimated. The studied parameters included the initial crack length, the stress amplitude, the yield stress, and the critical stress intensity factor. Numerical simulation was performed by the Monte Carlo method. Based on the calculation results, the probability distribution functions were constructed for the service life of structural elements under two-frequency loading. Calculations were performed for typical welded joints, elements of crane structures and pressure vessel.

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Keywords: Fatigue crack model, growth rate, Monte Carlo, structural elements

* Corresponding author. Tel.: /
E-mail address: fortuna@ict.nsc.ru

Multiscale model of mechanical behavior of ceramics composite with soft matter filling based on movable cellular automaton

Alexey Smolin[a,b], Evgeny Shilko[a,b], Anna Shalomeeva[b,*]

[a]*Institute of Strength Physics and Materials Science SB RAS, pr. Akademicheskiy 2/4, Tomsk, 634055, Russia*
[b]*Tomsk State University, pr. Lenina 36, Tomsk, 634050, Russia*

Abstract

In this paper, movable cellular automaton method (MCA) is applied to the multiscale simulation of 3D samples of ceramics composite with soft matter filler. MCA is an efficient numerical method in particle mechanics, which assumes many-particle interaction among discrete elements and makes a feasible simulation of solid behavior including deformation, crack initiation and propagation, and further fragmentation of the material at different scales. The lowest scale of the proposed model corresponds to the characteristic size of the smallest pores/inclusions. Herein we start with modeling uniaxial compression of several representative ceramics samples with an explicit account of small pores randomly distributed in space. The results are the average values of Young's modulus, Poisson's ratio, and strength, as well as the parameters of the Weibull distribution of these properties at the current scale. The data obtained allow us to describe the material behavior at the next scale were large cylindrical inclusions are considered explicitly, while the influence of small pores is accounted via the effective properties determined at the previous scale. The simulation results show that for each value of volume fraction of cylindrical soft inclusions there is no scattering of elastic modulus values while the scatter of strength and Poisson's ratio values is significant. Random orientation of soft elongated inclusions results in higher strength value and does not change Young's modulus of the model composites.

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Keywords: Ceramics composites, cellular automation, cylindrical soft inclusions

* Corresponding author. Tel.: +7-3822-286-975; fax: +7-3822-492-576.
E-mail address: asmolin@ispms.tsc.ru

Fracture behavior of roll bonded Al-brass-Al multilayer composites – Concept of the maximum undamaged defect size (d_{max})

Saeed Mousa[a,*], Amr A. Abd-Elhady[a,b], Gap-Yong Kim[c], Hossam El-Din M. Sallam[a,d]

[a]*Faculty of Engineering, Jazan University, Jazan 706, Kingdom of Saudi Arabia.*
[b]*Department of Mechanical Design, Mataria, Helwan University, Cairo 11718, Egypt.*
[c]*Department of Mechanical Engineering, Iowa State University, Ames, IA 50011, USA*
[d]*Department of Materials Engineering, Zagazig University, Zagazig 44519, Egypt*

Abstract

Multilayer sandwich composites consisting of two skin metals and perforated interlayer are rapidly becoming a good substitute for metal structures, especially in the automobile industry. Their good mechanical properties including excellent fatigue and impact strength, as well as damage tolerance, are accomplished. In this study, aluminum-perforated brass-aluminum sandwich composites are fabricated using roll bonding technique. Samples were made at different surface roughness, and their bonding behavior was investigated using peel test. The fracture behavior under mode-I was investigated. The effect of surface roughness (two different sand paper grits 50 and 80) on the fracture energy of mode-I peeling failure is studied experimentally. It is found that, the peeling resistance increased with increasing the surface roughness. To simulate the progressive failure of this sandwich composite, 3-D finite element model is employed in the present work. Virtual-Crack-Closing-Technique (VCCT) debonding model has been adopted to predicate the peeling failure in such sandwich composite. The concept of the maximum size of undamaged defect (d_{max}) has been adopted to predict the effect surface roughness on peeling load numerically. The numerical and experimental results showed an agreement between them. Therefore, the present 3D finite element model can be considered as a good candidate to expect the peeling damage in sandwich composites.

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Keywords: Roll bonding; metal/metal multilayer; brass-aluminum sandwich composites; maximum size of undamaged defect

* Corresponding author. Tel.: +966-5375-55599; fax: +966-17-329-7003.
E-mail address:dr.saeed.mousa@gmail.com

Molecular dynamics study of the influence of nonhydrostatic stress on the diffusion behavior of hydrogen in bcc-Fe

Ryosuke Matsumoto[a,*], Shunki Nagase[a], Shinya Taketomi[a]

[a]*Kyoto University, Kyoto, Japan*

Abstract

The precise estimation of hydrogen distribution and its time evolution in materials are important to predict materials behavior under hydrogen atmosphere. It is well known that the hydrogen diffusion occurs toward high hydrostatic-stress regions such as in front of mode I crack. Hence, various computer simulations which incorporated the effect of hydrostatic stress have been performed [1]. On the other hand, Taketomi et al. revealed the importance of nonhydrostatic stress on the hydrogen diffusion and distribution in bcc-Fe through molecular dynamics (MD) simulations of hydrogen diffusion around an edge dislocation [2]. Here, we first evaluated the diffusion coefficient and activation energy of hydrogen diffusion in bcc-Fe under various stress states by using MD simulations. It became clear that the diffusion coefficient of hydrogen has strong dependence on the uniaxial stress along <100> direction, and pronounced difference of the coefficients appears between tensile and orthogonal directions. The cause of the effects is anisotropic shape of octahedral (O-) site in bcc lattice: the change of the anisotropy of O-site by stress changes the stability of hydrogen at the site and influences the energy barrier of hydrogen diffusion between two neighboring tetrahedral sites. The activation energy of hydrogen diffusion along loading direction increases under tensile load, and it decreases under compressive load. On the other hand, the activation energy of hydrogen diffusion along orthogonal directions to loading direction increases under both tensile and compressive uniaxial load. Based on the MD results, we extracted an equation which gives the diffusion coefficient of hydrogen under arbitrary stress state, and confirmed the accuracy of the equation by comparing with the MD result of hydrogen diffusion under combined stress

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Keywords: Hydrogen, diffusion,hydrostatic stress, molecular dynamics, anisotropy

* Corresponding author. Tel.: /
E-mail address: matsumoto.ryosuke.6r@kyoto-u.ac.jp

Crystallographic orientation-dependent growth mode of microstructurally fatigue small crack in a laminated Ti-6Al-4V alloy

Akira Maenosono[a,*], Motomichi Koyama[a], Yoshihisa Tanaka[b], Shien Ri[c], Qinghu Wang[c], Hiroshi Noguchi[a]

[a]*Graduate School of Engineering, Kyushu University, 744 Motooka Nishi-ku Fukuoka 819-0395, Japan*
[b]*National Institute for Materials Science, 1-2-1 Sengen, Tsukuba, Ibaraki 305-0047, Japan*
[c]*National Institute of Advanced Industrial Science and Technology, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8560, Japan*

Abstract

The fatigue life of Ti–6Al–4V alloy exhibits significant scatter, which is derived from the statistical scatter of uncontrollable material factors. In particular, crack propagation behaviors in microstructurally small cracks strongly depend on material factors. It is necessary to understand the mechanisms underlying the scatter of fatigue properties. In this study, the dominant material/mechanical factors of microstructurally small fatigue crack growth behaviors are extracted, and the mechanisms of fatigue crack propagation life scatter derived from them are clarified. A Ti–6Al–4V billet was studied in which the microstructure was fully laminated with α and β phases. The major constituent phase was α. Microstructurally small artificial defects were introduced at a center of prior β grains by a focused ion beam (FIB). A fatigue test was carried out at a stress ratio $R = 0$, stress amplitude $\sigma_a = 400$ MPa, and frequency 1.3×10^{-2} Hz in a vacuum using scanning electron microscopy (SEM). In situ SEM observation was carried out around each FIB notch. After the fatigue test, the dependence of the crack growth path on crystallographic orientation was investigated by using electron backscattered diffraction. It was found that microstructurally small crack growth behaviors depended on crystallographic orientation. The dominant crack growth mechanism was the mode II crack growth mechanism by shear stress along the basal plane as a driving force. The dominant factor that causes large scatter of fatigue life in a α- Ti–6Al–4V alloy is the difference in resolved shear stress along the basal plane. Specifically, the difference in the angle between the basal plane and loading direction, the low reproducibility of the mode II crack growth mechanism, and the random position of pre-existing damage cause the scatter of fatigue crack growth rate.

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Keywords: Fatigue crack growth, microstructurally-small crack, in situ microscopic observation, Ti–6Al–4V alloy, fully laminated microstructure

* Corresponding author. Tel.: +81-92-802-7677; fax: +81-92-802-0001.
E-mail address: 2te17692@s.kuyshu-u.ac.jp

Temporal effects of dynamic yielding under high-rate loading

N.S. Selyutina[a,b,*], Yu.V. Petrov[a,b]

[a]Saint Petersburg State University, 7/9, Universitetskaya nab., St. Petersburg, 199034, Russia
[b]IPME RAS, Extreme States Dynamics Department, V.O., Bolshoj pr., 61, St. Petersburg, 199178, Russia

Abstract

A modeling of various effects of high-rate plastic deformation of metals on the basis of the relaxation model of plasticity is considered. It is shown that the relaxation model of plasticity is an effective tool to describe both temporal dependencies of the yield stress and a well-known yield stress drop effect on the deformation curve from the united viewpoint. One of the problems is that the classical Johnson-Cook model and its modifications describe only gradient junction on the stage of plastic deformation utilizing a smooth degree function of hardening. For higher strain rates, e.g. above 1000 1/s, modifications of these empirical models for prediction of the yield strength are required. A comparison of material hardening parameters of the modified Johnson-Cook model and parameters calculated within the relaxation model of plasticity is given.

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Keywords: High-rate loading, yield stress, characteristic relaxation time, dynamics, metals

* Corresponding author. Tel.: /
E-mail address: nina.selutina@gmail.com

The water-saturation effect for concretes and rocks subjected to high strain rates

N.S. Selyutina[a,b,*], Yu.V. Petrov[a,b]

[a]Saint Petersburg State University, 7/9, Universitetskaya nab., St. Petersburg, 199034, Russia
[b]IPME RAS, Extreme States Dynamics Department, V.O., Bolshoj pr., 61, St. Petersburg, 199178, Russia

Abstract

The behavior of dynamic strength of concrete and rocks (granite, tuff) is analyzed using structural-temporal approach. An influence of a saturation ratio on characteristic strength parameters of investigated materials is considered. The dynamic tensile strength and the compressive strength of saturated and unsaturated rocks under quasi-static and dynamic loading are compared. An increase of dynamic strength measured in terms of the incubation time parameter with the growth of the saturation ratio is studied and explained.

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Keywords: ultimate stress; incubation time; saturation ratio

* Corresponding author. Tel.: /
E-mail address: nina.selutina@gmail.com

Strain rate sensitivity of microstructural damage evolution in a dual-phase steel pre-charged with hydrogen

Tsubasa Kumamoto[a,]*, Motomichi Koyama[a], Kaneaki Tsuzaki[a,b]

[a]*Department of Mechanical Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan*
[b]*Hydrogenious, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan*

Abstract

We evaluated the strain rate sensitivity of the micro-damage evolution behavior in a ferrite/martensite dual-phase steel. The micro-damage evolution behavior can be divided into three regimes: damage incubation, damage arrest, and damage growth. All regimes are associated with local deformability. Thus, the total elongation of DP steels is determined by a combination of plastic damage initiation resistance and damage growth arrestability. This fact implies that hydrogen must have a critical effect on the damage evolution, because hydrogen enhances strain localization and lowers crack resistance. In this context, the strain rate must be an important factor because it affects the time for microstructural hydrogen diffusion/segregation at a specific microstructural location or at the damage tip. In this study, tensile tests were carried out on a DP steel with different strain rates of 10^{-2} and 10^{-4} s^{-1}. We performed the damage quantification, microstructure characterization and fractography. Specifically, the quantitative data of the damage evolution was analyzed using the classification of the damage evolution regimes in order to separately elucidate the effects of the hydrogen on damage initiation resistance and damage arrestability. In this study, we obtained the following conclusions with respect to the strain rate. Lowering the strain rate increased the damage nucleation rate at martensite and reduced the critical strain for fracture through shortening the damage arrest regime. However, the failure occurred via ductile modes, regardless of strain rate.

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Keywords: Hydrogen embrittlement; dual-phase steel; quantitative damage analysis

* Corresponding author. Tel.:+81-92-802-3288.
E-mail address: 2TE17831S@s.kyushu-u.ac.jp

Localized plasticity and associated cracking in stable and metastable high-entropy alloys pre-charged with hydrogen

Kenshiro Ichii[a,*], Motomichi Koyama[a], Cemal Cem Tasan[b], Kaneaki Tsuzaki[a, c]

[a]*Department of Mechanical Engineering, Kyushu University, Japan*
[b] *Department of Materials Science and Engineering, Massachusetts Institute of Technology, USA*
[c]*Hydrogenious, Kyushu University, Japan*

Abstract

We investigated hydrogen embrittlement in Fe20Mn20Ni20Cr20Co and Fe30Mn10Cr10Co (at.%) alloys pre-charged with 100 MPa hydrogen gas by tensile testing at three initial strain rates of 10^{-4}, 10^{-3}, and 10^{-2} s^{-1} at ambient temperature. The alloys are classified as stable and metastable austenite-based high-entropy alloys (HEAs), respectively. Both HEAs showed the characteristic hydrogen-induced degradation of tensile ductility. Electron backscatter diffraction analysis indicated that the reduction in ductility by hydrogen pre-charging was associated with localized plasticity-assisted intergranular crack initiation. It should be noted as an important finding that hydrogen-assisted cracking of the metastable HEA occurred not through a brittle mechanism but through localized plastic deformation in both the austenite and ε-martensite phases

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Keywords: High-entropy alloy; hydrogen embrittlement; martensitic transformation; austenitic steels; hydrogen desorption

* Corresponding author. Tel.: /
E-mail address: 2te17807s@s.kyushu-u.ac.jp

Modelling of dynamic crack propagation on concrete matrix-aggregate interface

Baijian Wu[a,b], Keke Tang[c,*]

[a]*Department of Engineering Mechanics, Southeast University, Nanjing 210096, China.*
[b]*Jiangsu Key Laboratory of Engineering Mechanics, Southeast University, Nanjing 210096, China*
[c]*School of Aerosapce Engineering and Applied Mechanics, Tongji University, Shanghai 200092, China*

Abstract

This paper is focused on the formulation of a numerical model for dynamic crack propagation on concrete aggregate interface. The concept of energy release rate is incorporated in the algorithm that is conducted in Abaqus through Python script interface. The proposed model is capable of manipulating free propagation of interface cracks. Thus, the on-surface growth of the interface crack, as well as the crack penetration into the concrete matrix, are successfully implemented. A case in point is the rupture behavior of concrete matrix containing one-single aggregate. Simulation of one matrix containing an isolated aggregate was conducted. Influence of the side-edge constraint, the aggregate direction as well as the fracture energy of the interface, was investigated. The results show that, tensile constraint on the side edge, a smaller angle between tensile axis and aggregate, and higher fracture energy could lead to a higher rupture strength of the interface. Once the interface starts to grow, it immediately and unstably propagates to the two ends of the aggregate major axis, and further enters the matrix. The three factor influences less on the character of above rupture path. Though the conclusion is prudently stipulated to concrete matrix with single aggregate, the numerical model can be also further modified to study the trans-scale propagations of multiple cracks in concrete materials or components.

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Keywords: Concrete rupture; dynamic crack propagation; matrix-aggregate interface; fracture energy; interfacial crack; trans-scale propagation; energy release rate

* Corresponding author. Tel.: +86-21-65982267; fax: +86-21-65983267.
E-mail address: kktang@tongji.edu.cn

Fatigue behaviour of additively manufactured polylactide (PLA)

O.H. Ezeh[a], L. Susmel[a,*]

[a]*Department of Civil and Structural Engineering, The University of Sheffield, Mappin Street, Sheffield, S1 3JD, United Kingdom*

Abstract

Additive manufacturing (AM) is a group of fabrication techniques through which materials are joined, usually layer upon layer, to make objects from three-dimensional virtual models. Owing to its unique features, this disruptive technology is set to transform the way designers across all engineering disciplines engage with manufacturing. Since this fabrication process affect the way materials behave under static, dynamic and time-variable loading, it is evident that the mechanical performance during in-service operation of additively manufactured (AM) materials must be studied in depth in order to effectively de-risk their usage in situations of engineering interest. Not only by running appropriate experiments, but also by re-analyzing a number of data sets taken from the literature, the present paper investigates the influence of raster orientation as well as of non-zero mean stresses on the fatigue behavior of AM polylactide (PLA). PLA is a biodegradable polymer that can be 3D printed easily and at a relatively low cost. As far as objects are manufacture flat on the build plate, the results being obtained suggest that: (i) the effect of the raster direction can be neglected with little loss of accuracy; (ii) the presence of non-zero mean stresses can be modelled effectively by simply using the maximum stress in the cycle.

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Keywords: Additive manufacturing; polylactide (PLA); fatigue; mean stress effect, raster orientation

* Corresponding author. Tel.: /
E-mail address: l.susmel@sheffield.ac.uk

Crack path stability in brittle fracture under pure mode I loading

M.R. Ayatollahi[a,*], S.M.J. Razavi[b], F. Berto[b]

[a]*Fatigue and Fracture Lab., Centre of Excellence in Experimental Solid Mechanic and Dynamics, School of Mechanical Engineering, Iran University of Science and Technology, Narmak, 16846, Tehran, Iran.*
[b]*Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology (NTNU), Richard Birkelands vei 2b, 7491 Trondheim, Norway*

Abstract

The crack growth path is expected to be along the initial crack line when the pre-cracked components possess symmetric geometry and loading conditions relative to the crack line. However, it has been previously shown that in some mode I specimens the path of crack growth is not stable and deviates from its initial line after some stages of crack growth. The aim of this paper is to develop an energy-based theoretical model for predicting the instability in the path of crack growth. The theoretical model takes into account both the singular term of stress ahead of the crack tip and the first non-singular term known as the T-stress. The corresponding two-term stresses are replaced in the energy relation around the crack tip and a model is extracted for predicting instability of crack path under mode I loading. The results obtained from the energy-based criterion was then compared to the results obtained from the well-known Generalized Maximum Tangential Stress (GMTS) criterion, which is a two-parameter stress-based fracture criterion that considers the effect of T-stress. To validate the theoretical model, the experimental results published recently from fracture test on several mode I cracked specimens are used. Very good prediction is provided for the path of crack growth in these specimens. It is shown the crack path instability is significantly geometry dependent and can be prevented by modifying the specimen geometry or loading type. The results obtained in this research are important because an appropriate knowledge about the stability of crack path and fracture trajectory can play a key role on the extent of damage that occurs in a cracked structure when it experiences mode I brittle fracture.

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Keywords: Brittle fracture; crack growth instability; crack growth path; strain energy density.

* Corresponding author. Tel.: +98-21-77240201; fax: +98-21-77240488.
E-mail address: m.ayat@iust.ac.ir

Microstructural and numerical analysis of fracture mechanisms in a thermal barrier coating system on Ni-based superalloys

Elena Fedorova[a,b,*], Andrey Burov[b], Nadezhda Sukhodoeva[a], Vladimir Moskvichev[b]

[a]*Siberian Federal University, Krasnoyarsk 660041, Russia*
[b]*Institute of Computational Technologies SB RAS, Krasnoyarsk Branch Office, Krasnoyarsk 660049, Russia*

Abstract

The numerical analysis of factors governing the magnitude and distribution of residual thermal stress in an oxide/metal system was carried out regarding industrial applications of Ni-based superalloys protected with the thermal barrier coating system (TBC). The particular emphasis was paid on the microstructural characterization of damaging behavior of the α-Al_2O_3 thermally grown oxide (TGO) and the integrity along the TGO/NiCoCrAlY-bond coat and TGO/ZrO_2-Y_2O_3 top coat interfaces which are the key to successful application of TBC systems.
The cross-sections of samples after the high temperature cyclic oxidation tests at 1100 °C in air were characterised by SEM-EDS to study the fracture mechanisms and to model the TBC system. The data on the TGO thickness, its uniformity, chemical and phase compositions, spallation occurrence, and geometry of the interfaces were obtained.
The numerical analysis of residual thermal stress was run for five different cooling rates using a finite element model. The following parameters influencing the stress state developed during cooling from the oxidation temperature were considered: physical and mechanical properties of the components, geometry of the interface including roughness and thickness. All the material layers were assumed to creep at elevated temperature. Finally results have been discussed in relation with creep mechanisms for TBCs layer.

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Keywords: Ni-based syperalloy; TBC; interface; residual thermal stress; FEM

* Corresponding author. Tel.: +7-913-532-7455.
E-mail address: efedorova@sfu-kras.ru

Hydrogen embrittlement in pipelines transporting sour hydrocarbons

G. Gabetta[a,]*, F. Pagliari[a], N. Rezgui[b]

[a]Eni SpA, Via Emilia 1, 20097 San Donato Milanese (Mi) Italy
[b]Eni Intern.Res. Ltd, AKSAI, Kazachstan

Abstract

Lamination-like defects in pipeline steels can be of both metallurgical and operational origin.
In pipelines transporting hydrocarbon usually such defects are not a big challenge since they do not propagate under operating conditions. Nonetheless, in presence of a corrosion phenomenon and sour gas (H_2S), it is possible to observe blisters and cracks which may propagate in the steel. The observed damage mechanisms is Hydrogen Embrittlement and in spite of a huge amount of study and publications available, it is quite difficult for a pipeline owner to get practical data (crack propagation rate for instance) allowing a reliable estimate of the fitness for service of a pipeline.
Taking advantage of a pipeline spool containing internal defects that was in service for more than 10 years and recently removed, a comprehensive study is underway to obtain a complete assessment of the pipeline future integrity.
The program is comprehensive of:

- Study and comparison of ILI reports of the pipeline, to determine the optimum interval between inspections
- Assessment of inspection results via an accurate nondestructive (UT) and destructive examination of the removed section, to verify ILI results
- Lab tests program on specimens from the removed spool at operating conditions (75-80 bar and 30°-36° C) in presence of a small quantity of water, H_2S (5%) and CO_2 (7%), in order to assess defect propagation and to obtain an estimate of crack growth rate
- Test in field of available methods to monitor the presence of Hydrogen and/or the growth of defects in in-service pipelines

This quite ambitious program is also expected to be able of offering a small contribution toward a better understanding of HE mechanisms and the engineering application of such complex, often mainly academic, studies.

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Keywords: Pipeline steel, sour service, lamination

* Corresponding author. Tel.: +390252063407.
E-mail address: giovanna.gabetta@eni.com

Hydrogen embrittlement in advanced high strength steels and ultra high strength steels: a new investigation approach

Antonello Cherubini[a], Linda Bacchi[b,*], Serena Corsinovi[b], Michele Maria Tedesco[c], Marco Beghini[a], Renzo Valentini[a]

[a]*University of Pisa, Largo Lucio Lazzarino 2, Pisa, Italy*
[b]*Letomec Srl, Navacchio (PI), Italy*
[c]*Fiat Chrysler Automobiles, CRF Research Center, Orbassano (TO), Italy*

Abstract

In order to reduce CO_2 emissions and fuel consumption and to respect current environmental norms, the reduction of vehicles weight is a primary target of the automotive industry. Advanced High Strength Steels (AHSS) and Ultra High Strength Steel (UHSS), which present excellent mechanical properties, are consequently increasingly used in vehicle manufacturing. The increased strength to mass ratio compensates the higher cost per kg, and AHSS and UHSS are proving to be cost-effective solutions for the body-in-white of mass market products.
Aluminized boron steel can be formed in complex shapes with press hardening processes by which higher strength without distortion can be induced, thus increasing protection from crashes. On the other hand, the martensitic microstructure is sensitiveto hydrogen delayed fracture phenomena and the dew point reduction in the furnace can produce hydrogen consequently to the high temperature reaction between water and aluminum. The high temperature also promotes hydrogen diffusion through the metal lattice under the aluminum-silicon coating, thus increasing the diffusible hydrogen content. However, after cooling, the coating actsas a strong barrier preventing the hydrogen from going out of the component. These phenomena in crease the probability of delayed fracture. As this kind of failure brings to the rejection of the component during production, or, even worse, in operation, diffusible hydrogen absorbed in the component needs to be monitored during the production process.
For fast and simple measurements of the response to diffusible hydrogen of aluminized boron steel, HELIOS II, one of the HELIOS innovative instruments, was used. Unlike the Devanathan cell that need a double electrochemical cell, HELIOS II isbased on a single cell coupled with a solid-state sensor. The instrument is able to give an immediate measure of the the usible hydrogen content in steel sheets, semi-products or components, avoiding time-consuming palladium coating, and it can be appliedwith a simple procedure that requires virtually zero training.
Two examples of diffusible hydrogen analyses are given for UsiborR1500-AS, one before hot stamping/quenching, and one afterhot stamping/quenching. The results suggest that the increase in the number of dislocations during hot stamping could be the mainresponsible for the lower apparent diffusivity of hydrogen.

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Keywords: Hydrogen; HE; Usibor; boron steel; delayed fracture; SSRT; permeation; quenching; stamping; HELIOS;

* Corresponding author. Tel.: /
E-mail address: l.bacchi@letomec.com

The effect of microstructure constituents on the static and dynamic fracture behavior of high strength quenched and tempered martensitic steels

Frank Tioguem Teagho[a, b,*], Matthieu Maziere[a], Franck Tankoua[b], André Galtier[b], Anne-Françoise Gourgues-Lorenzon[a]

[a]*MINES ParisTech – PSL Research University – Centre des Matériaux – UMR CNRS 7633 – BP 87 – 91003 EVRY CEDEX, France.*
[b]*ASCO Industries – Centre de Recherche CREAS – BP 70045–avenue de France, 57301 HAGONDANGE CEDEX, France.*

Abstract

The aim of the present work is to contribute to a microstructural-based predictive tool of Charpy impact toughness for the design of new grades of quenched and tempered (QT) martensitic steels. The effect of carbides on the true strain to fracture under uniaxial tension has been extensively studied; but very little attention has been paid yet to the effect of carbides on the upper shelf energy (USE) of QT martensite. The present work focuses on the contribution of microstructural constituents, carbide in particular, to the fracture behavior in the USE domain of the ductile-to-brittle transition curve. A hot-rolled, martensitic 40CrMo4 steel bar, quenched from 875°C and tempered at 600°C was used. In order to keep similar matrix while varying the carbide precipitation state, an additional tempering at either 690°C or 720°C was applied to some specimen blanks. The three matrix microstructures and carbide populations were characterized in detail. The impact toughness, M_3C carbide size and intercarbide spacing were shown to increase with tempering temperature. Instrumented Charpy impact curves were used to derive the respective contributions of initiation energy and propagation energy to the overall fracture energy of each microstructure. The propagation energy gives a major contribution and a correlation has been proposed with the intercarbide spacing distribution. The reported results shed new light on the effect of carbide size and spatial distribution on the impact toughness behavior in the USE domain of QT martensitic steels.

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Keywords: High strength steel; martensite; impact toughness; carbides; ductile fracture

* Corresponding author. Tel.: +33 (0)1.60.76.30.49
E-mail address: frank.tioguem-teagho@mines-paristech.fr

Bio-inspired design ideas for improving the damage resistance

Otmar Kolednik[a,*], Roland Kasberger[a], Masoud Sistaninia[b], Darjan Kozic[b], Jozef Predan[c], Marko Kegl[c], Dieter F. Fischer[d], Peter Fratzl[e]

[a] *Erich Schmid Institute of Materials Science, Austrian Academy of Sciences,1030 Vienna*
[b] *Materials Center Leoben Forschung GmbH, 8700 Leoben, Austria*
[c] *Faculty of Mechanical Engineering, University of Maribor, 2000 Maribor, Slovenia*
[d] *Institute of Mechanics, Montanuniversität, 8700 Leoben, Austria*
[e] *Max-Planck Institute of Colloids and Interfaces, 14476 Potsdam, Germany*

Abstract

Many biological materials exhibit interesting mechanisms to increase their fracture toughness and damage resistance, see e.g. [1,2]. Deep-sea glass sponges utilize the so-called “material inhomogeneity effect” by having a multilayered microstructure consisting of hard bio-glass and thin, compliant protein interlayers. This type of composite architecture causes a strong decrease of the crack driving force when a crack enters the compliant interlayer, leading to crack arrest [3]. Arthropod cuticles or lamellar bones utilize “twisted plywood structures” [2]; these are fiber reinforced composites with a progressive rotation of the fiber direction so that crack propagation becomes very difficult. A methodology to determine the crack driving force for such structures has been recently presented [4]. The analysis shows that again local minima in the crack driving force appear which increase the fracture toughness.
Numerical investigations have been conducted in order to resolve these mechanisms and to apply such bio-inspired ideas for the improvement of technical materials. Hereby we have used the concept of configurational forces, which is a powerful tool for describing the behavior of defects in materials [3-6].
These bio-inspired mechanisms are effective only if the composite architectures fulfill certain design rules. Such design rules have been worked out, e.g. for improving the fracture toughness of inherently brittle matrix materials by implementing thin, soft interlayers; decisive architectural parameters are the thickness and the spacing of the interlayers [3,5].
Experiments have been conducted to check the theoretical findings. For example, various multilayer compounds consisting of two different types of high-strength steels as matrix materials and a low-strength steel as interlayer material were manufactured by hot-forging. Fracture mechanics experiments exhibit a strongly increased fracture toughness compared to the homogeneous matrix material [6].

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Keywords: Material inhomogeneity effect, fracture toughness, materials and composite design, concept of configurational forces

* Corresponding author. Tel.: +81-3-5841-6574; fax: +81-3-5841-6574.
E-mail address: Otmar.Kolednik@oeaw.ac.at

Dynamic fracture and wave propagation in a granular medium: A photoelastic study

Koji Uenishi[a,b], Tsukasa Goji[b,*]

[a]*Department of Advanced Energy, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, 277-8561 Chiba, Japan*
[b]*Department of Aeronautics and Astronautics, The University of Tokyo, 7-3-1 Hongo, Bunkyo, 113-8656 Tokyo, Japan*

Abstract

In our earlier work on the generation mechanisms of earthquakes and related failures, fracture phenomena were treated in the framework of continuum mechanics, and the existence of the universal critical condition for earthquake nucleation as well as the strong dependence of earthquake-induced structural failure patterns on the frequencies and types of incident seismic waves was pointed out. However, other significant seismic phenomena such as landslides and liquefaction may not be simply explained using the theories established for continuum media. For example, in order to clarify the physics of the formation of the geological flame structure, possibly due to liquefaction and ensuing gravitational instability in water-immersed sediments, the mechanical behavior of particles under dynamic load and the influence of waves, if any, on fracture should be understood for granular media beforehand. Here, as an initial investigation into wave and fracture propagation inside granular media, under dry conditions first of all, experimental technique of dynamic photoelasticity is employed. Penny-shaped particles made of birefringent polycarbonate are prepared and placed on a rigid horizontal plane to form two-dimensional model slopes with certain inclination angles. Dynamic impact is given to the top (approximately) horizontal free surface of the slope, and the transient evolution of stress and fracture is recorded by a high-speed digital video camera. It is shown that depending on the profile of energy imparted by the impact, (i) one-dimensional force-chain-like stress transfer or (ii) widely spread multi-dimensional wave propagation can be found. While the case (i) results in mass flow, i.e. total collapse of the slope, in (ii) waves can induce dynamic separation of only slope faces similar to toppling failure. The experimentally observed wave and fracture phenomena in granular media are compared to those in continuum media and the actual slope failure repeatedly caused in Japan, New Zealand and USA.

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Keywords: Wave propagation in granular media; Fracture of granular media; Dynamic slope failure

* Corresponding author. Tel.: +81-3-5841-6574; fax: +81-3-5841-6574.
E-mail address: goji@dyn.t.u-tokyo.ac.jp

Small scale fatigue crack growth and fracture of ductile materials: a case study in the nickelbase superalloy CMSX-4

Patrick Grünewald[a,]*, Florian Schäfer[a], Matthias Thielen[a], Michael Marx[a], Christian Motz[a]

[a]*Materials Science and Methods, Saarland University, Saarland, Germany*

Abstract

Fracture phenomena at small scales have been under discussion in the recent past. Intensive investigations have been made regarding the simplifications made for static fracture toughness evaluations at small scales such as the use of notches cut with a focused ion beam (FIB) as initial failures. Literature reports that J-integral based evaluation methods of microspecimens with such FIB cut notches result in valid fracture toughness evaluations. It also reports a change in fracture toughness at small scales, which is ascribed to the influence of size effects.

However, one challenge in small scale fracture analysis is testing highly ductile materials, where the assumptions for the lower bounds of the J-integral based evaluation methods are violated. For this purpose, we performed fatigue crack growth experiments as well as static fracture toughness measurements on microcantilevers made from the ductile nickelbase superalloy CMSX4. We tested the differences between FIB cut notches and fatigue precracks as initial failures for the static fracture toughness evaluations. The fracture toughness of microcantilevers has been compared to that of macroscopic bending beams. The capability of a ductile material to grow fatigue cracks in micron sized specimens has been tested. Thereby, the influence of size effects and grain boundaries on the fatigue crack growth behavior has been investigated as well.

Our experiments show differences between notches and fatigue cracks as initial failures, indicating that the use of fatigue precracks is inevitable for a fracture toughness evaluation even at small scales. However, a strong deviation between microscopic and macroscopic fracture toughness values can still be measured. Finally, the fatigue crack growth experiments show a distinct interaction of the cracks with the neutral axis of the bending beams and with grain boundaries. Overall, it shows that care has to be taken when fatigue cracks and fracture phenomena are investigated at small scales.

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Keywords: J-integral, fracture, fatigue, small scale

* Corresponding author. Tel.: /
E-mail address: p.gruenewald@matsci.uni-sb.de

The crucial defects induced in austenitic stainless steel upon hydrogen embrittlement by positron annihilation spectroscopy

Masanori Fujinami[a,*], Akari Komatsu[a], Luca Chiari[a]

[a]*Department of Aeronautics and Astronautics, The University of Tokyo, Tokyo, Japan*

Abstract

Austenitic stainless steels are considered to be one of the most important structural materials for hydrogen energy systems. It is well-known that the Ni equivalent is strongly related to the hydrogen susceptibility. Hydrogen stabilizes the formation of vacancies, so that their behavior in HE is very important. In this study, two types of austenitic stainless steels, ANSI 304 and ANSI 316L, were investigated by positron annihilation lifetime spectroscopy (PALS) and the crucial defects in HE were discussed.
ANSI 304 sheets were pre-charged with hydrogen by cathodic reaction and subject to tensile straining at room temperature (RT). The H-charged layer (10 μm thick) of the 10%-strained sample was etched off and the mechanical properties were compared before and after etching. The 10% strained ANSI 304 sheet did not show the formation of the strain-induced martensitic phase, but the formation of vacancy clusters was revealed by the PALS results. On the other hand, the etched sample showed HE after subsequent straining and vacancy clusters appeared after the fracture. Furthermore, the defects in the etched sample annealed out at 100 ºC, indicating that they became unstable by the release of hydrogen. It is, therefore, concluded that the crucial defects upon HE in ANSI 304 are vacancy-hydrogen complexes in the fcc phase.
ANSI 316L sheets were exposed to 95 MPa of hydrogen gas at 300 ºC for 72 h and the hydrogen concentration was estimated to be 90 ppm. The specimens were subject to tensile stress at temperatures from -150 ºC to RT. ANSI 316L showed no hydrogen susceptibility at -150 ºC and RT, while HE took place during straining at -70 ºC. The fractured sample strained at RT showed much smaller vacancy clusters, indicating the agglomeration of the monovacancies. The straining at -150 ºC induced monovacancy-related defects. On the other hand, larger vacancy clusters formed in the fractured sample strained at -70 ºC. It is understood that the straining at -70 ºC induced highly strained fields, such as at the boundary between the fcc and martensitic phases, where a lot of vacancy-hydrogen complexes locally formed. It is, therefore, concluded that the crucial defects upon HE in the austenitic phase are vacancy-hydrogen complexes.

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Keywords: wave propagation in granular media, fracture of granular media, dynamic slope failure

* Corresponding author. Tel.: /
E-mail address: fujinami@faculty.chiba-u.jp

Cleavage fracture assessment of cold charged steel slabs using experimental and numerical approaches

Reza H. Talemi[a,b,*], Negar Gilani[c], Quang Tien Ngo[c],
Antônio de Souza Braga Neto[a,d], Annick Willems[a]

[a]*ArcelorMittal Global R&D Gent-OCAS N.V., Pres. J.F. Kennedylaan 3, 9060 Zelzate, Belgium*
[b]*Present address: Department of Materials Engineering, KU Leuven, 3001 Leuven, Belgium*
[c]*ArcelorMittal Global R&D Maizières Process, Voie Romaine, F-57283 Maizières-lès-Metz Cedex, France*
[d]*School of Mines, Federal University of Ouro Preto, Ouro Preto, MG, Brazil*

Abstract

Drop Weight Tear Test (DWTT) set-up has been used to investigate cleavage fracture of steel slabs at different elevated temperatures up to 500°C. Fracture surfaces of broken samples have been analyzed using Scanning Electron Microscope (SEM) to understand ductile and brittle fracture appearances at the elevated temperatures. The eXtended Finite Element Method (XFEM)-based cohesive segment technique has been used to simulate the dynamic crack propagation of the DWTT at all tested temperatures. The obtained numerical results were in good agreement with the observed experiments. Eventually, a hybrid experimental-numerical method is proposed to define a set of critical cleavage stresses for cold/hot charged steel slabs.

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Keywords: AHSS; Steel slab; continuous casting; cleavage fracture; numerical modelling; DWTT; XFEM; cohesive zone

* Corresponding author. Tel.: +32 9 331 65 01
E-mail address: reza.hojjatitalemi@kuleuven.be

Phase-field modelling of fracture in viscoelastic solids

Zhengkun Liu[a,*], Julian Roggel[a], Daniel Juhre[a]

[a]*Otto von Guericke University Magdeburg, Germany*

Abstract

The phase-field modeling has emerged as an extremely powerful numerical method to simulate crack propagation with significant success. The crack is herein modeled by a field variable that distinguishes between fully broken and undamaged material. In the proposed phase-field model for crack propagation in viscoelastic solids, a model with a fracture threshold similar to gradient damage theories is developed which can distinguish between fracture behavior in compression and tension. A viscoelastic material model in the framework of finite deformations is used for rubber-like material response. The full model is implemented in the framework of the FE program FEAP and allows both a monolithic and a staggered scheme for the numerical solution. Within FEAP a parameter study and various numerical benchmark tests are realized. In the parameter study phase-field parameters of a phase-field model with a fracture threshold are analyzed in details. In the benchmark tests an L-bracket is reviewed, here the loading is a combination of the crack loading modes of fracture mechanics. In this numerical example also plate with holes are examined and the influence of these holes concerning the crack path is investigated. Finally, a summary of the results is presented and an outlook for improvements of the modeling for fracture in viscoelastic solids is given.

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Keywords: Phase-field model, brittle fracture, finite strain, finite elements, viscoelastic material

* Corresponding author. Tel.: /
E-mail address: zhengkun.liu@ovgu.de

Analysis of fracture approaches based on a critical distance and comparison with experiments for cross-ply laminates

Israel G. García[a,]*, Vladislav Mantic[a]

[a]*University of Seville*

Abstract

The main objective of this work is the analysis of several fracture criteria based on a critical distance, used typically to predict crack initiation under quasistatic loading. These fracture criteria are typically grouped in a common framework under the terms of "finite fracture mechanics" or "theory of critical distances". Due to the existence of a critical distance (material-based or problem-based) which does not necessarily scale with the geometry, these criteria typically predict a size effect in the fracture phenomena studied. However the size effect predicted is different for each criterion, even qualitatively between some criteria. Thus, this work focuses the comparison on this size effect.

When a cross-ply [0/90]s laminate is subjected to uniaxial tension along the outer-ply direction a size effect is found in experiments: the critical strain for which the first cracks initiate depends strongly on the laminate thickness. This size effect is well-known and has been interpreted using several criteria based on a critical distance. In fact this result has inspired many of these criteria, even some of them which are not traditionally classified in the framework of the "theory of critical distances".

For the comparison the main criteria are discussed and reformulated in a common notation. The elastic solutions required for the application of each criterion are obtained from the same source for all the criteria: a very accurate Boundary Element Analysis. The prediction of each criterion is compared with a new set of experiments designed to span the maximum range of laminate thickness.

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Keywords: Size effect, theory of critical distances, finite fracture mechanics, composites, cross-ply laminates

* Corresponding author. Tel.: /
E-mail address: israelgarcia@us.es

Phase-field modelling of crack propagation in anisotropic polycrystalline materials

Zhengkun Liu[a,*], Daniel Juhre[a]

[a]Otto von Guericke University Magdeburg

Abstract

Nowadays, products consisting of polycrystalline materials have been widely used in engineering applications, e.g. automobile and renewable energy. The macroscopic defects are generally strongly influenced by the fracture behavior of the polycrystalline materials at the meso- and microscopic level. In this paper, the proposed phase-field model for anisotropic fracture, which accounts for the preferential cleavage directions within each randomly oriented crystal, as well as an anisotropic material behavior with cubic symmetries, has been used to simulate the complex crack pattern in solar-grade polycrystalline silicon in a robust and straightforward manner. Furthermore, multi-field coupled finite element problems are performed with monolithic solution schemes. A representative numerical example for crack propagation in polycrystals is carried out. Finally, a summary of the numerical results in polycrystalline materials is presented and an outlook for next work steps is given.

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Keywords: Finite elements; phase-field model; anisotropic fracture; solar-grade polycrystalline silicon

* Corresponding author. Tel.: /
E-mail address: zhengkun.liu@ovgu.de

Structures with bridged cracks and weak interfaces

Mikhail Perelmuter[a,*]

[a]*Institute for Problems in Mechanics, Moscow, Russia*

Abstract

Structures with bridged cracks and weak interfaces under mechanical and thermal loading are considered. In the frames of this analysis is assumed that: a) there are cracks at the interface between different materials; b) the crack surfaces interact in some zones behind of the crack tips (bridged zones whose size can be comparable to the whole crack length); and c) the interface between different material (including interface ahead of cracks tips) can be considered as non-ideal (weak) interface, where a relative displacement of initially adjacent materials might occur.
The relation for these relative displacements is subdivided into two components for plane or axisymmetric problems: transverse separation and slip tangent to the interface surface. Bonds properties at cracks bridged zones and at weak interface regions define the fracture toughness of the composite material.
The bridged crack and weak interface models are incorporated into the program based on the direct boundary integral equations method. The multi-regions technique is used for modeling of cracks with bridged zone and weak interface regions. The supplement conditions along the ideal sub-regions boundaries (without cracks and weak zone) are used. The energy characteristics of the crack such as the energy release rate and the rate of the energy dissipation by the bonds are considered. These energetic characteristics are used for the nonlocal criterion of bridged crack growth.
The results for different properties of composite materials and bonds and for different sizes and shapes of the cracks are presented. The key point of the proposed model is the possibility to consider a crack of different scales and, hence, the model can be applied for microscopic and macroscopic cracks in brittle or quasi-brittle materials. It is possible to consider bonds of different physical nature and artificial bonds due to repair of macroscopic flaw at an interface junction.

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Keywords: Interfacial cracks; crack bridged zone; weak interface; boundary elements

* Corresponding author. Tel.: /
E-mail address: perelm@ipmnet.ru

Effect of crack opening velocity on the fracture behavior of hyperelastic semi-structural adhesive joints subjected to mode I loading

Christopher Schmandt[a,*], Stephan Marzi[a]

[a]*Technische Hochschule Mittelhessen, Giessen, Wiesenstraße 14, 35390, Germany*

Abstract

Rubber-like adhesive joints provide substantial advantages compared to epoxy-based adhesive joints regarding their damping properties, fatigue resistance and energy consumption under impact. Polyurethane-based adhesives with high modulus are even used in structural applications like car body production. The work to be presented describes the dependency of mechanical mode I failure of a hyperelastic semi-structural adhesive on loading rate.
Double cantilever beam (DCB) specimens were manufactured with an adhesive layer thickness of 3 mm. In a first test setup, driving velocity of the testing machine was controlled on optically measured crack opening velocity, varying over several orders of magnitude within external setpoint generation. The tests were driven until crack propagation took place and the position of optical measurement was not valid anymore. The J-integral according to Rice (1968) was calculated directly from measured force acting on the DCB specimen and rotation angle of force introduction points, using an analytical approach of Anthony and Paris (1988). In a second test setup, driving velocity of the testing machine was varied over several orders and tests were driven until complete failure of the adhesive joint. Pictures recorded from specimen's edge were used to analyze the rate dependency of crack propagation and fracture behavior.
The observed correlation between J and current crack opening velocity showed that fracture energy was significantly and cohesive strength slightly increasing under higher crack opening velocities, while cohesive stiffness remained constant. In a certain range of loading rates, discontinuous crack growth with stick-slip crack propagation was observed. Below and above this range, crack propagation rate was tending to be more stable.

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Keywords: Adhesive; rubber; mode i fracture; viscoelasticity

* Corresponding author. Tel.: /
E-mail address: christopher.schmandt@me.thm.de

Multi-scale analyses of the different interactions between defects and hydrogen: on the contribution of the elastic fields

Christopher Xavier Feaugas[a,*], Guillaume Hachet[a], Jiaqi Li[a], Arnaud Metsue[a], Abdelali Oudriss[a]

[a]*University of La Rochelle LaSIE UMR CNRS 7356 La Rochelle, France*

Abstract

Hydrogen Embrittlement (HE) is one of the causes mainly evoked in premature rupture of industrial components exposed to aggressive environment. Many studies have been conducted in order to understand the mechanisms involved during this degradation, and the influence of metallurgical states. A good knowledge of hydrogen interactions with crystal defects is a key element in the understanding of the different damage processes associated with the HE in fcc materials. In this state of mind, we undertook a systematic study of these interactions in nickel alloys using coupled multiscales approaches. These latter correspond to the association of the atomistic calculations (EAM, DFT) with experimental tests: Electrochemical Permeation (EP), Secondary Ionization Mass Spectrometry (ToF-SIMS) analysis, Thermal Spectroscopy Desorption (TDS), and Nanoindetation in order to evaluate the hydrogen states in the presence of different crystal defects. Among the major results, we focus our attention on the interaction between hydrogen and vacancies in nickel single crystals, the trapping and segregation of hydrogen for several dislocation distributions (cells, PSB, GBs,…) and the contribution of grains boundaries (GBs) and precipitation to the hydrogen diffusion and trapping in nanocrystals, polycrystals and bicrystals of nickel. In all the cases, we questioned the impact of elastic field associated with the defect to apparent solubility and diffusion of hydrogen. In a second part, we explore the potential impacts of hydrogen on elastic properties and their implication on the mechanisms of plasticity.

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Keywords: Adhesive, rubber, mode I fracture, viscoelasticity, hysteresis

* Corresponding author. Tel.: /
E-mail address: xfeaugas@univ-lr.fr

Environmentally-assisted fatigue crack growth mechanisms in ARMCO iron under high pressure of gaseous hydrogen

Tomoki Shinko[a], Damien Halm[a], Guillaume Benoit[a], Gilbert Hénaff[a,*]

[a]*Pprime Institute, ISAE-ENSMA, Poitiers, France*

Abstract

Previous studies have shown that the fatigue crack growth resistance of steels can be severely altered under high pressure of gaseous hydrogen. Meanwhile attempts to describe this phenomenon using numerical models based on coupled diffusion laws and cohesive zone elements still fail in accounting for the tremendous fatigue crack growth enhancement observed at high pressure and/or low frequency. This might be partly due to a lack of reliable data on some variables that generally depend on the microstructure in a complex manner. In order to address this problem in the case of a simpler microstructure, it was decided to conduct fatigue crack propagation tests on ARMCO iron using the HYCOMAT test rig under different values of the gas pressure and for different load frequencies. This paper presents the fatigue crack growth results and their analysis. The results indicate that fatigue crack growth rates in ARMCO iron are also substantially enhanced by hydrogen, but a lesser extent than in a martensitic steel. In addition it is shown that at low DK values, the exposure to gaseous hydrogen immediately induces a change in fracture mode without any concomitant effect on crack growth rates, with the presence of numerous intergranular facets covered by regular markings, while the enhanced growth regime at high DK value is characterized by a brittle transgranular fracture mode with the presence of coarse brittle striations. FIB milling of foils for STEM observations has been carried out to analyze the dislocation substructures beneath these two typical fracture surfaces..

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Keywords: Hydrogen embrittlement, hydrogen diffusion and hydrogen solubility, defects, elastic fields

* Corresponding author. Tel.: /
E-mail address: gilbert.henaff@isae-ensma.fr

Structural reliability of engineering plastics

Alexander Chudnovsky[a,*]

[a]*The University of Illinois, IL, United States*

Abstract

Assessment of structural reliability is directly linked with an accelerated testing of failure. A mild loading is usually applied to structures with long life expectancy (50 or 100 years). Accelerated testing is naturally conducted at much more severe conditions in order to observe failure within a short time in comparison with life expectancy. The main requirements for accelerated testing are (i) to reproduce the mechanisms of failures observed in service, and (ii) to have a scientifically justified procedure for extrapolation of a relatively short test results into long-term material behavior. Fracture acceleration by load violates (i). Indeed, it is usually ductile at high load and brittle at a low one. Acceleration by elevated temperature, the most common at the present, also has problem associated with the variations in the mechanism and kinetics of fracture processes with temperature and load level. The relation between the load and crack growth rate also changes depending on a combination of load and temperature. It is associated with a transition from a brittle to ductile behavior on microscale. Such a transition implies a limitation of temperature accelerated testing. Indeed, a significant reduction of applied load is required to reproduce at high temperature the mechanism and kinetics of fracture at low temperature. Load reduction leads to an increase of test duration, which reduces or even eliminates accelerating effect. An alternative approach is discussed in this presentation. It consists of development of constitutive equations of fracture based on specially designed tests, numerical simulation of fracture process and evaluation of the lifetime. An experimental examination of such protocol is required. Illustrative examples of proposed program are presented.

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Keywords: Structural reliability, accelerated testing, ductile-brittle transition, engineering plastics

* Corresponding author. Tel.: /
E-mail address: chudnovsky.alexander@gmail.com

Free volume in strained rubber with carbon black filler by in-situ positron annihilation lifetime spectroscopy

Madoka Nippa[a,]*, Yuko Ikeda[b], Atsushi Kato[c], Luca Chiari[a], Masanori Fujinami[a]

[a]*Chiba University, Chiba, Japan*
[2]*Kyoto Institute of Technology, Kyoto, Japan*
[3]*NISSAN ARC, LTD. Yokosuka, Japan*

Abstract

The main component of tires is natural rubber, and various additives such as carbon black (CB) are added to increase the strength of the rubber. Especially CB, which is dispersed in the rubber, is known to play an important role to remarkably improve its mechanical properties. However, the detailed reinforcement mechanism is still unknown. In this study, we aimed to investigate the change in free volume within strained rubber with various amounts of carbon black filler by in situ positron annihilation lifetime spectroscopy (PALS).The rubber consisted of isoprene rubber filled with various amount of CB. The rubber specimens were prepared by mixing them and 1 phr dicumyl peroxide as the crosslinking agent. The CB content was varied from 0 to 80 phr. The rubber samples were strained to a ratio of 160% with a tensile tester and in situ PALS measurements were carried out. In the CB-free samples, the straining resulted in an increase in the intensity of the o-Ps formation component, while the o-Ps lifetime was unchanged. The o-Ps lifetime represents a measurement of the size of free volume. Hence, it was concluded that the size of free volume was constant in the strained sample. Although the reason for the change in the o-Ps intensity is still unknown, the alignment of molecular chains by straining may be related to the o-Ps formation . A comparison of the o-Ps intensity during the stretching to that before the stretching for different CB contents was also carried out. A large decrease in the o-Ps intensity was observed at 40 phr CB. In particular, the o-Ps intensity was constant up to 30 phr CB, while it became smaller during the straining of the samples with more than 40 phr CB. The change in the o-Ps intensity can be explained in terms of the sample straining leading to the ordering of the molecular chains in the amorphous phase. The branched fraction of the CB network affected the ordering of molecular chain during the straining.

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Keywords: Rubber, carbon black, strain, free volume, positron annihilation spectroscopy

* Corresponding author. Tel.: /
E-mail address: madoka.nippa@chiba-u.jp

Effect of welding parameter on dynamic fracture properties of 2024-T3 aluminum friction stir welded joints

Yanning Guo[a], Yue Ma[a,*], Fei Wang[a]

[a]*School of Aeronautics, Northwestern Polytechnical University, Xi'an, Shaanxi 710072, China*

Abstract

Friction stir welding is widely used in the aerospace structure. It is important to study mechanical response of aluminum welded joints under dynamic loading. This paper aims to investigate the effect of welding parameter on rate-dependent dynamic tensile properties of 2024 aluminum welded joints. Samples in different weld zones were designed and dynamic tests with different strain rates were performed. It is observed that as the non-uniform heat and plastic flow during welding, yield strength of the heat-affected zone (513MPa) is much higher than the stirred zone (370MPa) and the thermo-mechanically zone (336MPa). Under the rotation speed of 400rmp, the heat affected zone and the stirred zone show much better tensile ductility, which is 25% higher than that of samples welded with the 600rmp rotation speed. The strain rate strengthening effect is obviously obtained. Furthermore, 2024 aluminum has been considered to have low strain rate sensitivity. The fracture morphology of specimens shows that as the function of rotating tool, equiaxed and fine grains help to enhance the strength.

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*Keywords:*Friction stir welding; welding parameter; dynamic tensile; strain rate; fracture morphology

* Corresponding author. Tel.: /
E-mail address: ma.yu.e@nwpu.edu.cn

A discussion about multi-axial fatigue criteria for NiTinol cardiovascular devices

Francesca Berti[a], Lorenza Petrini[b,*], Andrea Spagnoli[c]

[a]Laboratory of Biological Structure Mechanics, Department of Chemistry, Materials and Chemical Engineering "Giulio Natta", Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano (Italy)
[b]Department of Civil and Environmental Engineering, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano (Italy)
[c]Department of Engineering and Architecture, Università di Parma, Parco Area delle Scienze, 181/A - 43124 Parma (Italy)

Abstract

Nickel-Titanium (NiTinol) alloys exploit a typical super-elastic behavior which makes them suitable for many biomedical applications, among which peripheral stenting, requiring the device being subjected to the high mobility of the lower limbs. Unfortunately, this complex environment can lead to the device fatigue fracture with likely other more severe complications, e.g. restenosis. Standards require to experimentally verify stent fatigue life behavior, without giving indications on how to select the loads to be applied for resembling most critical in-vivo conditions. Moreover, different multi-axial fatigue criteria have been originally developed for standard metals to predict the behavior under cyclic loads, but none of them is specifically formulated for NiTinol. This paper presents a numerical study having two aims: i) understanding how non-proportional loading conditions due to combination of axial compression, bending and torsion induced at each patient gait on the femoro-popliteal artery affects the implanted stent stress/strain distribution; ii) understanding how stent fatigue life prediction may be affected by the choice of the fatigue criteria. Accordingly, two different peripheral stent geometries, resembling commercial ones, were analysed under different sets of loading conditions. The cyclic deformations induced over the device structure by macroscopic loads are interpreted through four different fatigue approaches recently used in Nitinol fatigue analyses: Von Mises, Fatemi-Socie, Brown-Miller and Smith-Watson-Topper. The comparison between the outputs highlights that they are strongly influenced by the loading path, recognizing the major role in fatigue due to the combined torsional and bending actions. On the other hand, the choice of the fatigue criterion impacts on the fatigue life prediction.

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Keywords: Shape memory alloys; multi-axial fatigue; NiTinol; peripheral stents

* Corresponding author. Tel.: +39 02 2399 4307; fax: +39 02 2399 4286.
E-mail address: lorenza.petrini@polimi.it

Numerical simulation of hydrogen embrittlement in iron

Shinya Taketomi[a,]*, Ryosuke Matsumoto[b]

[a]Saga University, Saga, Japan
[b]Kyoto University, Kyoto, Japan

Abstract

Hydrogen embrittlement (HE) is well known phenomenon in which hydrogen lowers the strength and ductility of metals. To clarify the whole picture of HE, an understanding of the fundamental processes during the HE crack growth should be important. HEDE (Hydrogen Enhanced Decohesion) is one of the potential mechanisms which attributes the decrease of cohesive energy due to solute hydrogen, thus the mechanism basically yield in brittle manner crack growth. In counter, HELP (Hydrogen Enhanced Localized Plasticity) is the other potential mechanism which attributes the enhancement of local plastic deformation in the vicinity of a crack, thus the mechanism basically yields in ductile manner fracture. These are representative mechanisms for HE and have been discussed for long. Thus, the understanding of ductile to brittle transition in HE should be important as a fundamental understanding of embrittlement process. In this study, we applied two dimensional simple dislocation dynamics (DD) method around a mode I crack in alpha iron. The mechanical properties for the analyses (i.e. dislocation velocity, elastic constants, stacking fault energy, surface energy) are obtained by atomistic simulations in order to take into account the effects of hydrogen. The results indicate the ductile to brittle transition behavior could change depending on boundary conditions, such as hydrogen concentration and applied stress intensity factor rate. The results also suggest that the dominant mechanism of HE could change depending on environmental and/or mechanical conditions.

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Keywords: Hydrogen embrittlement, hydrogen, atomistic simulation, dislocation dynamics

* Corresponding author. Tel.: +39 02 2399 4307; fax: +39 02 2399 4286.
E-mail address: taketomi@me.saga-u.ac.jp

Mechanical modelling of self-diagnostic polymers

Roberto Brighenti[a,*], Federico Artoni[a]

[a]*Department of Engineering & Architecture, University of Parma, Parco Area delle Scienze 181/A, 43124 Parma, Italy*

Abstract

The safety level in advanced load bearing applications can be enhanced if the material would be able to detect the in-service deformation, allowing a real time evaluation of the reliability state of the components. Polymeric materials can be used to get such a functionality through the insertion of so-called mechanophore units, whose main property is to chemically respond to mechanical stimuli. In the present paper, a micromechanical approach is developed to model the response of polymers containing reporting units, whose activation is triggered by the deformation of the underneath network or by a chemical stimulus. The model, through an Arrhenius-like equilibrium reaction law, provides a quantitative evaluation of the fraction of stress-activated molecules. Moreover, if the mechanophore activation involves also a change in their geometrical conformation, it influences the network deformation and the corresponding mechanical effects must be also accounted for. The formulated micromechanical model is presented and implemented in a FE code in order to simulate structural elements made of a self-diagnostic material. In particular, we consider the fluorescence-based strain detection of pre-cracked elements made of polymers with supramolecular complexes cross-linked to the polymer's chains; the fluorescence intensity is assumed to be proportional to the volume fraction of the activated units, thus enabling to quantify the associated material's strain value.

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Keywords: Polymers; mechanophores; self-diagnostic; micro-mechanical model.

* Corresponding author. Tel.: +39 0521 905910; fax: +39 0521 905924.
E-mail address: brigh@unipr.it

Hydrogen-microvoid interaction: bridging the gap between hydrogen embrittlement and ductile failure

Haiyang Yu[a], Jim Stian Olsen[b], Jianying He[b], Zhiliang Zhang[b,*]

[a]*University of Oxford, Oxford, United Kingdom*
[b]*Norwegian University of Science and Technology, Trondheim, Norway*

Abstract

The influence of hydrogen on microvoid process has been observed in experiments, indicat-ing that hydrogen could either enhance internal necking failure or induce internal shearing failure of microvoids. On the numerical aspect, the former mode has been captured, while the latter is still insufficiently explored due to the lack of a proper failure criterion. In this talk, a hydrogen induced internal shearing failure criterion is introduced first, and hydrogen-microvoid interaction is then systematically studied via hydrogen diffusion coupled unit cell analyses. It is found that the hydrogen effect on microvoid process is both stress state and trap strength dependent. Hydrogen enhanced internal necking failure is observed over the entire stress space with weak traps. While such failure is still observed in the high triaxiality regime with strong traps, hydrogen induced internal shearing failure is observed in the low triaxiality regime. Further, quantitative investigation is performed on hydrogen failure loci. The hydro-gen induced internal shearing failure locus is found to be approximately independent of stress triaxiality while the hydrogen enhanced internal necking failure locus maintains similar triax-iality dependency as in the absence of hydrogen. The loss of ductility, in terms of reduction in failure strain and dimple size, is more pronounced in the case of hydrogen induced internal shearing failure. These results bridge the gap between hydrogen embrittlement and ductile failure and pave the way for the development of micromechanically based hydrogen embrit-tlement assessment models.

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Keywords: Hydrogen; hydrogen diffusion; shearing failure;

* Corresponding author. Tel.: /
E-mail address: zhiliang.zhang@ntnu.no

Crack initiation of a 7XXX aluminium alloy in humidity analysed via Slow Strain Rate Testing

Elisabeth Schwarzenböck[a,*], Levke Wiehler[a], Theo Hack[a], Christian Engel[a]

[a]*Department of Engineering & Architecture, University of Parma, Parco Area delle Scienze 181/A, 43124 Parma, Italy*

Abstract

In general, Al-Zn-Mg(-Cu) alloys tend to Environmentally Assisted Cracking (EAC) in water vapour if loaded with external or internal stresses. When aluminium alloys are exposed to humid gases, hydrogen is generated according to 2Al (s) + $3H_2O$ (g) → Al_2O_3 (s) + 6H. Hydrogen atoms are absorbed by the metal which reduces its ductility leading to brittle failure. Several mechanisms have been proposed in literature to explain the hydrogen embrittlement of aluminium alloys in humidity, e.g. Adsorption-Induced Dislocation Emission (AIDE), Hydrogen Enhanced Decohesion (HEDE), Hydrogen Enhanced Localized Plasticity (HELP). For the interaction of hydrogen and aluminium, all mechanisms consider time-dependent steps like the diffusion and accumulation of hydrogen in the metal. Therefore, tensile testing at strain rates between 10^{-4} to 10^{-7} s^{-1} is considered as appropriate to reveal the effect of hydrogen on mechanical properties of aluminium alloys - in particular, the reduction of ductility. This technique is called Slow Strain Rate Testing (SSRT).
A high-strength 7XXX alloy has been analysed with SSRT in dry and humid environments at temperatures below 100°C and compared with tensile tests performed at a typical extension rate of 1 mm/s. Furthermore, the alloy has been pre-exposed to humidity for several days with and without mechanical stress to assess a possible effect on ductility. The results show that slow strain rate testing is suitable to investigate the sensitivity of a high-strength 7XXX alloy for hydrogen embrittlement in humidity. While the alloy responds with a reduction of its ductility, the strength properties are not reduced by the absorption of hydrogen. Fractographic analysis confirms that the embrittlement of the alloy exposed to humidity is attributed to crack initiation and growth along the grain boundaries, without the formation of dimples. The short-term pre-exposure of this aluminium alloy to humidity further reduces the ductility, especially if the sample has been mechanically stressed during pre-exposure.

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Keywords: Environmentally assisted cracking; humidity; Al-Zn-Mg-Cu alloy, slow strain rate testing;

* Corresponding author. Tel.: /
E-mail address: elisabeth.e.schwarzenboeck@airbus.com

ECF22 - Loading and Environmental Effects on Structural Integrity

Prediction model of corrosion losses based on probabilistic approach

Vit Krivy[a], Monika Kubzova[a,*], Katerina Kreislova[b], Martin Krejsa[a]

[a]*Faculty of Civil Engineering, VSB-Technical University of Ostrava, L. Podeste 1875, 708 00 Ostrava, Czech Republic*
[b]*SVUOM Ltd., U Mestanskeho Pivovaru 934/4, 170 00 Prague 7, Czech Republic, email:kreislova@svuom.cz*

Abstract

The article deals with the prediction of corrosion losses of weathering steels based on the application of dose-response functions. The following environmental characteristic incoming the dose-response functions are analyzed using statistic and probabilistic methods: mean annual values of the temperature *T*, concentration of sulfur dioxide SO_2, relative air humidity *RH*, deposition of chlorides Cl^-. Long-term measurements of environmental parameters at atmospheric test sites were used for the analysis. All the environmental parameters incoming the dose-response functions are considered to be random variables represented by corresponding histogram. Using the probabilistic analysis it is possible to predict the expected range of corrosion rates and to analyze the impact of particular environmental characteristic on corrosion process.

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Keywords: corrosion losses; weathering steel; dose-response function; probabilistic method; environmental parameters; histogram

[*] Corresponding author. Tel.: +420-597-321-980.
E-mail address: monika.kubzova@vsb.cz

Evaluation of the compressive behavior of Periodic Central Voronoi Tessellation (PCVT) cellular structures under quasi-static condition using finite element method

Jungsub Lee[a], Byoung-Ho Choi[a,]*

[a]*Korea University, South Korea*

Abstract

Light weight structures can be found easily in nature. Woods, sea sponges and bones are the good examples. Cellular structures make their weight lighter than bulk material while maintaining reasonable mechanical properties. Many models have been suggested to mimic the characteristics of those structures. Tetrakaidecahedron, often called as a Kelvin cell, is well known for its symmetric shape. It can fill the space without any niche. The unit cell is simple and regular but not able to construct inhomogeneous structures. Central Voronoi Tessellation (CVT) is proposed to overcome the limit. It results random seeds but the cell size and its distribution, which are the key factors regarding mechanical behaviors of the structure, can be modified easily by the iteration process. Using Periodic Central Voronoi Tessellation (PCVT), we can obtain the optimal unit cell which can fill the space as the Kelvin cell does and is anisotropic. In this study, the mechanical behaviors of PCVT structures under the quasi-static compressive loading condition were evaluated using finite element method. Analyses were implemented by ABAQUS. To evaluate the effect of the cell size and its distribution, the number of seeds and iteration were controlled by MATLAB codes. Relative density was fixed since it affects the mechanical properties of the structure. By comparing the specific stiffness and the specific strength of the unit cells we evaluated the possibility of the cellular structure of replacing traditional bulk materials. In the future study, the results drawn in this research will be verified by experiments.

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Keywords: Cellular structure, light weight, periodic central voronoi tessellation (PCVT), quasi-static loading

* Corresponding author. Tel.: +420-597-321-980.
E-mail address: bhchoi@korea.ac.kr

Fatigue crack growth behavior and associated microstructure in a metastable high-entropy alloy

Takeshi Eguchi[a,*], Motomichi Koyama[a], Yoshihiro Fukushima[a], Cemal Cem Tasan[b], Kaneaki Tsuzaki[a]

[a]*Department of Mechanical Engineering, Kyushu University, Motooka 744, Nishi-ku, Fukuoka 819-0395, Japan*
[b]*Department of Materials Science and Engineering, Massachusettes Institute of Technology, 77 Massachusettes Avenue, Cambridge, MA 02139, USA*

Abstract

High-entropy alloys (HEAs) containing different kinds of high-concentration solute atoms provide new concepts for obtaining excellent balance of strength and ductility. In particular, a metastable dual-phase HEA (Fe30Mn10Cr10Co; FCC matrix and HCP second phase) shows superior ductility and strength owing to the transformation-induced plasticity effect associated with deformation-induced HCP-martensitic transformation. In this context, the fatigue properties of metastable HEAs are to be investigated towards practical applications as structure materials. In this study, the fatigue crack growth behaviors of HEA and type 316L austenitic stainless steel (FCC single phase) were comparatively examined. The crack growth rate of HEA was comparable to that of 316L. In HEA, the fatigue crack was covered by a large amount of HCP-martensite. In general, the HCP-martensite was cracked easily because of the smaller number of slip systems. However, the negative effect of HCP-martensite did not appear in the fatigue crack growth rate of HEA. By electron channeling contrast imaging, we found that the HCP-martensite beneath the fracture surface contained significant orientation gradient and high density of dislocations, indicating that HCP-martensite in the present Fe30Mn10Cr10Co HEA had high plastic deformability and associated stress accommodation capacity.

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Keywords: High-entropy alloy; HCP-martensite; fatigue; crack growth behavior.

* Corresponding author. Tel.: +81-92-802-3288.
E-mail address: 2TE17803T@s.kyushu-u.ac.jp

Fatigue behavior of single-crystal nano-sized Cu beams

Per Hansson[a,*]

[a]*Division of Mechanics, Lund University,P.O. Box 118, 22100 Lund, Sweden*

Abstract

It is well-known that the response to mechanical loading of nano-sized metal structures differs from what applies to the macroscopic scale, and often non-intuitive behaviors are revealed. Here beams of square cross section, containing defects in terms of voids and loaded in fatigue with $R = 0$ under displacement controlled conditions, are investigated. The structures under consideration are single-crystal copper beams, chosen since such elements are common parts of a large variety of products found on the market today. The aim is to determine the resistance against fatigue failure through 3D molecular dynamic simulations. The simulations have been performed employing the 3D molecular dynamics free-ware LAMMPS.
The outcome of the investigations will highlight the influence of defects on the fatigue resistance at the nano-scale. The knowledge gained will give input into how to design structures on the nano-scale considering the presence of defects.

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Keywords: defect nano-beams; fatigue loading; single-crystal Cu

* Corresponding author. Tel.: +46462223078;
E-mail address: per.hansson@mek.lth.se

Fracture and damage behavior in an advanced heat resistant austenitic stainless steel during LCF, TMF and CF

Hugo Wärner[a,*] , Mattias Calmunger[a], Guocai Chai[a,b], Jaroslav Polák[c], Roman Petráš[c], Milan Heczko[c], Tomáš Kruml[c], Sten Johansson[a], Johan Moverare[a]

[a]*Engneering Materials, Linköping University, Linköping, 581 83, Sweden*
[b]*Strategy Research, Sandvik Materials Technology, Sandviken, 811 81, Sweden*
[c]*Institute of Physics of Materials, Academy of Sciences of the Czech Republic, Brno, 623 00, Czech Republic*

Abstract

Future advanced ultra-supercritical power plant will be run at higher temperature and pressure. New materials will be used to meet the requirements. However, the structure integrity of these materials needs to be evaluated. Sanicro 25 is a newly developed advanced austenitic heat resistant stainless steel with the aim to be used in future 700 °C or 650 °C power plants to replace part of Ni based alloys. This paper provides an overview on the fracture and damage behavior in this material during LCF, TMF and CF. The cyclic hardening and fatigue life during LCF, TMF and CF will be discussed. The influence of prolonged service degradation has been analyzed by the use of pre-aged material for TMF and CF loading conditions.

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Keywords: AUSC power plant; austenitic heat resistant stainless steel; Sanicro 25; low cycle fatigue; thermomechanical fatigue; creep-fatigue interaction

* Corresponding author. Tel.: +4613-282213; fax: +4613-281101.
E-mail address: hugo.warner@liu.se

Assessment of hydrogen embrittlement via in-situ imaging techniques in high Zn Al-Zn-Mg alloys

Hiroyuki Toda[a,]*, Hang Su[a], Kazuyuki Shimizu[a], Hiro Fujihara[a], Kyosuke Hirayama[a], Akihisa Takeuchi[b], Kentaro Uesug[b]

[a]*Kyushu University, Kyushu, Japan*
[b]*Japan Synchrotron Radiation Research Institute, Kyoto, Japan*

Abstract

Hydrogen repartitioning behavior among various trap sites during loading, which is necessary for establishing a mechanical criterion for hydrogen embrittlement, has been estimated based on an in-situ imaging technique. Vacancy production and dislocation multiplication due to plastic deformation have been calculated to precisely characterize the density values for all the hydrogen trap sites. The hydrogen repartitioning analysis has revealed that an estimated hydrogen concentration at dislocations is associated with the initiation of a quasi-cleavage crack, and a critical hydrogen concentration is around 2.5 x 10^{17} m^{-3}. On the other hand, the hydrogen repartitioning behavior is strongly dependent on pre-existing intermetallic particles due to its high hydrogen trap density together with the in-situ increase in vacancy, nano voids and dislocations. It is of crucial importance that hydrogen repartitioning behavior is controlled by changing the content and species of intermetallic particles thereby controlling the resistance for hydrogen embrittlement.

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Keywords: Hydrogen embrittlement; hydrogen partitioning; 3D X-ray tomography; Al-Zn-Mg aluminum alloys; 3D strain mapping

* Corresponding author. Tel.: /
E-mail address: toda@mech.kyushu-u.ac.jp

Intergranular/transgranular fracture in the liquid metal embrittlement of polycrystalline zinc

Naoyuki Tsutsui[a], Hirokazu Koizumi[a,*]

[a]*Department of Physics, Meiji University, Tama-ku, Kawasaki, Kanagawa, 214-8571 Japan*

Abstract

Tensile tests were performed on polycrystalline Zn specimens in contact with liquid Ga, In, In–Bi eutectic alloy, or Sn–Bi eutectic alloy below 450 K. These low-melting-point metals and alloys embrittled Zn specimens when they were in the liquid state. Although single-crystalline Zn is known to be embrittled by liquid Ga, intergranular cracking occurred in polycrystalline Zn in the presence of liquid Ga, while transgranular cracking occurred in the presence of In and Sn. Just above the melting point of Ga, only Ga atoms were found to penetrate along the grain boundaries of polycrystalline Zn. Although all these embrittlers reduced the cleavage fracture stress, only Ga atoms in the grain boundaries significantly reduced the strength of the grain boundaries, resulting in intergranular cracking. For the specimens in contact with liquid Ga, the incidence of transgranular cleavage fractures increased at high temperatures due to the reduction in the number of Ga atoms in the grain boundaries by diffusion into the grains.

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Keywords: Liquid metal embrittlement, intergranular fracture, transgranular fracture, penetration of atoms, grain boundaries, Zn;

* Corresponding author. Tel.: +81-44-934-7440 ; fax: +81-44-934-7911.
E-mail address: koizumi@meiji.ac.jp

A numerical and experimental investigation of dynamic fracture in Polyamide 11: the effect of the sample geometry

Jean-Benoit Koppa[a,*], Christophe Fond[b], Gilles Hochstetter[c]

[a]*I2M, Arts et M´etiers Paris Tech, Esplanade des Arts et M´etiers, F33800 Talence, France*
[b]*ICube, Universit´e de Strasbourg, 2 rue Boussingault, F67000 Strasbourg, France*
[c]*Arkema France, 420 rue d'estienne d'orves, F92700 Colombes, France*

Abstract

An experimental set-up and a numerical model are proposed to study the rapid crack propagation (RCP) resistance of polyamide 11 (PA11). Pipe and plate samples are studied. The solicitation type, imposed displacements or pressure, of polymer pipes is discussed. The necessity to pre-stress polymer pipe with imposed displacements is highlighted. Indeed, the work of external forces is not negligible for pressurized polymer pipes. A reliable estimate of the dynamic energy release rate G_{Id} is in this last case not guaranteed. A new experimental set-up is used to Pre-Stress Pipe Specimen (PS2) in mode I. The crack is initiated artificially with an external impact on a razor blade. A quasi-constant dynamic regime of propagation is then reached on about 20 cm. A finite element procedure is used to estimate G_{Id}. Knowing the crack tip location during RCP inertia effects i.e. kinetic energy are quantified. Numerical results reveal a higher dynamic correction factor for a pipe (0.2) than a plate structure (0.9). An important and non
negligible part of the stored energy is dissipated by the structure during RCP in pipe structure. Crack tip location as a function of time is measured with the help of a high speed camera during dynamic regime of propagation. The calculated mean crack tip velocity is quasi-constant in PA11 whatever (i) the initial stored energy in the structure, (ii) the sample geometry and (iii) the crack configuration. This velocity is known to be the crack branching velocity (0.6cR). The dynamic energy release rate G_{Id} is equal to 1.5 ± 0.1 kJ m^{-2} for a pipe sample and 9.2 ± 0.7 kJ m^{-2} for a plate sample at the crack branching velocity. Fracture surface analyses are leaded to explain this significant difference..

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Keywords: Rapid crack propagation;dynamic fracture;energy released rate;polymers;pipes;strip band specimen; finite element; inertia effects; fracture surface analysis

* Corresponding author. Tel.: +33 5 56 84 53 92
E-mail address: jean-benoit.kopp@ensam.eu

Cohesive zone modeling of interface influences on the tensile fracture behavior of bimodal nanostructured Cu

Xiang Guo[a,*], Guang Yang[b], George Weng[c], Jian Lu[d]

[a]*Tianjin University, Tianjin, China*
[b]*Automotive Engineering Research Institute, China Automotive Technology and Research Center*
[c]*Rutgers University*
[d]*City University of Hong Kong, Hong Kong*

Abstract

Bimodal nanostructured (NS) metals possess ultrahigh strength and also good ductility. The nanograined (NG) matrix leads to their ultrahigh strength, while their good ductility is due to the coarse-grained (CG) inclusions. We adopt the strain gradient plasticity model to describe the constitutive relation of the NG phase, and use cohesive zone model to investigate the tensile fracture process of the bimodal NS Cu. Three types of cohesive elements are considered: cohesive elements in the CG phase, those in the NG phase, and those at the interface of the two phases. The ratio of the number of the interface cohesive elements to that of all cohesive elements is less than 2%, while small changes in interface cohesive strength could influence the overall strength and ductility significantly. Our simulation shows that when the interface cohesive strength reaches certain level, the overall strength and ductility of the bimodal NS Cu will saturate.

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Keywords: AUSC power plant; austenitic heat resistant stainless steel; Sanicro 25; low cycle fatigue; thermomechanical fatigue; creep-fatigue interaction

* Corresponding author. Tel.: /
E-mail address: xiangguo@tju.edu.cn

Failure analysis of carbon steel gas pipeline

Saad Khodir[a], Mohamed Newishy[a,]*, Hamed Abdel-Aleem[a]

[a]Central Metallurgical R&D Institute

Abstract

Reduction in wall thickness (40%) was observed over a long section of carbon steel gas pipeline after few months of operations. The investigations carried out in this report shows without doubt that the large decrease in thickness observed at the internal surface of the carbon steel gas pipeline can be classify as flow enhanced CO_2 corrosion failures. The absence of inhibitors materials accelerates the corrosion reaction at the pipe internal surface. The formed $FeCO_3$ scale did not provide protection to the internal surface due to flow containing sand particles. The flow containing sand damaged and removed the protective scale ($FeCO_3$ scale), leading to creation of fresh surfaces for further corrosive attack. Although, the results obtained showed the conformity of pipe material to API 5L X52 steel, typically microstructure, tensile properties and hardness values with no abnormalities in the material structures, but this kind of carbon steel material is not a good choice for environments contain CO_2 gas. The highest reduction in the wall thickness was at the direct impingement between the erosive turbulent flow with the pipe internal surface. It is recommended to using corrosion inhibitors to reduce the corrosion rate and select other pipe material having good resistance to CO_2 corrosion with higher hardness like 13% chromium martensitic steel.

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Keywords: Flow enhanced CO_2 corrosion; carbon steel; inhibitors; sand particles; tensile properties;

* Corresponding author. Tel.: /
E-mail address: saadamma21@yahoo.com

Cohesive zone model for the high-cycle fatigue of surface-nanostructured metals under axial-torsional load

Qiuqiu Sun[a], Xiang Guo[a,*], George Weng[b,*], Gang Chen[a]

[a]*Tianjin University, Tianjin, China*
[b]*Rutgers University*

Abstract

High-cycle fatigue behavior of both coarse-grained (CG) and surface-nanostructured (SNS) metals under axial-torsional load is modeled by cohesive zone model. In order to describe the random nature of metal fatigue, the Monte Carlo simulation is combined with the Weibull distribution. For both CG and SNS metals, we find that the axial load levels have greater effects than random fields on the amplitude of specimen rotation. In comparison with the CG metals, the damage process of the SNS metals initiates from the subsurface beneath the nanograined layer and then extends to the exterior surface. It is found that the SNS metals exhibit an improved fatigue resistance and fatigue life. The agreement between the numerical results and the experimental data shows the applicability of the cohesive zone model for damage evolution analysis and fatigue life estimation of metals.

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Keywords: Flow enhanced CO_2 corrosion; carbon steel; inhibitors; sand particles; tensile properties;

* Corresponding author. Tel.: /
E-mail address: xiangguo@tju.edu.cn, agang@tju.edu.cn

Cyclic loading induced heterogeneous deformation and damage in an austenitic-ferritic two phase steel during low cycle fatigue

Guocai Chai[a,*], Lars Ewenz[b]

[a]Sandvik group
[b]Sandvik Materials Technology

Abstract

Cyclic loading induced heterogeneous deformation and damage in an austenitic ferritic steel with different phase strengths have been studied. Low cycle fatigue tests were performed at RT. The structures were studied using EBSD and ECCI. The results show that the softer phase and grain with a higher Schmid factor will undertake plastic deformation first. However, the deformation structures in the FCC and BCC phases are totally different. In austenitic or FCC phase, cyclic deformation induced twinning has occurred. This is the first observation in this type of material. In ferritic or BCC phase, dangle dislocations and dislocation subcells can be observed. However, they can be greatly influenced by material condition. No twinning occurred in the cold deformed material, and planar dislocation slips can now be observed in the ferritic phase in the aged material. The mechanisms related to the stacking fault energy of the material have been discussed.

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Keywords: Duplex stainless steels, low cycle fatigue; strain localization deformation twinning;

* Corresponding author. Tel.: /
E-mail address: guocai.chai@sandvik.com

Calibration of constitutive equations for the stress level estimation in domain with the large strains

Andrzej Neimitz[a,]*, Ihor Dzioba[a], Sebastian Lipiec[a]

[a]*Kielce University of Technology, Al.1000-lecia P.P.7, 25-314 Kielce, Poland*

Abstract

In the paper the calibration technique of the true stress - logarithmic strain curves is proposed, based on the modified Bai-Wierzbicki method. Calibration was done using four various specimen geometries selected to provide a wide range of stress triaxialities and Lode parameters. The level of plasticity was controlled by selection of three various materials tested at three temperatures: +20ºC, -20ºC, -50ºC. Modification of Bai-Wierzbicki method includes another way of computing the stress triaxiality and Lode parameter, taking into account the evolution of these parameters during the loading process. Also the material softening was included before the final failure.

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Keywords: constitutive equations; Lode parameter; large strain

* Corresponding author. Tel.: +48 41 34-24-307
E-mail address: neimitz@tu.kielce.pl

A computationally efficient fe approach for residual stress induced by additive manufacturing

Li Sun[a], Xiaobo Ren[b], Jianying He[a], Jim Stian Olsen[a], Sakari Pallaspuro[a], Zhiliang Zhang[a,]*

[a]*Department of Structural Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway*
[b]*Materials and Chemistry, The Foundation for Scientific and Industrial Research (SINTEF) , Trondheim, Norway*

Abstract

The aim of the work is to study the thermo-mechanical performance of additive manufacturing process and improve the computational efficiency of finite element approach to the prediction of residual stress induced by additive manufacturing. A two-dimensional transient thermo-mechanical FE model of AA2319 was built to study the relationships among the plastic strain, temperature, and residual stress. The results show that the residual stress is dependent not only on the peak temperature T_P that each node experienced but also on the max temperature T_M that the whole model experienced. Thermal-mechanical model can be divided into three zones: elastic zone, transition zone and yield zone by two critical temperature T_1 and T_2 the nodes experienced based on T_P and T_M. For unmelted model, the whole model is elastic when T_M is less than 180℃. The two critical temperatures T_1 and T_2 decrease with T_M increasing when T_M is greater than 180℃. For melted model, the residual stress is only dependent not on T_P, and the two critical temperatures are 70℃ and 260℃ respectively. The residual stress is linear to the peak temperature T_P in the transition zone and the relationship can be applied to other materials. For both unmelted model and melted model, the parameterized equations were presented for the residual stress of transition zone, relating T_P and T_M. Based on the thermo-mechanical analysis results of these three zones, a finite element computational procedure for simulating the process of additive manufacturing has been proposed, whereby the mechanical part of the computation is replaced by static analytical algorithms. In addition, the application of this approach to 3D additive manufacturing model was analyzed..

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Keywords: Thermal-mechanical Analysis, Critical Temperature; Plastic Strain, Residual Stress

* Corresponding author. Tel.: /
E-mail address: zhiliang.zhang@ntnu.no

Corrosion cracking of carbon steels of different structure in the hydrogen sulfide environment under static load

M.S. Khoma[a], V.R. Ivashkiv[a,*], M.R. Chuchman[a], Ch.B. Vasyliv[a], N.B. Ratska[a], B.M. Datsko[a]

[a]*Karpenko Physico-Mechanical Institute NAS of Ukraine, 5 Naukova str., Lviv, 79601, Ukraine*

Abstract

Hydrogen sulfide corrosion is one of the main reasons of steels destruction in the oil and gas industry. Damages appear as a result of corrosion and hydrogen embrittlement, and corrosion cracking occurs when the load is applied. The influence of the steels structure on its stress corrosion cracking under the loads in hydrogen sulfide environment is insufficiently studied. The aim of the study is to determine the influence of the steels structure on its corrosion, hydrogenation and corrosion cracking in the NACE hydrogen sulfide solution. It was established that the corrosion rate and hydrogenation of steel У8 in the NACE solution grows when the structure dispersion increases from perlite to sorbite, troostite and martensite. The corrosion rate and hydrogenation of steel 45 are the greatest in pearlite-ferrite, while the smallest - in sorbite. The corrosion of steels У8 and 45 in the NACE solution is localized: the average size of the ulcers is 50 ... 80 μm on the steel У8 and 45 ... 65 μm on steel 45. The depth of ulcers is maximal on the steel У8 with the martensite structure (~ 260 μm) and on the steel 45 with the troostite structure (~ 210 μm). Static load (σ = 300 MPa) increases the hydrogenation of steels in the hydrogen sulfide environment. The concentration of hydrogen in steel У8 with troostite structure increases by ~ 1.8 times. The concentration of hydrogen in steel 45 with troostite and martensite structures increases by ~ 1.2...1.3 and by ~ 1.4...1.6 times, respectively. The steel У8 with martensite and perlite structures and steel 45 with troostite structure has the lowest resistance to corrosion cracking. Steels destruction depends on both hydrogen permeation and the corrosion localization, which leads to the increase of the microelectrochemical heterogeneity of the surfaces.

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Keywords: hydrogen sulfide; corrosion;, stee; structure; hydrogenation

* Corresponding author. Tel.: /
E-mail address: vasyl-1@ukr.net

Examples of combined atomistic and gradient-elasticity approaches in fracture mechanics

Petr Skalka[a], Martin Friák[a], Tomáš Profant[a], Michal Kotoul[a], Jaroslav Pokluda[a,*]

[a]*Brno University of Technology, Czechia*

Abstract

The coupling of atomistic ab initio (AI) and molecular dynamics (MD) approaches with higher order continuum theory involving intrinsic length-scales, the so called strain-gradient elasticity (SGE), appears to be an efficient tool for investigation of size-dependent fracture properties of brittle and quasi-brittle nanofilms and nanosamples. The fracture nanomechanics formulates a plausible criterion for breakdown of classical continuum fracture mechanics in nanoscale components which is related to the size of the near-tip region where the components of the singular stress field are inversely proportional to the square root of a distance from the crack tip. This characteristic length-scale parameter depends of the component size or the film thickness.
The paper shows two examples how to use AI and MD methods to determine the material length scale parameter in the simplified form II of Mindlin's theory of SGE theory. In the first example, the crack opening displacement in the centre cracked silicon nano-panel obtained elsewhere [1] by MD simulations was used as a benchmark for adjusting the finite-element SGE model of this panel. The second example presents an AI solution for the displacement field near the screw dislocation in tungsten single crystal along witch the best-matching SGE solution. These examples show a possibility to address deformation and fracture problems at micro and nano scales in an effective and computationally robust manner thus helping to bridge the gap between the classical continuum theories and the atomic-lattice theories.

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Keywords: ab initio; molecular dynamics;, strain-gradient elasticity; nanosamples; fracture mechanics

* Corresponding author. Tel.: /
E-mail address: pokluda@fme.vutbr.cz

Extracting the T-stress in the vicinity of 3D straight singular edges by the Qausi-Dual Function Method

Yaron Schapira[a,]*, Zohar Yosibash[b]

[a]*Ben Gurion University, Israel*
[b]*Tel Aviv University, Israel*

Abstract

Edge stress intensity functions, and the T-stress among them, are of high importance for the determination of crack propagation and kinking, especially in realistic three dimensional domains containing flat cracks. Usually, edge stress intensity functions (ESIFs) are extracted pointwise along the crack edge in 3D domains from finite element solutions but there is a lack of methods to extract the T-stress, especially from a 3D elastic solution.
The objective of this work is to first present the 3D asymptotic solution in the vicinity of a crack edge, including the non-singular term termed T-stress, and using it, to present an efficient method to extract ESIFs and the T-stress (as functions along the edge) from finite element solutions. This method has been firstly presented in [1], and was since denoted the Quasi-Dual Function Method. It was already used successfully to extract ESIFs associated with non-integer eigenvalues of the elasticity PDE's [2], but had not yet been extended to the extraction of the T-stress. Herein we show that the dual eigenpairs associated with integer eigenvalues (required to extract the T-stress) contain logarithmic terms [3] and are used successfully to extract these T-stresses.
The methods have been implemented into a commercially popular FE program (Abaqus) and we provide numerical evidence that accurate results may be obtained using the presented methods.

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Keywords: Edge stress intensity functions; t-stress; quasi-dual function method; dual singularities; logarithmic singularities; 3D singularities

* Corresponding author. Tel.: /
E-mail address: schapira.y@gmail.com

Spatio-temporal variations of acoustic emission in the deformed granite under various modes of vibration

Ivan Panteleev[a,*], Leonid Bogomolov[b], Oleg Naimark[a]

[a]*Institute of Continuous Media Mechanics UB RAS, Russia*
[b]*Institute of marine geology and geophysics FEB RAS, Russia*

Abstract

A large number of works is devoted to the investigation of trigger effects under vibration in loaded geomedia. This effect can be observed as instantaneous or delayed in time acoustic emission (AE) activity with different levels of released energy depending on the spatial scale of the object. Despite large volume of experimental data on the effect of vibration on laboratory specimens, the question of the mechanisms and the dependence of the released energy on the parameters of such impact is still open.

This work is devoted to the experimental investigation of the effect of continuous and periodic vibrations on the damage accumulation in the process of uniaxial compression of granite. A series of quasistatic experiments with periodic and continuous vibrations have been carried out on the granite specimens (Isetskiy deposit). A piezo-radiator have been used to initiate vibrations with the given shape, frequency and amplitude. The signal had a sinusoidal form in the experiments with the periodic and continuous vibrations. A series of the separate experiments has been carried out on the continuous vibrations with triangle shape.

Experiments with periodic vibrations have shown that there is decrease in the slope of the repeatability curve for AE amplitudes and increase in in the slope of the repeatability curve for power of AE pulses. Solution to the problem of three-dimensional location has shown that during the last vibrations the localization of the AE sources from the location of the piezo-radiator is observed.

Comparative analysis of AE data in the experiments with continuous vibrations of sinusoidal and triangular shapes has shown that vibrations with sinusoidal pulses lead to relative increase of high-frequency pulses of AE and the reduction of the low-frequency pulses.

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Keywords: acoustic emission; weak vibrations; damage accumulation; cluster analysis; trigger effects

* Corresponding author. Tel.: /
E-mail address: pia@icmm.ru

Influence of loading rate on the fracture toughness of high strength structural steel

A.A. Alabi[a,b,]*, P.L. Moore[c], L.C. Wrobel[d], J.C. Campbell[a,b], W. He[e]

[a]*Department of Mechanical and Aerospace Engineering, Brunel University London, Uxbridge, UB8 3PH, UK*
[b]*National Structural Integrity Research Centre, Granta Park Great Abington, Cambridge, CB21 6AL, UK*
[c]*TWI Ltd, Granta Park Great Abington, Cambridge CB21 6AL, UK*
[d]*Institute of Materials and Manufacturing, Brunel University London, Uxbridge, UB8 3PH, UK*
[e]*Lloyds Register Global Technology Centre, Southampton, SO16 7QF, UK*

Abstract

It is known that rates of loading influence the fracture behaviour of most ferritic steels. High loading rates could change a stable ductile tearing behaviour to an unstable brittle fracture by altering the ductile-to-brittle transition curve. This is predicted to be material dependent, with lower strength structural steels showing a larger tensile property loading rate sensitivity compared to high strength structural steels. A programme of mechanical testing was carried out on S690QL and S960QL to determine the influence of loading rate on the fracture behaviour of high strength structural steels with yield strength > 690 MPa and yield-to-tensile ratio above 0.90. The loading rates considered are those anticipated in offshore in-service conditions, with K-rates up to the order of magnitude of 10^6 MPa√m/s. Results from tensile tests show that the strengths of these grade of steels are relatively unaffected by the effect of loading rate. However, brittle fracture, which is controlled by material strengthening as a result of principal stress in front of the crack, is both loading rate and temperature dependent. Results from tests at quasi-static and elevated loading rates show changes in the fracture behaviour in terms of transition temperature. A shift to a higher ductile-to-brittle transition temperature was observed as the loading rate increases. This was associated with a reduction in the fracture toughness value on the lower transition region. The reference temperature, T_0, at a K-rate of 1 MPa √m/s using Master Curve concepts is estimated to be around -116 °C and -108 °C for Charpy-sized pre-cracked and standard (25x25 mm) SENB specimens respectively, under quasi-static conditions for S690QL. The dynamic $T_{0,d}$ is -70.4 °C in the same steel for Charpy-sized pre-cracked specimens at K-rates up to 10^6 MPa √m/s.

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Keywords: Ductile-to-brittle transition curve, high strength structural steel, loading rate, Master Curvem transition temperature, yield-to-tensile ratio

* Corresponding author. Tel.: +447572141987
E-mail address: aderinkola.alabi@brunel.ac.uk

Dependence of strength characteristics of aluminum alloys on strain rate under tension

Alexey Evstifeev[a,*], Anastasiia Chevrychkina[a,b], Yuri Petrov[a,b], Svetlana Atrochenko[a,b]

[a]*St. Petersburg State University, Universitetskaya nab. 7/9, St. Petersburg, 199034, Russia*
[b]*Institute of Problems of Mechanical Engineering, Russian Academy of Sciences,Bolshoi pr. 61, St. Petersburg, 199178, Russia*

Abstract

The study presents the results of investigation for different aluminum alloys. Small samples of these materials were subjected to static and dynamic tension. A numerical analysis using an incubation time fracture criterion has been carried out. For each material a set of fixed constants were obtained that allows determine the dependencies of the tensile strength of material in a wide range loading conditions.

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Keywords: Tension, dynamic, analysis, aluminum alloy.

* Corresponding author. Tel.: +7 921-432-1524.
E-mail address: ad.evstifeev@gmail.com

A computational implementation of 3D mixed-mode fracture criteria which are invariant with respect to the reference system

Luis Tavara[a,*], Jose Reinoso[a], Antonio Blazquez[a], Vladislav Mantic[a]

[a]*University of Seville, Spain*

Abstract

Many interface damage events occurring in engineering applications are nowadays studied using interface models like Cohesive Zone Models (CZMs) and Linear Elastic-Brittle Interface Model (LEBIM). Mixed-mode fracture criteria in 2D version of these models have been extensively studied; nevertheless, there are still many open questions regarding more general fracture criteria in 3D problems. Previous results pointed out that current implemented 3D versions of CZMs and LEBIM do not consider the correct reference system for the behavior law (resulting in different predictions of the crack front evolution when different reference systems are used). In the present investigation, a 3D LEBIM proposal is implemented in the commercial code ABAQUS through the user subroutine UEL. Special attention is given to the adequate treatment of the mixed-mode for a 3D crack surface. Preliminary results show that the presented numerical tool is robust and able to suitably capture a 3D crack front for any reference system used to model the behavior of the interface.

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Keywords: LEBIM, 3D fracture criteria, interface crack, fracture mixed-mode, UEL .

* Corresponding author. Tel.: /
E-mail address: ltavara@us.es

In-situ measurement of near-tip fatigue crack displacement variation in laser melting deposited Ti-6.5Al-3.5Mo-1.5Zr-0.3Si titanium alloy

Yanzeng Wu[a], Rui Bao[a,*], Shaoqin Zhang[a]

[a]*Institute of Solid Mechanics, Beihang University, Beijing 100191, China*

Abstract

Laser melting deposition (LMD) is an attractive additive manufacturing technique for fabricating titanium alloy components. A variety of distinct layer bands, heat affected bands (HABs), were found in the LMDed sample, which lead to a periodic fluctuation in the fatigue crack growth rate. In this paper, an in-situ fatigue testing was performed to investigate the crack tip opening displacement (CTOD) variation within a full loading cycle. Digital image correlation (DIC) technique was implemented for obtaining the displacement fields at the vicinity of the crack tip. The crack closure phenomenon is observed from the CTOD variation and the crack opening stress level is different between HAB and non-HAB zone. Another key difference between HAB and non-HAB zone is the value of CTOD when the crack is opening. Besides, the variation of the CTOD loop and its influence on fatigue crack growth rate were also discussed in detail.

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Keywords: In-situ; Crack tip opening displacement; Laser melting deposition; Digital image correlation.

* Corresponding author. Tel.: +86-10-82339233.
E-mail address: rbao@buaa.edu.cn

Adaptation of hydrogen transport models at the polycrystal scale and application to the U-bend test

Y. Charles[a,]*, M. Gaspérini[a], K. Ardon[a], S. Ayadi[a], S. Benannoune[a], J. Mougenot[a]

[a]*Université Paris 13, Sorbonne Paris Cité, Laboratoire des Sciences des Procédés et des Matériaux, LSPM CNRS, UPR 3407, 99 avenue Jean-Baptiste Clément, F-93430 Villetaneuse, France*

Abstract

Hydrogen transport and trapping equations are implemented in a FE software, using User Subroutines, and the obtained tool is applied to get the diffusion fields in a metallic sheet submitted to a U-Bend test. Based on a submodelling process, mechanical and diffusion fields have been computed at the polycrystal scale, from which statistical evaluation of the risk of failure of the sample has been estimated.

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Keywords: Hydrogen diffusion, Kinetic Trapping, Finite elements calculations, Abaqus, User Subroutine ; crystal plasticity

* Corresponding author. Tel.: +33-1-49-40-34-61 ; fax: +33-1-49-40-39-38 .
E-mail address: yann.charles@univ-paris13.fr

Nonlinear fracture resistance parameters for cracked aircraft GTE compressor disk

R.R. Yarullin[a,*], A.P. Zakharov[a], I.S. Ishtyriakov[a]

[a]*Kazan Scientific Center of Russian Academy of Sciences, Kazan, Russia*

Abstract

This study is concerned with numerical analysis of cracked aircraft gas turbine engine (GTE) compressor disk based on plastic stress intensity factor (SIF) approach. Damage accumulation and growth at operation have occurred in slot fillet of disk and blade attachment. In all of these failures, crack propagation started from part-trough quarter elliptical corner surface flows. In order to determine elastic-plastic fracture resistance parameters full-size stress-strain state analysis of compressor disk was performed for a quarter elliptical surface cracks under operation loading conditions. The process of numerical calculations includes the analysis of the elastic constraint parameters in the form of the non-singular T-stress and T_Z –factor, as well as the elastic-plastic constraint parameters in the form of the local stress triaxiality h and I_n-factors for the various crack sizes and different operation temperatures. The plastic SIF K_p, which is shown to be sensitive to the constraint effects and environmental conditions, offers an attractive option as a self-dependent, unified parameter for use in characterizing the fracture resistance for a variety of aircraft GTE rotating components.

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Keywords: Gas turbine engine; compressor disk; surface crack; plastic stress intensity factor.

* Corresponding author. +7-843-236-31-02; fax: +7-843-236-31-02.
E-mail address: yarullin_r@mail.ru

Elastic and plastic stress intensity factor in specimen of aluminum alloys under tension and bending in the temperature range

N.V. Boychenko[a,*]

[a]*Kazan scientific Center of Russian Academy of Sciences, Lobachevsky str, 2/31,Kazan, Russia*

Abstract

The elastic and plastic stress intensity factors (SIF) are studied through computations for two aluminum alloys in the temperature range. Subject for studies is central notched specimens with external semi-elliptical surface crack. Wide range of relative crack depth and aspect ratio is studied. The calculations are carried out under uniaxial tension and a three-point bending for aluminum alloys D16 and B95 at -60°C, 20°C and 250°C.
The elastic and plastic stress intensity factor distributions along the curvilinear semi-elliptic crack front are obtained as a function of the relative sizes of defects, the loading type and temperature.
Fundamental differences in the behavior of the elastic and plastic SIFs for surface cracks are established at high, room and low temperatures. The distributions of elastic SIF are the same at different temperatures for both materials. Contrary to that, the plastic SIF is sensitive to the plastic properties of the materials. The plastic SIF gradually increases by increasing the temperature. The plastic SIF, which is sensitive to the constraint effects and elastic-plastic material properties, is attractive as the self-dependent unified parameter for characterization of the material fracture resistance properties.

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Keywords: Plastic stress intensity factor, elastic stress intensity factor, surface flaw, uniaxial tension, three-point bend, low temperature, high tenperature

* Corresponding author. Tel.: +78432363102; fax: +78432363102.
E-mail address: nataboi@yandex.ru

An experimental study on crack-hole interaction under dynamic loads

Irfan Habeeb[a], Chuzhali Nilath[a,*], Shmuel Osovski[a]

[a]Technion - Israel Institute of Technology, Israel

Abstract

Brittle (or quasi-brittle) materials are frequently used for impact-loaded components. Dynamic crack growth in brittle materials, is largely dominated by the interaction of the growing crack with pre-existing flaws, such as voids and micro-cracks, as well as the evolution of the later under the applied load and the interactions among them. The evolution of pre-existing flaws, as well as the creation of new ones, was proposed to be responsible for a large portion of the excess energy dissipation in the dynamic case compared to quasi-static fracture.
A question then arises: what is the effect of the initial population of flaws, in terms of size and spatial distributions, on the dynamic fracture process?
We present an experimental study on the interaction of a dynamically loaded mode I crack with an existing distribution of flaws. For this purpose, a new specimen made of is introduced, which allows for the propagation of a Mode I crack under a large range of loading rates for large distances (several cm). Voids with different radii and spatial distributions are introduced in the specimen to observe their influence on the resulting stress field, crack velocity and crack path. The experiments are held using a Hopkinson bar, triggering a high-speed camera. Digital image correlation is used to study the mechanical fields in the specimen throughout the crack growth process, shedding light on the nature of the interaction between the crack and the pre-made flaws. Some conclusions regarding the crack path resulting from the above-mentioned interactions will be discussed.

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Keywords: Stress intensity factor, Dynamic brittle failure, PMMA, micro-cracks, Digital Image Correlation

* Corresponding author. Tel.: /
E-mail address: cnirfan@gmail.com

Mean stress effect on fatigue behavior of austenitic stainless steel in air and LWR conditions

Wen Chen[a,*], Philippe Spätig[a], Hans-Peter Seifert[a]

[a]*Paul Scherrer Institute, Switzerland*

Abstract

In this work, the influence of mean stress on fatigue behaviour of 316L austenitic stainless steel in air and LWR environment 288 °C has been studied using load-controlled tests. Hollow specimens were used and tested under simulated LWR water environment with our in-house built water loop system. Both positive mean stress (+50 MPa) and negative mean stress (–20 MPa) were observed having beneficial effect on fatigue life. This is tentatively attributed to secondary hardening. The test results are illustrated in the Figure 1 and Figure 2 below showing the results obtained in high-purity hydrogen-water chemistry typical of boiling water reactor and in high-temperature air respectively. Tests in air are still under progress. In order to gain insight into the physical micro-mechanism controlling the fatigue behaviour under mean stress and environmental influence, the microstructures evolution was investigated via TEM and ECCI characterization on samples cut from interrupted fatigue tests. The fatigue tests were also supplemented with fractographical SEM striation spacing measurement and EBSD characterization around cracks.

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Keywords: Fatigue, mean stress, light water reactor, austenitic stainless steel

* Corresponding author. Tel.: /
E-mail address: wen.chen@psi.ch

A method for component-oriented toughness analysis of modern multiphase steels

Markus Könemann[a,*], Victoria Brinnel[a], Manuel Henrich[a], Sebastian Münstermann[a]

[a] *Steel Institute (IEHK) RWTH-Aachen University, Intzestraße 1, 52072 Aachen, Germany*

Abstract

Steel is still the most important construction material for private and utility vehicles. The saving of fuel based on crude oil is therefore always associated with a reduction in weight of the components made of steel. The dimensioning of these components plays an important role for the weight reduction of modern vehicles. If components are particularly efficient, they are able to withstand the loads occurring with minimum material usage throughout the entire product life. For efficient components, considering the toughness of modern multiphase steels is a main factor. So far, there is no suitable method to investigate sheets with small thicknesses in an experiment that is comparable to the Charpy impact test. Therefore, a new test procedure for steels with sheet thicknesses below 2 mm has been developed in recent years at the Steel Institute of RWTH-Aachen. This procedure can be used to avoid over-dimensioning with unnecessary reserves, which lead to inefficient vehicles with high fuel consumption.
The method proposed in this article for the investigation of these materials is the tensile impact test. This enables the toughness examination of thin sheets and provides information about their behavior in relevant stress situations.
In the presented study, the experiment is presented and a procedure for the quantitative estimation of necessary material properties in special stress situations is described. Numerical simulations can be used to identify highly stressed regions and define stress states that characterize these regions. In a sample catalogue created for the tensile impact test, a sample can be selected that matches the stress state in the component. Thus, the potential of the material can be checked quickly and without great effort. The article shows the test procedure and presents the sample catalogue. In addition, an outline of a procedure to link experiments and simulation-based investigations will be presented.

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Keywords: Tensile impact test, charpy impact test, damage mechanics, component oriented design,toughness characterization of sheet material

* Corresponding author. Tel.: +49-241-80-92911; fax: +49-241-80-92796
E-mail address: Markus.Koenemann@iehk.rwth-aachen.de

Assessment, regulation and management of risks induced by critical facilities

Dmitry Reznikov[a,]*, Nikolay Makhutov[a]

[a]*Mechanical Engineering Research Institute, Russia*

Abstract

The term critical facilities (CFs) hereafter is used to include high-risk man-made systems whose failure may cause multiple deaths and severe economic losses. These include power stations, chemical and oil refinery plants, transportation facilities, etc. Functioning of critical facilities is connected with storing, processing, and transportation of huge amounts of hazardous materials and/or energies. The unauthorized release of these materials and energies may cause disastrous consequences and trigger cascading failures in interrelated infrastructures.

Critical facilities are characterized by a complex structure, behavior, and interaction between their components, which determine the ability to redistribute loads and to resist cascading failures occurring after local failure of their individual components. Owing to the high level of uncertainty concerning the governing parameters of CFs, environmental conditions, and external impacts, the estimation of the CFs performance should be probabilistic. Their evolution may develop along multiple scenarios. The list of possible scenarios includes scenarios of normal operation as well as catastrophic ones. In this regard, the operation of critical facilities becomes impossible without the risk assessment, the development of rational criteria for the acceptability of risks, and procedures for reducing risks to levels that society is ready to accept in the view of the benefits provided by CFs.

A comparative assessment of risk regulation practices regarding operation of critical facilities that are adopted in different countries is presented in the paper. Various risk indexes that can be used for rational decision making in design process are considered. The paper addresses the application of the ALARP principle and the principle of controlled risks in decision making regarding implementation of protection measures aimed at reduction of individual, social and economic risks induced by critical facilities.

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Keywords: Critical facilitie; tolerable risk; acceptable risk; risk assessment; risk regulation; risk management

* Corresponding author. Tel.: /
E-mail address: imashreznikoff@yandex.ru

Influence of the welding process on the residual welding stresses in an orthotropic steel bridge deck

Evy Van Puymbroeck[a,*], Wim Nagy[a], Hans de Backer[a]

[a]Ghent University, Technologiepark 904, 9052 Ghent, Belgium

Abstract

An orthotropic steel bridge deck consists out of a number of longitudinal and transverse stiffeners. These stiffeners are welded to the deck plate which cause residual stresses to be present near the vicinity of this connection. In addition, the welding operation causes multiple fatigue problems across the bridge deck which lead to the formation of fatigue cracks. For an accurate fatigue design of an orthotropic bridge deck, the residual stresses should also be taken into account to determine the effect of these stresses with respect to the load-induced stresses. Tensile residual stresses should be avoided since they tend to open fatigue cracks which results in a shorter fatigue life. The welding of the longitudinal stiffener to the bridge deck plate is simulated with finite element modelling. The effect of the size of the tack welds, the welding current and the welding speed on the residual stresses is determined. These different welding sequences are modelled in order to minimize tensile residual stresses near the weld connection. The welding configuration which leads to smaller tensile residual stresses will result in an orthotropic steel bridge deck with a longer fatigue lifetime.

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Keywords: Residual weld stresses; finite element modelling; orthotropic bridge deck

* Corresponding author. Tel.: +329-264-54-36
E-mail address: Evy.VanPuymbroeck@UGent.be

Evaluation of lifetime, risk and safety of critical technical systems

Dmitry Reznikov[a,*], Nikolay Makhutov[a]

[a]*Mechanical Engineering Research Institute, Russia*

Abstract

Historically, problems of ensuring strength and lifetime in a deterministic formulation were the key elements of the complex task of technical system designing. As the technical systems becoming more and more complex, the level of operational loads, ranges of operating temperatures and aggressiveness of the environment being constantly increased, the need to develop probabilistic approaches to solving the problems of strength and lifetime, as well as setting and solving problems of reliability, damage tolerance and resilience became a critical priority. These problems were in the focus of research efforts over the last decades.

Some of technical systems, such as nuclear and thermal power stations, hydro engineering facilities, chemical, metallurgical, and oil refinery plants, etc., are critical in terms of population life support and ensuring sustainable economic development. The functioning of such systems hereafter referred to as critical technical systems (CTSs) is associated with a high level of uncertainty caused by: (1) natural variability of the system parameters and impacts on it; (2) the random nature of damage accumulation processes and the degradation of the structural material properties; (3) lack of knowledge about complex processes occurring at different stages of the CTSs lifecycle. In this regard, estimates of the strength and lifetime of such systems must be probabilistic. The evolution of CTSs is multivariate and should be described by branched scenario trees. In the spectrum of scenarios, along with scenarios of normal operation, there are inevitably scenarios of failures, accidents and catastrophes, which should become a subject of detailed consideration within the framework of risk assessment procedures. Therefore, in addition to solving traditional problems of strength, durability, reliability, and damage tolerance, the creation of critical technical systems requires comprehensive risk and safety assessments.

Stable operation of CTSs is associated with the provision of basic services to the population and economic entities. The design, construction and operation of the CTSs have to be carried out in the presence of two competing groups of requirements aimed at ensuring their economic efficiency, on the one hand, and safety, on the other. A comprehensive risk assessment and management is a key element in resolving this contradiction and ensuring sustainable development of the economy and society.

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Keywords: Critical technical system; strength; lifetime; risk; safety

* Corresponding author. Tel.: /
E-mail address: imashreznikoff@yandex.ru

Environmental degradation effect of high-temperature water and hydrogen on the fracture behavior of low-alloy reactor pressure vessel steels

Z. Que[a,]*, H.P. Seifert[a], P. Spätig[a], A. Zhang[a], G.S. Rao[a], S. Ritter[a]

[a]*Laboratory for Nuclear Materials, Paul Scherrer Institut, 5232 Villigen PSI, Switzerland*

Abstract

Structural integrity of reactor pressure vessel (RPV) in light water reactors (LWR) is of highest importance regarding operation safety and lifetime. The fracture behaviour of low-alloy RPV steels with different dynamic strain aging (DSA) & environmental assisted cracking (EAC) susceptibilities in simulated LWR environments was evaluated by elastic plastic fracture mechanics tests (EPFM) and by metallo- and fractographic post-test analysis. Exposure to high temperature water (HTW) environments at LWR temperatures revealed only moderated reductions in the fracture initiation and tearing resistance of low alloy RPV steels with high DSA or EAC susceptibility, accompanied with a moderate, but clear change in fracture morphology, which indicates the potential synergies of hydrogen/HTW embrittlement with DSA and EAC under suitable conditions. The most pronounced degradation effects occurred in a) RPV steels with high DSA susceptibility, where the fracture initiation and tearing resistance reduction increased with decreasing loading rate and were most pronounced in hydrogenated HTW and b) high sulphur steels with high EAC susceptibility in aggressive occluded crevice environment and with preceding fast EAC crack growth in oxygenated HTW. The moderate effects are due to the low hydrogen availability in HTW together with high density of fine-dispersed hydrogen traps in RPV steels. Stable ductile transgranular tearing by microvoid coalescence was the dominant failure mechanism in all environments with additional varying few % of secondary cracks, macrovoids and quasi-cleavage in HTW. The observed behavior suggests a combination of plastic strain localisation by the Hydrogen-enhanced Local Plasticity (HELP) mechanism, in synergy with DSA, and Hydrogen-enhanced Strain-induced Vacancies (HESIV) mechanism with additional minor contributions of Hydrogen-enhanced Decohesion Embrittlement (HEDE) mechanism.

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Keywords: Low alloy steels; hydrogen embrittlement; dynamic strain aging; environmental assisted cracking; fracture resistance

* Corresponding author. Tel.: +41 563102528;
E-mail address: zaiqing.que@psi.ch

Development of a damage mechanics based limit strain concept using an enhanced Rousselier model

Florian Fehringer[a,*], Xaver Schuler[a], Michael Seidenfuß[b]

[a]Materials Testing Institute (MPA) – University of Stuttgart, Pfaffenwaldring 32, 70569 Stuttgart, Germany
[b]Institute for Materials Testing, Materials Science and Strength of Materials (IMWF) – University of Stuttgart, Pfaffenwaldring 32, 70569 Stuttgart, Germany

Abstract

Several incidents in the past showed the risks of environmental caused accidents, which exceed the design limits of power plant components. According to technical standards, for the evaluation of safety margins usually stress based criteria are used. These criteria are unable to fully utilize the high deformation capabilities of most materials used for power plant components. To overcome this disadvantage, a proposal for a strain based structural integrity assessment (SIA) concept will be made.

The proposed SIA concept is based on damage mechanics simulations using an enhanced Rousselier model. Therefore, three extensions were made to the standard Rousselier model. First, the integration of an additional term allowing the prediction of failure under shear stress conditions developed by Nahshon and Hutchinson is presented. Second, the extension with a kinematic term using a back-stress tensor to the Rousselier model to properly describe very low cyclic loading behavior will be described. For the description of the back stress tensor, models developed by Drucker/ Prager, Armstrong/ Frederick and Chaboche are used. Third, the plasticity behavior at low stress triaxialities was improved by replacing the von Mises plasticity law by a Hosford like yield criterion. The extensions were evaluated with a large experimental program using a ferritic and an austenitic steel.

For the derivation of the limit strain concept, the different influences of stress triaxiality, component size, non-proportional loading and multiple loading on the limit strains are investigated experimentally and numerically.

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Keywords: damage mechanics; Rousselier model; limit strain concept; stress triaxiality; non-proportional loading, size effect

* Corresponding author. Tel.: +49-711-685-69695; fax: +49-711-685-62635.
E-mail address: Florian.Fehringer@mpa.uni-stuttgart.de

Finite element analysis of fatigue response of nickel steel compact tension samples using ABAQUS

Danilo D'Angela[a,*], Marianna Ercolino[a]

[a]University of Greenwich, Department of Engineering and Science, Central Avenue, Chatham ME4 4TB, United Kingdom

Abstract

Fatigue is a major issue for critical structures, and it can be very significant for structural systems composed of metal plate-like components. Finite Element (FE) analysis has been proved to be an efficient and reliable simulation tool for damage assessment of plate structures under fatigue. However, this approach is still quite challenging and some issues still need to be fully addressed. The FE models are often extremely complex as well as the required computational costs are frequently high. This study presents the numerical simulation of the fatigue fracture in Nickel steel compact tension (CT) samples by means of FE analysis in ABAQUS. The eXtended Finite Element Method (XFEM) is coupled to the direct cyclic Low-Cycle Fatigue (LCF) approach to address the issues related to common modelling of fracture. The fatigue response is implemented by using the well-known *Paris law*. The model is easy to implement and the analysis does not require high computational time. The numerical crack propagation curves fit the experimental results better than the analytical solution. The numerical assessment of the fatigue life and fracture toughness also agrees with the experimental data.

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Keywords: fatigue fracture; compact tension; XFEM technology; ABAQUS; fatigue life;

* Corresponding author. Tel.: +44 (0) 7447 156365
E-mail address: d.dangela@greenwich.ac.uk

Plasticity induced heating – an underestimated effect in monotonic and cyclic deformation?

Jürgen Bär[a,*]

[a]*University of the Bundeswehr, Institute for Materials Science, 85577 Neubiberg, Germany*

Abstract

The increase of the specimen temperature under monotonic and cyclic loading is investigated on pure copper and an aluminum alloy. The temperature increase under monotonic loading leads to an increase of the strain to failure in copper, whereas in the case of the investigated aluminum alloy the mechanical properties remain unaffected. Under fatigue loading the specimen heating rises with the loading level and the frequency. Measurements of the temperature change within a cycle show, that the influence of the frequency can be ascribed to the time for cooling available in the loading cycle. Especially in materials with localized deformation behavior, an effect of the deformation induced heating on the cyclic lifetime can be expected.

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Keywords: Type your keywords here, separated by semicolons ;

* Corresponding author. Tel.: +49-89-6004-2561; fax: +49-89-6004-3055.
E-mail address: juergen.baer@unibw.de

A numerical analysis of the effects of manufacturing processes on material pre-strain in offshore wind monopiles

Satya Anandavijayan[a,]*, Ali Mehmanparast[a], Feargal Brennan[a]

[a]*Cranfield University*

Abstract

The majority of offshore wind turbines in Europe are supported by monopile type foundation structures. Monopiles are made of large thickness steel plates which are longitudinally welded to fabricate "cans" and these cans are subsequently welded around the circumference to manufacture a monopile. Monopile structures can have diameters of 4-10 m, with wall thicknesses of 40-150 mm. To achieve the cylindrical shape in individual cans, large thickness steel plates are typically cold formed via the three-roll bending process. During forming of these plates, the material is subjected to plastic pre-strain, which subsequently influences the fracture and fatigue properties of monopile structures. In this study, a finite element model has been developed to predict the pre-straining levels in monopiles of different dimensions. To determine the influence of numerous manufacturing practices, a sensitivity analysis of different factors has been conducted. These include fabrication dependent variables such as the influence of friction coefficient and bending force, and geometry dependent factors such as plate thickness, length, and distance between rollers. From the numerical results, a range of expected material pre-strain levels have been identified and presented in this paper.

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Keywords: material pre-strain; monopile; fatigue; fracture; S355; finite element analysis; three roll bending

* Corresponding author. Tel.: /
E-mail address: s.anandavijayan@cranfield.ac.uk

Vibrodiagnostics as the tool of a tap wear monitoring

Peter Monka[a], Katarina Monkova[a,*], Marek Uban[b], Lumir Hruzik[c], Martin Vasina[c]

[a]*Faculty of Manufacturing technologies with the seat in Presov, Technical University in Kosice, Sturova 31, 080 01 Presov, Slovakia*
[b]*Faculty of mechanical engineering, West Bohemia University in Pilsen, Universitni 22, 306 14 Pilsen, Czech Republic*
[c]*Faculty of Mechanical Engineering, VSB-Technical University of Ostrava, 17. listopadu 15/2172, 708 33 Ostrava-Poruba. Czech Republic*

Abstract

The article deals with vibro-diagnostics of wear of selected taps - tools for inner thread making. During machining process, it occurs to the tool wear. Except the abrasion on the tool flank and the plastic deformation, it begins to appear also the built-up edge on the face of the cutting tool that is a reason of the worse quality of machined surface and deformed threads. The tests have shown that a short time after these phenomena, it occurs to the cutting-edge cleavage or the tool body breaks in "brittle fracture" way. On-line monitoring of vibrations enables operator to control cutting process and to observe the level of tool wear without necessity to interrupt machining process caused by taking out the tool and measuring values of cutting wedge wear. The taps for M12 thread making with tolerance 6H and with helix lead 0°, 15° and 35° were used during experiments. The functional length of threads was 20 mm what means that the tool worked to the depth of 25.25 mm of pre-drilled hole. The tools were made from High Speed Steel (HSS-E) and they were uncoated. Machined material was the steel C45 (STN 41 2050). It is unalloyed steel that is usually used as a reference material for tool life tests according to appropriate standards.
Records of vibrodiagnostics signals were done by means of TDG141-recorder-USB-4k equipment. Signals were processed and evaluated by means of software NI LabVIEW at two cutting speeds of tap $v_c = 10$ and 20 $m \cdot min^{-1}$. Three accelerometers were used for signals obtaining. The first one was joined to spindle of the machine (CNC milling center Pinnacle VMC 650), the next two were joined to the workpiece in two different axes normal to each other. The most important and corresponding signals were obtained from the accelerometer no.1, where the changes in the wear level have been registered. Using the Fast Fourier Transformation, it has been specified that the tool wear is related to frequency spectra in the range of 750-1000 Hz.

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Keywords: vibrations, diagnostics, tap – tool for thread making, tool wear, brittle fracture, Fast Fourier Transformation

* Corresponding author. Tel.: /
E-mail address: katarina.monkova@tuke.sk

ECF22 - Loading and Environmental Effects on Structural Integrity

Investigation of physical and mechanical properties of rolled electrolytic copper strips

Rozina Yordanova[a,*], Svetla Yankova[a], Donka Angelova[a]

[a]*University of Chemical Technology and Metallurgy, Bulgaria*

Abstract

The Bulgarian Metallurgical Plant SOFIA MED SA, Sofia, is the biggest producer of electrolytic-tough-pitch copper strips, which quality is under investigation. The copper strips have different thickness and are produced in three different tempers – soft, half hard and hard – under different rolling and heat-treatment conditions. The strips from different tempers are subjected to specialized testing and their mechanical and high-electrical-conductivity characteristics are analyzed. For each thickness the mechanical rolled-strip parameters – yield strength, ultimate tensile strength, Vickers hardness, and elongation after fracture – are presented in a way of specific graphical figures: three-dimensional Stress-hardness spaces and Stress-hardness-elongation spaces. These Spaces together with the corresponding High-electrical-conductivity parameters for each thickness can be used as an instrument for general evaluation of the used rolling technology and for prediction of copper-strip physical-mechanical behaviour under given exploitation conditions.

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Keywords: Rolled electrolytic-tough-pitch copper strips, electrolytic copper in soft temper, electrolytic copper in half hard temper, electrolytic copper in hard temper

* Corresponding author. Tel.: /
E-mail address: r.yordanova@uctm.edu

Analysis of stresses concentration in dental implants

Mikhail Perelmuter[a,*]

[a]*Institute for Problems in Mechanics, Russia*

Abstract

Stresses concentration in dental implants was analyzed numerically by the developed boundary elements method software which is based on the solution of the boundary integral equations of linear theory elasticity problems. Computational analysis of implants consists of the two stages: 1) analysis of the structure whole with smoothed screw in the junction between an implant and a bone; 2) analysis of the stresses concentration in the screwed junction at the contact boundary between the implant and the bone.

The computational model of the first stage contain of 7 sub-domains which are conforming to various parts of the implant. The plane strain state in the model was assumed. On all boundaries between sub-domains of the implant model were imposed the ideal contact conditions. Full osseointegration conditions were imposed between the implant and bone. Analysis of the stresses concentration at the screw and bone junction was performed at the second stage of the research. It was assumed, that hollows in the spongy bone, formed in a bone after an implant penetration, are conformed to the screw thread on the implant. Two types of mechanical models were considered: the plane strain state and 3D-model with axial symmetry. The following parameters of models were investigated: mechanical properties of implants and surrounding bones; shape of screw thread; the quality of junction conditions between implants and bones - from full sliding to full osseointegration. In the latter case the boundary between the implant screw thread and the bone was considered on the basis of weak interface model. It was found that the higher stress concentration is observed near the first thread of screw and near at the implant ending. The conditions of cracks formation at the bone-implant junction are considered. The results for different parameters of the model will be presented.

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Keywords: Stresses concentrations, dental implants, boundary elements, Symposium- Damage and Fracture of Biological and Biomedical Materials

* Corresponding author. Tel.: /
E-mail address: perelm@ipmnet.ru

Validating 3D two-parameter fracture mechanics for structural integrity assessments

C.A. Simpson[a,*], S. Tonge[a], A. Cinar[a], C. Reinhard[b], T.J. Marrow[c], M. Mostafavi[a]

[a]*Department of Mechanical Engineering, University of Bristol, University Walk, Bristol, BS8 1TR, UK*
[a]*DIAD Beamline, Diamond Light Source, Harwell Science & Innovation Campus, Didcot OX11 0DE, UK*
[c]*Department of Materials, University of Oxford, Oxford OX1 3PH, UK*

Abstract

In-situ fracture tests were carried out on the I12 beamline at the Diamond Light Source. Four Al-Ti metal-matrix composites (MMCs), with varying combinations of thickness and crack length, were studied to assess for the impact of in-plane and out-of-plane constraint. Synchrotron X-ray computed tomography and synchrotron X-ray diffraction were used to measure total strain and elastic strain respectively. The total strain was calculated via digital volume correlation, with Ti particles within the MMC providing sufficient texture to track the internal displacement vectors in 3D. The total, elastic-plastic strain energy release rate, Jtotal was calculated from 2D slices extracted from the 3D displacement field, with Jtotal reaching a maximum value at the sample surface. It is, however, still unclear whether calculating Jtotal on a slice-by-slice basis provides an accurate representation of strain energy release rate across the crack front; techniques to evaluate the J-integral from the full 3D displacement field are being developed.

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Keywords: Strain energy release rate; J-integral; plastic constraint; XRD; XCT; DVC; DIC

* Corresponding author. Tel.: /
E-mail address: c.simpson@bristol.ac.uk

Justification of the hydraulic turbines lifetime from the standpoint of the fracture mechanics

Evgeniia Georgievskaia[a,]*

[a]JSC "NPO CKTI", Atamanskaia st. 3/6, 191195, Russia

Abstract

Reliable life assessment of hydraulic turbines is important part of the planning of reconstruction, modernization, repairs and replacement.
Long-term positive experience of hydraulic units operation has proved their reliability and the possibility of very long working periods. However, accidents and equipment failures support the need for the development of new approaches to the lifetime assessment of the hydraulic turbines with account of modern technical capabilities and scientific achievements.
At present, both in Russia and in other countries with developed hydropower, there are no established methods or normative methods for estimating of hydro turbine lifetime. The use of the calculation methods applied at the design stage of the equipment, it is not feasible due to high cost and complexity of adapting them to the conditions of the particular unit.
The approach presented in the report is based on the application methods of fracture mechanics to the lifetime-determining nodes of hydraulic turbines and taking into account constructive, technological and operational features. An individual forecast of the development of dangerous defects is based on mathematical models describing the change in the technical condition of equipment in time at the conditions of actual operation. The size and position of the initial defects are determined by the sensitivity of non-destructive methods of control and accessibility of the control areas. The critical crack length corresponds to the instant when the influence of high-frequency loads having small amplitude becomes decisive, which leads to a rapid destruction of the structure.
The proposed approach has a relatively low cost and small time for performing settlement work. At the same time, it allows building long-term forecasts of the hydraulic turbine lifetime and just in time planning repairs or replacement of equipment.

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Keywords: Hydraulic turbines, fracture, failure, defect, crack, reliability, lifetime assessment, non-destructive method;

* Corresponding author. Tel.: +7-921-971-64-43; fax: +7-812-271-12-04.
E-mail address: e_georgievskaya@mail.ru

Fracture of brittle materials under uniaxial compression

Mina Iskander[a,]*, Nigel Shrive[b]

[a]*PhD Candidate, University of Calgary, Calgary, AB, T2N 1N4, Canada*
[b]*Professor, University of Calgary, Calgary, AB, T2N 1N4, Canada*

Abstract

Fracture under compressive loading is distinctly different compared to fracture under tensile loading. One contributing factor is that interatomic bonds have to be stretched to be broken: compressing the interatomic spacing cannot break an interatomic bond. This is demonstrated by the fact that no fracture occurs in materials loaded in hydrostatic compression, even at extreme magnitudes. It is believed that fracture in compressive stress fields starts due to local tensile stresses which develop around a discontinuity (e.g. an air bubble). A 2D numerical study is conducted to study the effect of the shape and size of such a discontinuity on crack propagation in a macroscopic uniaxial compressive stress field. The results of this study highlight the major differences between tensile crack propagation and compressive crack propagation in brittle solids.

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Keywords: Compression; uniaxial; crack propagation; fracture; brittle

* Corresponding author. Tel.: +1-587-500-2995
E-mail address: mina.iskander@ucalgary.ca

Nonlinear solid mechanics: applications to loading of structures in damaged materials

Vera Turkova[a,]*

[a]*Samara National Research University, Moskovskoe shosse 34, Samara, 443086, Russian Federation*

Abstract

Nowadays the damage and failure of the material are of critical interest to designers of engineering structures, as there is a lack of methods for accurate failure prediction and damage analysis. Especially for early stages of the design process, a quick way of estimating material behavior is needed. There is a need for a material model coupled with a damage evolution law. In the paper a damage model, based on continuum damage mechanics, is presented. The material law is implemented computationally as a user defined subroutine (UMAT) in a commercially available FEM package Simulia Abaqus. The active damage accumulation zone for rod specimen is analyzed. Distribution of each damage component is given.

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Keywords: Damage analysis, continuum damage mechanics, subroutine UMAT, damage accumulation zones

* Corresponding author. Tel.: +89276544393.
E-mail address: turkova.ver@yandex.ru

Toughness of highly ductile pipeline steels

Jacques Besson[a,*], Takahiro Sakimoto[b], Yazid Madi[c]

[a]*Mines ParisTech, PSL Research University, Centre des Matériaux, UMR CNRS 7633, France*
[b]*JFE Steel Corporation, Japan*
[c]*EPF-Ecole d'Ingénieures, France*

Abstract

Over the past decades, ductility and toughness of pipeline steels has been drastically improved. Material thickness is suited to the application and usually relatively small (e.g. less than 20 mm). This can lead to difficulties when carrying out toughness tests following well established standards (e.g. ASTM-E1820) which require the specimen size to be large enough to consider that the test is valid. For instance the measurement of the J-integral is considered as valid as long as: $J \leq 1/10 \min(B,b_0)\sigma_Y$ where B is the specimen thickness, b_0 the ligament size and σ_Y the average of the 0.2% offset yield strength and the ultimate ensile strength. In addition the large distortion of the specimen can make it difficult to measure crack extension using the elastic unloading compliance method.
In this study a modern ferrite--bainite API5L X65 steel plate before pipe forming is investigated at room temperature. Tests were carried out along the rolling direction (L), long transverse direction (T) and the diagonal direction 45° between directions L and W in the sheet plane referred to as (D). Test specimens include: (i) smooth axisymmetric tensile bars, (ii) axisymmetric notched bars with various notch radii, (iii) plane strain specimens, (iv) Compact Tension (CT) specimens, (v) Single Edge Notch Tensile (SENT) specimens.
The database is first used to fit a macroscopic plasticity model able to represent the anisotropic elasto-plastic behavior of the material. A GTN model accounting for plastic anisotropy is then used to represent ductile fracture. The model is tuned so as to represent ductility for tests carried out along the T direction. However fracture anisotropy is limited for this material. The fracture model is able to represent the entire database. It is shown that valid tests cannot be carried out using standard CT (B = 12.5 mm) or SENT (B = 14 mm) specimens. The model is then used to simulate the entire testing procedure for cracked specimens including elastic unloadings used to measure crack advance.
A *virtual* test on a thick specimen can then be simulated allowing for the determination of a valid J-Δa curves for Δa up to 3 mm for a J value of about 2500 kJ/m^2. The methodology is also applied to miniature specimens representative of test specimens that could be machined from test coupons extracted from in-service installations.

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Keywords: API5L X65 steel, toughness, validity, ASTM E1820, CT SENT specimens

* Corresponding author. Tel.: /
E-mail address: jacques.besson@ensmp.fr

Simulation of fatigue fracture of FeMn-based shape memory alloys at cyclic mechanical tests

Fedor S. Belyaev[a]*, Margarita E. Evard[a], Aleksandr E. Volkov[a]

[a]*Saint Petersburg State University, Saint Petersburg,199034, Russian Federation*

Abstract

In this microstructural simulation of the mechanical behavior of FeMn-based shape memory alloy samples at mechanical cycling the threefold symmetry of the close-packed planes {111} of the austenitic fcc phase and basic planes {0001} of the martensitic hcp structure and the multi-variance of the reverse martensitic transformation are taken into account. Damage accumulation and resulting fatigue fracture are described in the terms of the internal variables associated with a damage variable and the densities of the oriented and scattered deformation defects. A deformation-and-stress criterion of fracture is proposed. It takes into consideration the effect of hydrostatic pressure, deformation defects and material damage. It is shown that the approach is suitable for describing the fatigue fracture of iron-based shape memory alloys at cyclic mechanical loading.

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Keywords: FeMn, FeMnSi, shape memory, plasticity, defects, fatigue, fracture criterion.

* Corresponding author. Tel.: +7-812-428-4220; fax: +7-812-428-7079.
E-mail address: f.belyaev@spbu.ru

Effect of defects on failure of welded steam boiler flange

Hamed Abdel-Aleem[a,]*, Saad Khodir[a], Mohamed Newishy[a]

[a]*Central Metallurgical Research and Development Institute, Egypt*

Abstract

Steam boiler flange made of carbon steel alloy ASTM A105 was failed at area adjacent to the welding zone when the operating pressure and temperature suddenly increased over than designed values. The failure occurred after 6 years in service. The flange and connected pipe failed segments was received for failure analysis and data collections. The flange was subjected to visual examination, non-destructive test, chemical analysis, microstructure observation, and hardness test. The results of chemical composition showed the conformity of flange material with the required specifications of ASTM A105, typically microstructure, hardness values with no abnormalities or creep indications and Absence of cracks close to the ruptured area excluding the possibilities of defective materials or overheating. Macro and micro-structures examination of the weld joint showed numerous welding defects such as porosity, lack of fusion and non-metallic inclusion at the boundary line between the root and filling passes. Apparently the steam boiler flange material fractured due to fatigue crack. Fine striations within the beach mark of the fractured surface observed by SEM give a strong indication of fatigue failure. The crack initiated at the edges of welding defects and proceeded in the flange material due to the fluctuating radial stresses resulted from increasing and decreasing working pressure during service. A proper welding techniques carried out by qualified welders are recommended for prevention of similar failure in the future.

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Keywords: Steam boiler flange, carbon steel, welding defects, fatigue failure.

* Corresponding author. Tel.: /
E-mail address: hamedaa@gmail.com

Integrity assessment of ammonia spherical storage tank

Aleksandar Milovanović[a,]*, Aleksandar Sedmak[b]

[a]Sinterfuse
[b]Faculty of Mechanical Engineering, University of Belgrade, Serbia

Abstract

The integrity of the ammonia spherical tank (with a volume of 1800 m3 and the outer diameter of 15120 mm, nominal wall thickness 30 mm) was analyzed due to discovered cracks on the longitudinal and transverse but joints of the segments, of different lengths and depth. The calculation according to EN 13445-3: 2014 specifies the minimum required spherical shell wall thickness. The finite element method was used to analyze the cracks and determine the hoop stress value. The stress intensity factor for the analysed cracks was analytically determined, and the obtained values were compared with the critical value of the stress intensity factor to assess the integrity of the observed structure.

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Keywords: Structure integrity; stress intensity factor; spherical tank; finite element method; calculation of spherical shell wall thickness

* Corresponding author. Tel.: /
E-mail address: a.milovanovic89@gmail.com

A study of fatigue notch sensibility on titanium alloy TiAl6V4 parts manufactured by selective laser melting

L.P. Borrego[a,b,*], J.A.M. Ferreira[b], J.D.M. Costa[b], C. Capela[b], J. de Jesus[b]

[a]*Coimbra Polytechnic - ISEC, Rua Pedro Nunes, 3030-199 Coimbra, Portugal*
[b]*CEMMPRE, Department of Mechanical Enginnering, University of Coimbra, Rua Luís Reis Santos, 3030-788, Coimbra, Portugal*

Abstract

Titanium Ti6Al4V alloy is a light alloy characterized by having excellent mechanical properties and corrosion resistance combined with low specific weight, commonly used in biomedical applications, automotive and aerospace components. Current work analyses the fatigue behavior of titanium alloy TiAl6V4 parts, manufactured by selective laser melting (SLM), intending to characterize fatigue strength from low to high life range, under constant amplitude strain control. Fatigue tests were carried out at room temperature, using round dog bone specimens where laser powder deposition occurred in layers perpendicular to the sample axle. All specimens were subjected to stress release treatment. A second batch of specimens was tested in order to investigate the notch sensibility of the material. All tests were performed under displacement control. The material was characterized in terms of the tensile mechanical properties, cycle curve, Basquin and Coffin equations. The analysis of the results showed a strain-softening behavior that increased with applied strain, and non-linear response in and plastic regime. In addition, this alloy exhibited a low transition life, about 250 reversals, which can be attributed to the combination of high strength and relatively low ductility. The material revealed a notch sensibility factor, that was quantified for the round notch with a stress concentration factor $K_t = 1.7$ (with respect to the effective cross section), increasing with fatigue life, from one for low cycle fatigue tending to 1.42 for high cycle fatigue (N_f of about one million cycles). SEM analysis showed that fatigue crack initiated from the surface and propagated through the cross section, occurring in many cases multi-nucleation.

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Keywords: Additive manufacturing, fatigue, notch sensibility, TiAl6V4 alloy.

* Corresponding author. Tel.: +351239790200; fax: +351239790331.
E-mail address: borrego@isec.pt

Microstructure degradation for damage measurement in a dual phase steel

Rodolfo Rodríguez-Baracaldo[a,*], Lais Mujica-Roncery[b], Avendaño-Rodríguez[a]

[a]*Universidad Nacional de Colombia, Colombia*
[b]*Universidad Pedagógica y Tecnológica de Colombia, Colombia*

Abstract

This paper presents an experimental characterization of ductile damage evolution in a DP600 steel containing 0.150 wt.% C, 1.04 wt.% Mn, 0.409 wt.% Si, 0.037 wt.% S, and 0.050 wt.% P, that was intercritically annealed at different temperatures from 715 to 875 °C and quenched in water, to produce dual-phase steel microstructure with different martensite volume fractions. A set of loading-unloading uniaxial tensile test was carried out, in order to characterize the material damage, based on the measurements of the deterioration exhibited by the Young's modulus due to increasing levels of plastic deformation. Detailed microstructure observation of the strained and sectioned samples was performed by scanning electron microscopy (SEM). The martensite volume fraction (V_m) has a dominant role in the damage mechanisms. At a high V_m, the prevalent mechanism of void nucleation is the martensite fracture, with an accelerated damage accumulation at low plastic strain.

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Keywords: Microstructure degradation; damage; dual phase steel .

* Corresponding author. Tel.: /
E-mail address: rodriguezba@unal.edu.co

Influence of hydrogen for crack formation during mechanical clinching

Daisuke Sasaki[a,*], Yuki Tampa[b], Toru Kato[b]

[a]National Institute of Technology, Kurume College, 1-1-1 Komorino, Kurume, Fukuoka, 830-8555, Japan
[b]National Institute of Technology, Ishikawa College, Kitacyujo, Tsubata, Ishikawa, 929-0392 Japan

Abstract

Hydrogen intrudes into the steel during pickling process which is a pre-processing before a joining process, promoting crack formation. In a mechanical clinching which is one of joining method in the automotive industry, cracks due to large strain sometimes forms. In order to guarantee reliability, it is important to clarify the influence of hydrogen on crack formation of the joint. In this study, we clarified the influence of hydrogen for the crack formation on the mechanical clinching. Hydrogen charge was carried out using an electrolytic cathode charge. After the charging, mechanical clinching was performed. Mechanical clinching was carried out with steel plate and aluminium alloy plate. To clarify the influence of hydrogen, mechanical clinching was conducted without hydrogen charring. To investigate the crack formation, the test piece was cut and the cut surface was observed. When the joint was broken during the clinching, the fracture surface was observed using an optical microscope and an electron microscope. The load displacement diagram showed that without hydrogen charging, the compressive load increased as the displacement increased. On the other hand, the compressive load temporarily decreased with high hydrogen charging, suggesting that cracks formed at the time. The cut surface observation showed that interlock was formed in both cases with low hydrogen charging and without hydrogen charging. With low hydrogen charging, no cracks were formed in the joint. When high hydrogen charging was performed, cracks were formed at the joining point. Fracture analysis showed brittle-like fracture surface. These results indicate that hydrogen induces crack formation in the mechanical clinching.

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Keywords: Mechanical clinching; hydrogen embrittlement; crack formation;.

* Corresponding author. Tel.: +81-942-35-9375 ; fax: +81-942-35-9425.
E-mail address: d-sasaki@kurume-nct.ac.jp

Emergence of distinct fatigue limit: impact of excess solute magnesium in 6061-T6 alloy

Yoshimasa Takahashi[a,*], Ryosuke Kuriki[a], Masaki Kashihara[a], Takahiro Shikama[b], Hiroshi Noguchi[c]

[a]Department of Mechanical Engineering, Kansai University, 3-3-35 Yamate-cho, Suita-shi, Osaka 564-8680, Japan
[b]Kobe Steel Ltd., Aluminum & Copper Business (Chofu Works), 14-1 Chofu Minato-machi, Shimonoseki,Yamaguchi 752-0953, Japan
[c]Department of Mechanical Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan

Abstract

The fatigue properties of 6061-T6 aluminum (Al) alloy containing additional solute magnesium (Mg) is studied. As previously reported, this special alloy exhibits eminent strain-aging characteristics which is absent in a normal 6061-T6 alloy with a stoichiometric Mg_2Si composition. In this study, particular attention is paid to the environmental effect on the fatigue properties of this new alloy. The *S-N* curves of the alloys are compared in different environments (ambient air, dry air, dry nitrogen). A clear knee-point (fatigue limit), which is atypical to the normal 6061-T6 alloy, appears for the new alloy irrespective of the environment. The fatigue limit is shown to be controlled by the threshold against small crack propagation in all environments. On the other hand, the coaxing effect, the manifestation of a *time-dependent* strengthening mechanism at the non-propagating crack tip, is clearly observed in the ambient air.

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Keywords: Distinct fatigue limit; aluminum alloys; 6061-T6; strain aging; extra magnesium; environmental effect

* Corresponding author. Tel.: +81-6-6368-0748; fax: +81-6-6368-0748.
E-mail address: yoshim-t@kansai-u.ac.jp

Numerical modeling of 3D woven hybrid composites for stiffness and strength prediction

Ahmed Sohail[a,*], Zheng Xitao[a], Shiekh Muhammad Zakir[a], Zhang Di[a]

[a]*School of Aeronautics, Northwestern Polytechnical University, Xi'an PR China*

Abstract

Due to recent development of the advanced 3D woven composites, it has been possible to adjust the mechanical properties either by placing the fiber tows in a certain direction or by replacing the fibers having nominal mechanical properties with the fiber of higher mechanical properties in a certain proportion. The later process is known as hybridization of reinforcement material. By adding the fibers with higher mechanical properties adds the cost and second and more important is the estimation of elastic and strength properties of hybridized material. In the current study, an efficient numerical model is established which can estimate the in-plane elastic and strength properties of 3D hybrid woven composites. At first a detailed geometry is constructed for a finite element mosaic model for a weave configuration which is already available in the literature. After validating the models successfully, fiber tows in a certain ratio are replaced with other materials to attain the hybridization of 3D woven composite. Finally, a numerical model established to find the elastic and strength properties of hybrid 3D woven composite

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*Keywords:*3D woven composites; hybridization; elastic properties; strength; numerical modeling

* Corresponding author. Tel.: +0086-15691970571.
E-mail address: s.ahmed@mail.nwpu.edu.cn

Effects of the building direction on fatigue crack growth behavior of Ti-6Al-4V manufactured by selective laser melting

Wenbo Sun[a], Yu'e Ma[a,*], Xiaopeng Ai[a], Jianghai Li[b]

[a]*School of Aeronautics, Northwestern Polytechnical University, Xi'an 710072, China*
[b]*AVIC Chengdu Aircraft Design and Research Institute, Chengdu 610041, China*

Abstract

Additive manufacturing selective laser melting (AM-SLM) are potential to be widely used in aircraft structural components. There are apparent layers along the building direction of titanium alloy samples manufactured by SLM. This will affect its fatigue properties. At present, few papers about effects of the building direction on fatigue crack growing behavior have been published. In this work, three kinds of titanium alloy Compact Tension (C(T)) specimens with different building directions were designed. Fatigue crack growth rate (FCGR) tests were performed. And fatigue crack growth rate versus stress intensity factor range ($da/dN - \Delta K$) curves were obtained and then effects of the building direction on crack growth was analyzed. It is shown that FCGR of specimen with 90° building direction is the fastest, and then that of the 0° sample is slower, and 45° sample is the slowest. Fatigue life of 45° specimen is 1.49 times longer and 1.46 times longer than that of 90° and 0° specimen separately. Fracture morphology of samples was studied. It shows that the fracture surface with 0° building direction is smooth and fatigue striations are observed. The fracture surface with 45°building direction has a slope along the thickness. The fracture surface of the sample with 90°is cluttered, and its building layers can be observed. But its fatigue striations are not clear.

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Keywords: Additive manufacturing selective laser melting; titanium alloy; building directions; fatigue crack growth; fracture surface

* Corresponding author. Tel.: /
E-mail address: ma.yu.e@nwpu.edu.cn

Stochastic analysis of discontinuous slow crack growth of high density polyethylene using crack layer theory

Jung-Wook Wee[a,*], Byoung-Ho Choi[a]

[a]Korea University, South Korea

Abstract

It is well known that the high density polyethylene (HDPE) structural components fail in different modes with regard to the applied stress level. Particularly, in the intermediate load range, the HDPE usually shows the brittle fracture followed by the slow crack growth (SCG). The HDPE reveals the continuous, discontinuous, and mixed SCG modes, depending on the load level and temperature. While the deterministic crack layer (CL) theory has been successfully employed to simulate such uncommon SCG kinetics, the stochastic study for the CL simulation has not been performed yet, thus it must be also performed in view of reliable design of HDPE structural components. In this study, the existing deterministic CL model was modified for the stochastic discontinuous SCG of HDPE in a single edge notched tensile (SENT) specimen under static loading. The influences of the stochastic distribution of input parameters on the discontinuous SCG were investigated, and the important parameters which affect the final lifetime notably were also identified. Then, the lifetime distributions followed by the discontinuous SCG were fitted by the Birnbaun-Saunders (B-S) distribution function. Finally, the equations of the scale and shape parameters of the B-S function with the distributions of important parameters were constructed.

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Keywords: High density polyethylene; crack layer theory; stochastic analysis; slow crack growth

* Corresponding author. Tel.: /
E-mail address: yjw0914@korea.ac.kr

Re-examination of fatigue crack propagation mechanism under cyclic mode II loading

Shigeru Hamada[a,]*, Taro Suemasu[b], Motomichi Koyama[a], Masaharu Ueda[c], Hiroshi Noguchi[a]

[a]*Faculty of Engineering, Kyushu University, 744 Moto-oka, Nishi-ku, Fukuoka 819-0395, Japan*
[b]*Graduate School of Engineering, Kyushu University, 744 Moto-oka, Nishi-ku, Fukuoka 819-0395, Japan*
[c]*Yawata R & D Lab., Nippon Steel & Sumitomo Metal Co., 1-1 Tobihatacho Tobata-ku, Kitakyushu 804-8501, Japan*

Abstract

The essence of rolling contact fatigue is the so-called "Mode II fatigue crack propagation." However, its understanding has not progressed as much as that of Mode I. We think that this cause is the name: "Mode II fatigue crack propagation." Originally, Modes I and II represented the loading modes for still cracks in fracture mechanics, and not the fatigue crack propagation mechanism. There are many cases where the knowledge of fatigue crack propagation under Mode I loading is applied to that under Mode II loading without consideration. Moreover, in the rolling contact fatigue region where the fatigue crack propagates under Mode II loading, a large plastic deformation is caused by the rolling contact load. Therefore, it is necessary for the test method to reproduce the effects of an actual machine to test materials that exhibit large plastic deformation. Therefore, in this study, we aim to classify the fatigue crack propagation phenomena, regardless of Mode I and II loadings, and re-examine the mechanisms. To that end, we developed a novel test method that enables pure Mode II loading. We used a micro-thin film disc as a specimen, making it possible to cut out and test a part subjected to a large plastic deformation from the actual machine. By observations of the crystallographic structure before the fatigue test and the successive observation of fatigue crack propagation behavior, we propose a crack propagation mechanism, namely, damage accumulation type fatigue crack propagation under Mode II loading, which is different from the opening type fatigue crack propagation.

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Keywords: Mode II; fracture mechanics; damage accumulation; fatigue crack propagation phenomenon; fatigue crack propagation mechanism

* Corresponding author. Tel.: +81-92-802-3061; fax: +81-92-802-0001.
E-mail address: hamada@mech.kyushu-u.ac.jp

Effect of Si on temperature dependence of non-propagation limit of small fatigue crack in a Fe-C alloy

Kohei Kishida[a,*], Motomichi Koyama[a], Nobuyuki Yoshimura[b], Eisaku Sakurada[c], Tatsuo Yokoi[d], Kohsaku Ushioda[e], Kaneaki Tsuzaki[a], Hiroshi Noguchi[a]

[a]*Faculty of Engineering, Kyushu University, 744 Moto-oka, Nishi-ku, Fukuoka-shi, Fukuoka 819-0395, Japan*
[b]*Nippon Steel & Sumitomo Metal Corporation, 20-1 Shintomi, Futtsu, Chiba 293-8511, Japan c*
[c]*Nippon Steel & Sumitomo Metal Corporation, 5-3 Tokai, Tokai, Aichi 476-8686, Japan*
[d]*Nippon Steel & Sumitomo Metal Corporation, 1 Oaza-Nishinosu,Oita, Oita 970-0922, Japan*
[e]*Nippon Steel & Sumikin Research Institute Corporation, Kokusai Bldg., 3-1-1 Marunouchi, Chiyoda, Tokyo 100-0005, Japan*

Abstract

Dynamic strain aging improves the non-propagation limit of a fatigue crack in ferritic iron alloys containing supersaturated carbon. However, upon increasing the test temperature, the non-propagation limit of the fatigue crack decreases owing to carbide precipitation. In this study, we present a guideline to improve high-temperature fatigue resistance in ferritic steels containing supersaturated carbon via Si addition that suppresses carbide formation. Compared with an Fe-0.017C binary alloy, an Fe- 0.016C-1.0Si alloy shows higher tensile strength at 293 and 433 K. The Si addition increased the fatigue limit at both temperatures as compared with that of the Fe–C binary alloy. The higher fatigue limit than that of the binary alloy at 293 K originated from the solid solution strengthening of Si, whereas the improved fatigue limit in Fe-0.016C-1.0Si at 433 K was attributed not only to the solution hardening, but also to the suppression of carbide formation at 433 K. With an increase in the temperature from 293 to 433 K, the reduction in the fatigue limit of the Fe-0.017C alloy was 65 MPa, while that for the Fe-0.016- 1Si alloy was only 40 MPa. These results indicated that the robustness against temperature can be improved by the addition of Si.

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Keywords: Ferritic steel; dynamic strain aging; dynamic precipitation; high temperature; small fatigue crack growth;

* Corresponding author. Tel.: +81-92 802-3141.
E-mail address: 2te18659p@s.kyushu-u.ac.jp

Effects of different equations of state on the oblique shock wave reflection in solids

Xin Yu[a,*], Xiao Huang[a], Miao Zheng[a]

[a]*Institute of Applied Physics and Computational Mathematics, Beijing 100094, China*

Abstract

The equations of state of solids under high pressure are more complicated than that of gases in a variety of forms. While the existing studies on the oblique shock wave reflection usually take just one of the equations of state, lacking of the comparisons among them. This paper aims at the investigation of oblique shock wave reflection in solids through shock polar methodology. Four different forms of equations of state are considered, principal shock taking with v_N particle velocity relationship and second shock taking with Grüneisen equation of state (1Du2 Grüneisen), principal and second shock both taking with v_N particle velocity relationship (1Du2Du), principal shock taking with v_N particle velocity relationship and second shock taking with stiffened gas equation of state (1Du2 Gamma), and principal and second shock both taking with stiffened gas equation of state (1Gamma2Gamma). The effects of different equations of state on the pressure behind the reflected shock show: different combination of EOS may lead to diverse results. In our opinion, the 1Du2 Grüneisen and 1Du2Du shows almost the same trends in most conditions and is suitable for the theoretical analysis of oblique reflection, and 1Du2Gamma and 1Gamma2Gamma should be carefully employed in studies to avoid the incorrect result.

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Keywords: Oblique shock wave reflection; shock polar; equation of state;solid

* Corresponding author. Tel.: +0-8610-5987-2194; fax: +8610-5987-2300.
E-mail address: yummuy@iapcm.ac.cn

Numerical simulation of spall behavior of metal under strong impact loading

Zheng Miao[a,*], Yu Xin[a], Yin Jian Wei[a]

[a]Institute of Applied Physics and Computational Mathematics, Beijing, 100094, China

Abstract

When the metal material undergo complex loading processes, such as strong impact loading, unloading, backward drawing and reloading, they are likely to spall in the reverse tension stage. In this paper, the following four items are considered in the modeling of material spallation (1) the damage variable in the spallation modeling adopts the concept of porosity; (2) the equation of state containing hole material is calculated by the solid component in the damage unit; (3) when the porosity of the unit reaches the critical porosity, it is considered that the pores are interpenetrated with each other to form a macro crack, and the material is fractured as a whole; (4) When the macro fracture unit is compressed again, if the average compression ratio of the unit reaches the closed critical value, it is considered that the unit is compressed into holed hole.
In the existing the two dimension Lagrange fluid dynamics program, we have added the hole fracture growth, polymerization and collapse effect of spallation processing function, and verify the model and program code through a numerical example. The damage evolution analysis of the unit near a single measuring point shows that the platform area in the velocity curve corresponds to the damage fracture zone in the metal. It is considered that the unit of the location has undergo the physical process of unload-stretching-damage-fracture-free flight- recompression.

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Keywords: Spall; simulation; metal

* Corresponding author. Tel: /
E-mail address: zheng_miao@iapcm.ac.cn

Influence of shear-affected-zone due to punching in tensile characteristics of steel plate

Kejin Zhang[a,]*, Shigeru Hamada[a], Motomichi Koyama[a], Tatsuo Yokoi[b], Hiroshi Noguchi[a]

[a]*Kyushu University, 744 Moto-oka, Nishi-ku, Fukuoka 819-0395, Japan*
[b]*Nippon Steel & Sumitomo Metal Corporation, 1 Oaza-Nishinosu, Oita, 870-0992, Japan*

Abstract

In punched steel plate, "punched specimen" from here onwards, the region near the edge of the punched hole is called the shear-affected-zone (SAZ), where tensile characteristics are compromised due to the punching process. However, the specific characteristics and influence on the tensile characteristics of the SAZ are unknown. Therefore, it is difficult to predict the effects of punching on the specimen. Here, we evaluated two kinds of specimens: punched and "honed." The hole of the honed specimen is formed by drilling and polishing, thus there is no SAZ on the honed specimens. In these specimens, we focused on the initiation and propagation of cracks under tensile loading and set the following objectives: (1) Determine whether any special events occur in the fracture mechanism of the punched vs honed specimens under tensile loading. (2) Find the reasons for any special events that occur. In our investigation, a punched specimen showed brittle fracture even within the static range of the strain rate. By failure surface observation of the punched specimens, we found that under tensile loading, cracks caused by the shear stress aligned with the tensile direction initiate in the SAZ. These cracks are the origin of the final fracture of the punched specimen. We assumed that whether the break is a ductile failure or brittle fracture depends on whether the crack tip becomes blunt. The differences in the fracture behaviors are investigated via detailed fracture surface observation.

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Keywords: Punched steel plate; shear-affected-zone; shear band; tensile characteristic; brittle-ductile transition

* Corresponding author. Tel.: +81-92-802-7677; fax: +81-92-802-0001.
E-mail address: zkj2b2b@gmail.com

Effect of vanadium-alloying on hydrogen embrittlement of austenitic high-nitrogen steels

Galina G. Maier[a,*], Elena G. Astafurova[a], Valentina A. Moskvina[a], Evgeny V. Melnikov[a], Sergey V. Astafurov[a], Alexander G. Burlachenko[a], Nina K. Galchenko[a]

[a]*Institute of Strength Physics and Materials Science, Siberian Branch of Russian Academy of Sciences, Akademichesky pr. 2/4, 634055 Tomsk, Russia*

Abstract

The effect of hydrogen on tensile behavior and fracture mechanisms of V-alloying and V-free high-nitrogen austenitic steels was evaluated. Two steels with the chemical compositions of Fe-23Cr–17Mn–0.1C–0.6N (0V-HNS) and Fe-19Cr–22Mn–1.5V–0.3C–0.9N (1.5V-HNS) were electrochemically hydrogen-charged in NaCl water-solution for 100 hours. According to X-ray diffraction analysis and TEM researches, V-alloying promotes particle strengthening of the 1.5V-HNS. Despite differences in chemical compositions, namely, carbon and nitrogen concentrations, a solid solution hardening is similar for both steels because of precipitate-assisted depletion of austenite by interstitial atoms (carbon and nitrogen) in 1.5V-HNS. For hydrogen-free state, the values of the yield stress and the tensile strength are higher for particle-strengthened 1.5V-HNS as compared to 0V-HNS. Hydrogen-charging increases both the yield stress and the tensile strength of the steels, but hydrogen-assisted fracture micromechanisms are different for 0V-HNS and 1.5V-HNS. Hydrogen-charging drastically reduces a total elongation in 0V-HNS but provides insufficient embrittlement in 1.5V-HNS. Hydrogen-assisted brittle layers form on lateral surfaces of the specimens, and the widths and fracture micromechanisms in them are different for two steels. For 0V-HNS, surface layers of 84 µm in width possess transgranular brittle fracture mechanism (quasi-cleavage mode). For 1.5V-HNS, the brittle surface layers (31 µm width) destroy in intergranular brittle fracture mode. The central parts of steel specimens show dimple fracture similar to hydrogen-free steels. The possible reasons for different hydrogen-induced effects in 0V-HNS and 1.5V-HNS are discussed.

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Keywords: High-nitrogen austenitic steels; particle strengthening; hydrogen-charging; fracture; hydrogen embrittlement.

* Corresponding author. Tel.: +7-903-952-1599; fax: +7(3822)-492-576.
E-mail address: galinazg@yandex.ru

Statistical peculiarities of the mechanical response of loaded solids at the pre-fracture stage

I.Yu. Smolin[a,b,*], P.V. Makarov[a,b], A.S. Kulkov[a,b], M.O. Eremin[a,b], V.A. Tunda[b], V.A. Mikushina[a,b]

[a]*Tomsk State University, Lenin Ave., 36, Tomsk 634050, Russia*
[b]*Institute of Strength Physics and Materials Science SB RAS, Akademicheskii Ave., 2/4, Tomsk 634055, Russia*

Abstract

The statistical analysis of the spatiotemporal dynamic mechanical response up to fracture for the loaded marble and ceramic specimens was performed. The revealed changes in the statistical parameters, which have common features in both experiments under consideration and simulation studies carried out before, can be regarded as precursors of catastrophic fracture. Time series reflecting the mechanical response evolution for the solids loaded up to fracture were analyzed. In the experiments being discussed, the velocity-time histories were measured by a laser-based technique. Statistical analysis was carried out by different methods in the suitable software available. Autocorrelation function indicates that the process has a high degree of autocorrelation. Cross-correlation analysis by the sliding window method showed that a high level of the correlation coefficient of the catastrophic fracture stage with the previous damage accumulation process is observed only in a very short time interval approximately equal to 8-10 times of the failure yield to the critical stage. Spectral analysis based on the fast Fourier transform of the signal (FFT) and the 2D hodograph of the FFT complex vector revealed a fractal nature of the deformation and subsequent fracture. Comparing enlarged and original hodograph fragments vividly demonstrate the multiscale character of fracture. Wavelet analysis using a symmetric Daubechies wavelet well captures short signal emissions corresponding to local failures. Their growth as the fracture point is approached shows that a large-scale catastrophe is close.

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Keywords: Mechanical response; statistical analysis; experiment, laser Doppler vibrometer; nonlinear dynamical system

* Corresponding author. Tel.: +7-3822-286-875; fax: +7-3822-492-576.
E-mail address: ismolin@ftf.tsu.ru

Modelling damage and localized failure of extruded aluminium alloy

Sandra Baltic[a,*], René Hammer[a], Julien Magnien[a], Werner Ecker[a], Thomas Antretter[b]

[a]*Materials Center Leoben, Austria*
[b]*Montanuniversität Leoben, Austria*

Abstract

Because of the excellent functional and structural properties, aluminium alloys have many applications: from large lightweight structures, over car bodies to the smallest electronic components. The present contribution aims to predict ductile failure of thin aluminium alloys formed into cans by impact extrusion and exposed to complex loading. The fracture strain loci of two material grades has been investigated: AW-1050 and AW-6082.
Characterized material is initially strain hardened to a great extent due to extrusion process. This causes abrupt strain concentration and localized failure, which is observed from performed tensile test experiments. Digital Image Correlation (DIC) is utilized to track the plastic flow and to identify the initiation and development of localized strain during tensile test. Experimental data and DIC calculations are accompanied by FEM to identify the true stress in localized region and strain to fracture for the calibration of the ductile fracture model.
We propose simple modelling technique to describe the influence of progressive damage degradation on the material response, incorporating the effect of stress triaxiality and Lode angle parameter on fracture strain. The starting point is coupling undamaged material response with damage variable, which depends on pre-defined fracture criterion involving stress triaxiality and Lode angle parameter.
The method allows to use any convenient fracture criterion and to introduce softening material behaviour, resulting in localized strain and failure. Numerical challenge of modelling damage evolution and failure accompanied by highly localized strain has been successfully overcame. The calibrated model is expected to precisely predict the mechanical response of extruded aluminium cans and breaking point design. The proposed technique brings simple but significant improvement in sense of precise failure prediction considering external loading, which is of great importance for safety design of structural components.

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Keywords: Damage, failure, strain localization, extruded aluminium

* Corresponding author. Tel.: /
E-mail address: sandra.baltic@mcl.at

Towards a reliable fracture prediction model for 3D printed Ti-6Al-4V

Mirco Peron[a,*], Jan Torgersen[a], Filippo Berto[a]

[a]*Norwegian University of Science and Technology, Norway*

Abstract

Additive manufacturing (AM) offers the possibility to directly produce geometries with high level of complexity making it attractive for aerospace and biomedical applications. Powder bed fused Ti-6Al-4V is attractive due to its excellent corrosion resistance, high specific strength, low density, and low elastic modulus. Yet, its fail-safe design requires accounting for internal material characteristics (non-isotropies, inclusions and impurities) and external geometry (geometrical discontinuities) at the same time. A fundamental, reliable and experimentally verified failure criterion for the fracture behavior of AM notched parts is a first step towards such a framework.
In this work, the notch sensitivity of AM Ti-6Al-4V manufactured by means of Electron Beam Melting (EBM) in monotonic tension has been assessed carrying out tensile tests on dog-bone, semi-circular and blunt V-notched specimens characterized by different notch root radii. In particular, the semi-circular notch is characterized by a radius of 5 mm, while the notch root radii of V-notched specimens are 1 and 0.1 mm. Then, the experimental tensile strength herein reported has been compared to the prediction provided by a local failure criterion. This strain energy density (SED)-based approach has been previously revealed to satisfactorily predict the fracture behavior of several materials regardless of the notch geometry. Due to the experimental basis of this criterion, being required few experimental data for its use, the authors consider this criterion to be able to reliably assess the tensile strength of components weakened by the combined effect of internal defects and external geometry. The results have confirmed the authors' idea, being the discrepancy between experimental and predicted results less than 10%. Thus, the presented criterion has revealed to be able to treat internal defects and notches of any geometries in a simple and unified way, which can be useful in a design framework tailored towards powder bed fusion based AM.

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Keywords: Ti-6Al-4V; SED; tensile strength prediction; notched components

* Corresponding author. Tel.: /
E-mail address: mirco.peron@ntnu.no

Plasticity-induced intergranular and “quasi-cleavage” fracture of lath martensitic steels in hydrogen

Mohsen Dadfarnia[a,*], Akihide Nagao[b], Brian P. Somerday[c], Petros Sofronis[a], Robert O. Ritchie[d]

[a]*University of Illinois at Urbana-Champaign, United States*
[b]*JFE Steel Corporation, Japan*
[c]*Southwest Research Institute, United States*
[d]*University of California, Berkeley, United States*

Abstract

Hydrogen embrittlement of lath martensitic steels is characterized by intergranular and “quasi-cleavage” transgranular fracture. Single-notched bend specimens were charged at different hydrogen gas pressures and four-point bend tests were conducted under slow strain rates. Hydrogen reduced the fracture resistance of the lath martensitic steel while changing the morphology of fracture from microvoid coalescence in the absence of hydrogen to a mixture of intergranular and “quasi-cleavage” transgranular fracture. Samples beneath the fracture surfaces were lifted through focused ion beam machining and examined in transmission electron microscope. The results revealed significant plasticity in the form of intense slip bands, destruction of lath boundaries, and a mechanism of fracture advancing through the synergistic action of hydrogen-enhanced localized plasticity and decohesion. A physical-based statistical micro-mechanical model is used to quantitatively describe how the dissolved hydrogen brings about the fracture processes/events. The model assumes that intergranular cracking takes place by dislocation pile-ups impinging on prior austenite grain boundaries whereas “quasi-cleavage” is the case when dislocation pile-ups impinge on block boundaries. The model’s predictions verify that introduction of nanosized (Ti,Mo)C precipitates in the steel microstructure enhances the resistance to hydrogen embrittlement. The implication of the results in the microstructural design of steels that are less susceptible to embrittlement when operating under fixed hydrogen content (closed systems) is discussed.

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Keywords: Hydrogen embrittlement, martensitic steels, plasticity, decohesion

* Corresponding author. Tel.: /
E-mail address: dadfarni@illinois.edu

Low cycle fatigue life prediction of circumferentially notch round bars

Richa Agrawal[a,*], Veerababu J[b], Sunil Goyal[b], Sandhya R[b], Rashmi Uddanwadiker[c], Pramod Padole[c]

[a]*Pillai College of Engineering, India*
[b]*Indira Gandhi Centre for Atomic Research, Kalpakkam, India*
[c]*Visvesvaraya National Institute of Technology, India*

Abstract

Structural components in nuclear reactors are subjected to high temperature gradients during start ups and shut downs. As a result, the components are subject to low cycle fatigue loading conditions. Apart from high temperature conditions, there exists stress concentration in these components due to the presence of flaws, defects and welds etc. Hence the life estimation procedures should involve both the temperature and the stress concentration effects while predicting the life of the components. Present work focuses on estimation of the low cycle fatigue (LCF) life of circumferentially notched specimens under strain controlled loading condition. Notches incorporated in the specimen mimics the multiaxial stress condition that is created by flaws in a component. The technique can be applied to estimate the life of components.
The low cycle fatigue tests were conducted on smooth and notched specimens of 316LN austenitic stainless steel in strain control mode at room temperature and at 873 K. The fatigue life decreased in presence of notch. As the components are subjected to stress-strain loading conditions beyond the elastic limit, the life has been estimated by applying the elasto-plastic fracture mechanics approach. The notch root stress-strain magnitudes are calculated from the J-integral obtained for the geometry used for present investigation. The fatigue life is then predicted by the local strain-life method. The estimated life is also compared with the experiments conducted on laboratory specimens in strain controlled LCF loading. The fatigue life predicted is found to be within a factor of 1.2 as compared to the experimental life. The fatigue life is also predicted by an FE based mathematical model. The mathematical model also could estimate the LCF life fairly on the basis of the notch root stress-strain values obtained by FE analysis.

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Keywords: Low cycle fatigue; 316 LN; J integral; notched specimens; finite element analysis

* Corresponding author. Tel.: /
E-mail address: rsagrawal79@gmail.com

Small fatigue crack growth in a high entropy alloy

Kai Suzuki[a,*], Motomichi Koyama[b], Hiroshi Noguchi[b]

[a] *Graduate School of Engineering, Kyushu University, 744 Motooka, Nishiku, Fukuoka, 819-0395, Japan*
[b] *Faculty of Engineering, Kyushu University, 744 Motooka, Nishiku, Fukuoka, 819-0395, Japan*

Abstract

High-entropy alloys (HEAs) contain a large amount of solid solution elements. This implies that the high capability of solid solution strengthening is expected to increase the resistance to fatigue crack growth. Therefore, we investigated the characteristics of microstructurally small fatigue crack growth of an HEA. In particular, we focused on microstructural fatigue crack growth behavior and associated scatter in crack growth rates. In this study, we used an equiatomic Fe-20Cr-20Ni-20Mn-20Co HEA and an Fe-18Cr-14Ni stable austenitic stainless steel. Rotating bending fatigue tests were performed at ambient temperature using smooth round bar specimens. The fatigue limits of the HEA and stainless steel were 250 and 200 MPa, respectively. The higher fatigue limit of the HEA was attributed to the solid solution strengthening. Furthermore, the scatter in crack growth rates of the HEA was more significant than that of the stainless steel owing to the temporal deceleration or non-propagation of the crack. In the stainless steel, as the crack length increased, the scatter in crack growth rates decreased. In contrast, in the HEA, even if the crack length increased, the scatter in crack growth rates remained significant As a factor that is perhaps related to the scatter characteristics, fatigue cracks with a length of approximately 500 μm in the HEA were highly deflected, compared to those of the stainless steel.

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Keywords: High-entropy alloys; small fatigue crack growth; scatter in crack growth rates.

* Corresponding author. Tel.: +81-92-802-7677; fax: +81-92-802-0001.
E-mail address: sukaisoccer36@gmail.com

Experimental study and numerical modelling of a dual phase steel behavior under dynamic loading

Valentin Davaze[a,*], Nicolas Vallino[a], Sylvia Feld-Payet[b], Bertrand Langrand[b], Jacques Besson[c]

[a]Groupe PSA / Mines ParisTech PSL Research University, France
[b]ONERA The French Aerospace Lab., France
[c]Centre des Matériaux, Mines ParisTech PSL Research University, France

Abstract

When a car crash occurs, parts made with steel or aluminum sheets can tear up. Rupture of ductile materials is not reliably predicted by simulation yet. Thus, when a crack is detected by certification tests, parts and tools have to be re-designed, which increases the development cost. To address this issue, a first step is an accurate numerical prediction of crack initiation. In this contribution, a dynamic constitutive model is proposed for a representative ductile material often used in car industry: DP450 "dual-phase" steel.
A large experimental campaign is necessary to observe all possible non-linear phenomena that can influence crack initiation. To analyze the plastic and damaging behavior at various stress triaxialities, different geometries (flat, notched and shear specimens) were tested at very low loading rates. Electron microscope pictures revealed the growth of pores with plasticity. Then, many tests were performed at high velocity to highlight the influences of strain rate : viscosity and self-heating. This last phenomenon is important since isothermal tests at several temperatures showed a loss of ductility with heat increase.
From the experimental results, a first plastic constitutive model was built with a Von Mises based criterion including Lode angle dependence and a hardening law. Then, this constitutive model was extended with a shear modified Gurson model to represent the damage-induced softening for a wide range of stress triaxialities. Viscous effects observed for high loading rates were taken into account through the Johnson-Cook equation. The obtained constitutive model was finally completed by a thermal softening term with a temperature evolution computed from plastic work to avoid costly thermomechanical calculations. At last, finite element simulations were carried out to show the model consistency with experiment.

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Keywords: Constitutive model; ductile damage; crack initiation; quasi-static testing; dynamic testing; strain rate effects; plasticity

* Corresponding author. Tel.: /
E-mail address: valentin.davaze@mpsa.com

The effect of overloads on fatigue crack propagation measured by DIC, BEMI and synchrotron

Matthias Thielen[a], Michael Marx[a,*], Christian Motz[a]

[a]*Saarland University, Germany*

Abstract

Fatigue crack propagation is determined by the stress field at the crack tip as driving force. Because the local stresses are hardly accessible in experiments, the macroscopic stress in-tensity factor is used since Paris and Erdogan to relate crack parameters and external load to fatigue crack growth in a simple way. Nevertheless, in various cases this simple law fails e.g. in the case of an overload (OL). In this work the mechanisms of the OL effect, residual stresses (RS) in front of the crack tip and plasticity induced crack closure (PICC) due to the plastic wake, have been studied. Therefore, cracks in S960Q steel have been followed before OL, after OL, at maximum retardation and recovery. The stress and strain fields induced by such OLs and their influence on transient crack growth retardation was measured by cali-brated magnetic Barkhausen noise (MBN) microscope and digital image correlation (DIC) based on in-situ SEM imaging. The results were compared to synchrotron x-ray diffraction. Thereby, a strong correlation of the local fatigue crack growth rate with the micro RS distri-bution was found. The RS field after the OL explains the subsequent retardation while the DIC results reveal the influence of the RS on crack tip's opening and strain fields under ex-ternal loads. While the strain fields show a strong decrease due to the OL, differences in crack opening stresses remain rather low at first, but prevail in the adjacent part of the OL region. With increasing growth through the OL region, crack closure becomes more im-portant since a larger part of the crack is affected by the OL PICC. At the same time, the RS become less pronounced as the crack tip strain fields exceed the OL region. Calculations based on these changes described the observed changes in fatigue crack growth rate accu-rately.

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Keywords: Fatigue crack growth; overload; residual stresses; plasticity induced crack closure

* Corresponding author. Tel.: /
E-mail address: m.marx@matsci.uni-sb.de

Quantification method for parameters affecting multi-scale roughness-induced fatigue crack closure

Tomoki Mizoguchi[a,*], Motomichi Koyama[b], Hiroshi Noguchi[b]

[a]*Graduate School of Engineering, Kyushu University, 744 Motooka, Nishiku, Fukuoka, 819-0371, Japan*
[b]*Faculty of Engineering, Kyushu University, 744 Motooka, Nishiku, Fukuoka, 819-0371, Japan*

Abstract

Our challenge is to clarify the relationship between crack roughness and microstructure. Roughness-induced crack closure (RICC) is known to be one of the main factors decelerating fatigue crack growth. Two factors trigger RICC: 1) nanometer-scale roughness on the crack surface (nano-roughness) and 2) degree of crack deflection (micro-roughness). These factors affect the friction stress acting on the crack planes and the stress intensity factor range for crack closure. For instance, S. Suresh and R. O. Ritchie discussed the effects of geometrical mismatch between fatigue crack planes on crack closure. We further attempt to measure multi-scale crack roughness to quantitatively estimate RICC with respect to both friction and crack closure effects. In this study, we examine the multi-scale crack roughness of a lamellar-structured Fe-9Mn-3Ni-1.4Al-0.01C steel sample as a case study. We verify the effect of crack surface friction. Here, we assume that the basic effect of nano-roughness on friction is significant when the inclination angle of micro-roughness against the loading direction is less than the angle of nano-roughness. If the inclination angle of micro-roughness against the loading direction is larger than the angle of nano-roughness, the nano-roughness effect does not occur because the crack surfaces do no contact with each other. To further discuss the underlying effects of multi-scale roughness, we will present more details on the microstructure- and mechanical condition-related roughness parameters and their quantification techniques.

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Keywords: Fatigue; Roughness-induced crack closure; In-situ fatigue test; TRIP-maraging steel

* Corresponding author. Tel.: +81-92-802-3141; fax: +81-92-802-0001.
E-mail address: 3TE18803M@s.kyushu-u.ac.jp

Proposal of fractographic analysis method coupled with EBSD and ECCI

Taketo Kaida[a,*], Motomichi Koyama[b], Shigeru Hamada[b], Hiroshi Noguchi[b], Eisaku Sakurada[c], Tatsuo Yokoi[c], Kohsaku Ushioda[d]

[a] *Graduate School of Engineering, Kyushu University,744 Moto-oka, Nishi-ku, Fukuoka-shi, Fukuoka 819-0395, Japan*
[b] *Faculty of Engineering, Kyushu University, 744 Moto-oka, Nishi-ku, Fukuoka-shi, Fukuoka 819-0395, Japan*
[c] *Nippon Steel & Sumitomo Metal Corporation, 1 Oaza-Nishinosu, Oita 870-0992, Japan*
[d] *Nippon Steel & Sumikin Research Institute Corporation, Kokusai Bldg., 3-1-1 Marunouchi, Chiyoda, Tokyo 100-0005, Japan*

Abstract

Fracture surface contains key information to analyze the crack propagation behavior and identify the causes of fracture in post-mortem specimens/structural parts. For instance, fatigue crack propagation rate and the associated ΔK can be estimated from a fractographic feature, i.e., the striation spacings. However, the current fractography-based methods for the estimation of fatigue crack propagation rate and ΔK require the presence of striations. This requirement limits the capacity for the quantitative analysis of the fracture surface. Therefore, further advancement of fatigue fractography is required to facilitate the quantitative assessment of fracture, using post-mortem specimens/structural parts. In this study, we propose fractography coupled with microstructural evolution underneath the fracture surface. Microstructural characterization was performed, using electron backscattering diffraction (EBSD) and electron channeling contrast imaging (ECCI). In this study, we used a Fe-3Al bcc single crystalline alloy. EBSD-based grain reference orientation deviation analysis showed discrete plastic zones appearing along the crack propagation direction, with spacings corresponding to the crack propagation rate. Furthermore, it was confirmed via ECCI that underneath the fracture surface low- and high-ΔK regions showed vein-like and labyrinth structures, respectively. This information is expected to be useful for microstructure-based estimation of fatigue crack propagation rate and ΔK.

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Keywords: Fractography; EBSD; ECCI; plastic zone; dislocation structures.

* Corresponding author. Tel.: +81-92-802-7677; fax: 81-92-802-0001.
E-mail address: 2TE18809K@s.kyushu-u.ac.jp

Structural integrity of butt welded connection after fire exposure

Dorin Radu[a,*], Teofil Gălățanu[a], Simon Sedmak[b]

[a]*Transilvania University of Braşov, Turnului street no.5, 500152 Braşov, Romania*
[b]*University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Republic of Serbia*

Abstract

The paper presents a study for fire behavior of the butt-welded joints subjected to low cycle fatigue loading, taken into account the post fire conditions and the possibility of welding strengthening. The need of in service life of a steel structure after being exposed to fire raises the problem of strengthening or replacement of some structural elements. There is presented a case study – a building structural element subjected to dynamic loading after fire exposure [1]. For the in case study, post fire investigations revealed several welding flaws including crack type flaws. An assessment was needed in order to determine the structural integrity and life assessment of some structural elements. From the fracture mechanics point of view, a Failure Assessment Diagrams level 2 – FAD 2 procedure was applied in order to determine the in service safety of the structure. Several flaws types were assessed and conclusions were taken. The results can be used for damage assessment and strengthening technique of post fire steel structures.

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Keywords: Structural integrity, welded joints, steel structures

* Corresponding author. Tel.: +40 268 548 228.
E-mail address: dorin.radu@unitbv.ro

Engineering critical assessment of an antenna tower steel shell elements welded joints

Dorin Radu[a,*], Aleksandar Sedmak[b], Simon Sedmak[c]

[a]*Transilvania University of Braşov, Turnului street no.5, 500152 Braşov, Romania*
[b]*University of Belgrade, Faculty of Mechanical Engineering, 11120 Belgrade, Republic of Serbia*
[a]*Innovation Centre of Faculty of Mechanical Engineering, 11120 Belgrade, Serbia*

Abstract

In case of antenna steel structures, existing flaws in critical parts of structural elements may lead to failures of the subassemblies and, in case of lack of redundancy, even to collapse of the entire structure. Considering the case of cyclic loading – wind load (including extreme phenomena as storms or blizzards), some of these type of structures have failed/collapsed. Following the post factum assessment, it resulted that the principal damage causes where the existing of welding flaws corroborated with corrosion (surface flaws).
The paper presents a method for structural integrity assessment, a fitness for purpose analysis (Engineering Critical Assessment), applied during design, in order to assist in the choice of welding procedure and/or inspection techniques. The evaluation is made with BS7910/2013 [2] standard using level 2 failure assessment diagrams for possible discovered flaws, considering a real case assessment – a new designed antenna tower – steel shell element type.

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Keywords: Steel shell structures; structural integrity; welded joints.

* Corresponding author. Tel.: +40 268 548 228
E-mail address: dorin.radu@unitbv.ro

Experimental research of the processes of accumulation of fatigue damages of GRP composites

Oleg Staroverov[a,]*, Valerii Wildemann[a]

[a]Perm National Research Polytechnic University, Russia

Abstract

Designing of structures from composite materials considering the features of their actual operation requires obtaining experimental data on mechanical behavior under various complex combined loads. Conducting experimental research in this area is necessary for a more detailed study of the processes occurring in the material during the operation of the structure, as well as for constructing and verifying models for reducing the strength characteristics of materials under static or cyclic loads.

The paper discusses the research of fatigue characteristics of composite materials, as well as estimates of changes in static deformation and strength properties as a result of preliminary cyclic loads of various levels.

The aim of the work was to obtain new experimental data on the processes of accumulation of fatigue damages of layered fibrous polymer composite materials under conditions of combined external loads.

The experimental research technique represented the realization of combined cyclic and quasistatic loading with the use of an infrared camera to monitor the heating zones and the noncontact video extensometer to record deformation of the samples during the quasi-static stretching.

An experimental study of the dependence of the change in residual properties during the fatigue accumulation of damages was carried out during the testing of laminated fibrous polymer composite materials. Samples were made with the reinforcement layers [0º / 90º] 8, the working area size is 140×10 mm. Preliminary cyclic loading was performed on the Instron ElectroPuls E10000 test system. The mechanical properties of the composite were determined in quasi-static uniaxial tensile tests, considering the recommendations of ASTM D 3039. The tests were carried out on the electromechanical system Instron 5882 with a constant traverse speed of 2 mm / min.

During the study, the analysis of the processes of fatigue accumulation of damages of composite materials was made, the stages of the change in the residual mechanical properties of the material during the cyclic action were noted. The temperature fields in the working zone of the samples are analyzed and the characteristic features of the temperature distribution in the destruction zone are revealed. The functions describing the change in the strength and stiffness properties of the composite are introduced. The introduced damage accumulation functions and the tensile strength reduction function can be used to describe the behavior of materials under fatigue loading.

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Keywords: composite materials, tests, cyclic and quasistatic combined loading, fatigue sensitivity, accumulation of damage

* Corresponding author.
E-mail address: cem_staroverov@mail.ru

The influence of fracture surface contact in fatigue crack propagation of material having texture under mode II loading

Taro Suemasu[a,*], Motomichi Koyama[b], Shigeru Hamada[b], Masaharu Ueda[c], Hiroshi Noguchi[b]

[a]*Graduate School of Engineering, Kyushu University, 744 Moto-oka, Nishi-ku, Fukuoka 819-0395, Japan*
[b]*Faculty of Engineering, Kyushu University, 744 Moto-oka, Nishi-ku, Fukuoka 819-0395, Japan*
[c]*Yawata R & D Lab., Nippon Steel & Sumitomo Metal Co., 1-1 Tobihatacho Tobata-ku,Kitakyushu 804-8501, Japan*

Abstract

In rolling contact fatigue (RCF), cyclic plastic deformation is caused by cyclic rolling contact, the texture develops, and the fatigue crack propagates in the texture under Mode II loading. As fatigue crack propagation under Mode II loading occurs inside the material, direct observation is difficult. Roughness-induced stress shielding (RISS) effect influences the fatigue crack propagation in RCF. However, as it is difficult to observe fatigue cracks in RCF directly, quantitative evaluation of RISS is difficult. Therefore, in this study, quantitative evaluation of RISS was performed by using a test method that enables direct observation of the fatigue crack propagation behavior under Mode II loading. In an actual machine in which RCF occurs, the texture has been generated. Hence, a material having texture was used for the test. From the results of the test, it was observed that the fatigue crack propagated in the same direction as the pre-crack. Therefore, fatigue crack propagation is considered to be successfully reproduced under Mode II loading. From a quantitative calculation result of the reduction rate of the stress intensity factor range owing to the contact between fracture surfaces by using the shape of the obtained fatigue crack shape and the assumed deformation shape, the reduction rate was determined to be very low. Therefore, the influence of RISS on the stress intensity factor range is considerably small, and it is considered that RISS does not exist in fatigue crack propagation under Mode II loading of a material having texture.

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Keywords: Mode II loading; Fatigue crack propagation; Roughness-induced stress shielding effect; Texture

* Corresponding author. Tel.: +81-92-802-7677; fax: +81-92-802-0001.
E-mail address: 2te17828e@s.kyushu-u.ac.jp

Fatigue life analysis of edge-notches with damage

Slobodanka Boljanović[a,]*, Stevan Maksimović[b], Andrea Carpinteri[c]

[a]Mathematical Institute of the Serbian Academy of Sciences and Arts, Kneza Mihaila 36, Belgrade 11000, Serbia
[b]VTI - Aeronautical Department, Ratka Resanovića 1, Belgrade 11000, Serbia
[c]University of Parma, Department of Engineering and Architecture, Parco Area delle Scienze 181/A, Parma 43124, Italy

Abstract

In the present paper, the fracture mechanics-based computational model is proposed for estimating the strength of double-edge notched configuration under cyclic loading. The propagation of a quarter-elliptical corner crack located at one of two semi-circular edge-notches is analytically investigated by means of the fatigue life to failure and crack path. Also, through experimental observations available in the literature the reliability of obtained theoretical results is discussed.

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Keywords: Fatigue strength; quarter-elliptical corner crack; two edge-notches; crack path.

* Corresponding author. Tel.:+381-63-805-6085; fax:+381-11-351-1282.
E-mail address: slobodanka.boljanovic@gmail.com

Atomistic modelling of light-element cosegregation at structural defects in iron

Eunan J. McEnirya[a,*], Tilmann Hickel[a], Jörg Neugebauer[a]

[a]*Department of Computational M aterials Design, Max-Planck-Institut für Eisenforschung GmbH, Max-Planck-Straße 1, 40237 Düsseldorf, Germany*

Abstract

Studying the behaviour of hydrogen in the vicinity of extended defects, such as grain boundaries, dislocations, nanovoids and phase boundaries, is critical in understanding the phenomenon of hydrogen embrittlement. A key complication in this context is the interplay between hydrogen and other segregating elements. Modelling the competition of H with other light elements requires an efficient description of the interactions of compositionally complex systems, with the system sizes needed to appropriately describe extended defects often precluding the use of direct *ab initio* approaches. In this regard, we have developed novel electronic structure approaches to understand the energetics and mutual interactions of light elements at representative structural features in high-strength ferritic steels. Using this approach, we examine the cosegregation of hydrogen with carbon at chosen grain boundaries in α-iron. We find that the strain introduced by segregated carbon atoms at tilt grain boundaries increases the solubility of hydrogen close to the boundary plane, giving a higher H concentration in the vicinity of the boundary than in a carbon-free case. Via simulated tensile tests, we find that the simultaneous presence of carbon and hydrogen at grain boundaries leads to a significant decrease in the elongation to fracture compared with the carbon-free case.

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Keywords: cosegregration, simulation & modelling, grain boundary fracture

* Corresponding author. Tel.: /
E-mail address: e.mceniry@mpie.de

Prediction model for fatigue life and limit of steel based on small crack micromechanics

Hiroaki Ito[a,*], Kazuki Shibanuma[a], Koya Ueda[a], Masao Kinefuchi[b], Katsuyuki Suzuki[c], Manabu Enoki[d]

[a]*Department of Systems Innovation, the University of Tojyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo, Japan*
[b]*KOBE STEEL, LTD, 1-5-5, Takatsukadai, Nishi-ku, Kobe, Hyogo, Japan,*
[c]*Research into Artifacts, Center for Engineering, 5-1-5, Kashiwanoha, Kashiwa-shi, Chiba, Japan,*
[d]*Department of Materials Engineering, the University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo, Japan*

Abstract

It is very important to predict fatigue life and limit of steels for material design and they are affected by microstructures. Although a model for the prediction based on microstructural information was proposed, such model doesn't consider the other important factors, the stress distribution and the crack closure. This study employed the weight function in order to describe the effect of the stress distribution. For the crack closure, a crack closure equation for small fatigue cracks was employed. Also, tension/compression fatigue experiments using three different steels were carried out to validate this model. Predicted fatigue lives and limits showed good agreement with experimental results for all steels. These new extensions expanded the application of this model, e.g. bending conditions.

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Keywords: Fatigue fracture; prediction; ferrite; pearlite; model;

* Corresponding author. Tel.: /
E-mail address: ito@struct.t.u-tokyo.ac.jp

Development of dynamic mesh superposition method for local tensile stress evaluation

Kota Kishi[a,*], Kazuki Shibanuma[a], Fuminori Yanagimoto[a], Katsuyuki Suzuki[b], Toshiyuki Matsumoto[c]

[a]*Department of Systems Innovation, the University of Tokyo. 7-3-1, Hongo, Bunkyo-ku, Tokyo, Japan*
[b]*Research into Artifacts, Center for Engineering, 5-1-5, Kashiwano-ha, Chiba, Japan*
[c]*Research Institute, Nippon Kaiji Kyokai, 3-3, Kioi-cho, Chiyoda-ku, Tokyo, Japan*

Abstract

The brittle crack propagation and arrest behavior has been studied for a long time. The critical condition is not completely clear, but the local fracture stress criterion is recently regarded as a most promising description of brittle crack propagation and arrest behavior. Although accurate finite element analyses should be employed to obtain the local stresses, it is not realistic to use conventional finite element analyses because computational cost is too high. According to the above background, we focused on mesh superposition method to cope with both reduction of computational cost and improvement of local stress evaluation accuracy. At first, stationary crack problem is solved and it is shown that results agree with conventional solutions, and verified the availability of this method. Then this method is used for dynamic crack propagation and it is verified that mesh superposition method is also applicable to dynamic crack growth.

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Keywords: Mesh superposition method; dynamic crack propagation;

* Corresponding author. Tel.: /
E-mail address: kishi@struct.t.u-tokyo.ac.jp

Simulating toughness properties under varying temperatures with micromechanical and phenomenological damage models

David Lenz[a,*], Markus Könemann[a], Victoria Brinnel[a], Julius Langenberg[a], Sebastian Münstermann[a]

[a] *Steel Institute (IEHK) RWTH-Aachen University, Intzestraße 1, 52072 Aachen, Germany*

Abstract

The sustainable and efficient use of high-strength micro-alloyed steels is of particular interest in today's industry. Using modern steels with high strength and excellent toughness enables thinner constructions, for example in infrastructure applications, for pressure vessels or pipelines. Sufficient toughness is of special importance to avoid catastrophic brittle failure. Yet, the simplified, conventional design rules prevent a full exploitation of the properties of modern high strength steels. Modern simulation models are able to represent the actual failure characteristics of high strength steels and thereby help to fully exploit the potential of these materials. To include toughness properties, it is essential that the models are able to describe the transition behaviour of these steels. The materials' behavior in the transition region is characterized by a competition of ductile and cleavage failure mechanisms. To simulate the corresponding behavior, it is necessary to adapt damage mechanics models for considering both effects. While numerous studies on the simulation of either ductile or cleavage failure exist, only a limited selection is available on investigations in the transition range. Therefore, the presented study investigates two representatives of the most popular groups of ductile failure models. The Gurson-Tvergaard-Needleman model (GTN) is investigated as a micromechanical model while the Modified-Bai-Wierzbicki model (MBW) is selected as a phenomenological model. Both are combined with the Orowan cleavage fracture model. Investigations are performed on a thermomechanical rolled S355, for which the cleavage fracture stress and the parameters for the ductile failure models were experimentally determined. The study compares simulations of Charpy impact toughness tests to experimental results to determine which model class delivers results that are more accurate. The focus of the investigation is hereby set on the simulation of the lower shelf and the lower transition area. In addition, the efficiency of the simulations performed is also evaluated.

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Keywords: mesh superposition method; dynamic crack propagation;

* Corresponding author.
Tel.: +49-241-80-95810; fax: +49-241-80-92796;
E-mail adress: david.lenz@iehk.rwth-aachen.de

Generalization of mixed mode crack behavior on the base of nonlinear fracture resistance parameters

V.N. Shlyannikov[a], A.P. Zakharov[a,]*, A.V. Tumanov[a], A.M. Tartygasheva[a]

[a]*Federal Research Center Kazan Scientific Center of Russian Academy of Sciencess, Lobachevsky str, 2/31, Kazan, Russia*

Abstract

Nonlinear crack-tip fracture resistance parameters for two types of cruciform specimens and a compact tension–shear specimen subjected to mixed mode loading are studied by using an elastic–plastic finite element (FE) analysis. FE analysis is performed for two types of steel and titanium and aluminum alloys with different elastic–plastic properties. A Ramberg–Osgood stress–strain relation is used to characterize the elastic-plastic properties of considered materials. Different degrees of mode mixity from pure Mode I to pure Mode II are realized in all considered specimens by combinations of the nominal stresses σ_n, remote biaxial stress ratio η, and the initial crack angle α with respect to the loading direction.
For the specified geometry of the specimens considered, the governing parameter of the elastic– plastic crack-tip stress field In-factor, the stress triaxiality, J-integral are determined as a function of mode mixity and elastic–plastic material properties, described by strain hardening exponent. As a result influence of the specimen configuration on all considered nonlinear fracture resistance parameters is evaluated.

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Keywords: Elastic-plastic material properties, stress triaxiality, J-integral, mixed mode loading

* Corresponding author. +7-843-236-31-02; fax: +7-843-236-31-02.
E-mail address: alex.zakharov88@mail.ru

The influence of hydrogen desorption on micromechanical properties and tribological behavior of iron and carbon steels

V. Pokhmurskii[a], M.Khoma[a], V. Vynar[a], Ch.Vasyliv[a], N. Ratska[a,*], T. Voronyak[a], I. Stasyshyn[a]

[a]*Karpenko Physico-Mechanical Institute of NAS of Ukraine, Lviv, 5, Naukova str., Lviv, 79601, Ukraine*

Abstract

The influence of the previous electrolytic hydrogenation on the micromechanical properties and tribological behavior of the surface layers of iron and carbon steels has been studied. The concentrations of diffusion-moving and residual hydrogen in steels are determined depending on the carbon content. It is shown that the amount of sorbed hydrogen is determined by the density of dislocations and the relative volume of cementite. After desorption of diffusion-moving hydrogen the microhardness increases and materials plasticity decreases. The change of these characteristics decreases with the increase of carbon content in the steels. Internal stresses increase and redistribute under hydrogen desorption. Fragmentation of ferrite and perlite occurs as a result of electrolytic hydrogenation. Ferrite is characterized by the structure fragmentation and change of the crystallographic orientation of planes. The perlite structure shows the crushing of cementite plates and their destruction.

The influence of hydrogen desorption on the microhardness of structural components of ferrite-perlite steels is shown. Large scattering of microhardness is found in perlite, due to different diffusion rates of hydrogen because of the unequally oriented cementite plates. It was found that the tendency of materials to blister formation is reduced with the increase of carbon content. The influence of hydrogen on the tribological behaviour of steels under dry and boundary friction has been studied. It is shown that hydrogen desorption intensifies the materials wear. After hydrogen desorption, tribological behaviour is determined by the adhesion interaction between the contacting pairs.

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Keywords: Hydrogenation; desorption; steel; microstructure; tribology.

* Corresponding author. Tel.: /
E-mail address: nadija.ratska@gmail.com

Large plastic zones and extensive influence of notch under near-threshold mode II and mode III loading of fatigue cracks

M. Hrstka[a,*], S. Žak[a], T. Vojtek[a,b]

[a]*Central European Institute of Technology (CEITEC), Brno University of Technology; Purkyˇnova 123, 612 00, Brno, Czech Republic*
[b]*CEITEC IPM, Institute of Physics of Materials, Academy of Sciences of the Czech Republic; ˇZiˇzkova 22, 616 62, Brno, Czech Republic*

Abstract

Plastic zone shapes and sizes were determined for a cylindrical specimen for mode II and mode III crack testing made of ARMCOiron. Three methods of calculation were applied: Irwins approximate solution, HRR field and finite element method. The plastic zones were found to be very large under mode II and mode III loading even at the loading level corresponding to fatigue crack growth threshold. The difference between sizes of plastic zones under tensile-mode and shear-mode loading was explained by different stress gradients and corresponding stress concentration factors of notches under shear and tensile type loading. This is also the reason for a much further influence of notch on stress intensity factors for mode II and mode III cracks emanating from the notch than the influence under mode I loading. Preliminary results for reversed plastic zone size indicated that it is smaller than the theoretical size of 1/4 of the monotonic zone which explained the presence of large monotonic zone at threshold loading.

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Keywords: plastic zone; mode II; mode III; fatigue; notch

* Corresponding author. Tel.: +420 726 81 2871
E-mail address: Miroslav.Hrstka@ceitec.vutbr.cz

Temperature dependence of tensile deformation and fracture micromechanisms in V-alloyed high-nitrogen steel: effect of solution-treatment temperature

Elena Astafurova[a,]*, Valentina Moskvina[a], Galina Maier[a], Nina Galchenko[a], Eugene Melnikov[a], Sergey Astafurov[a], Antonina Gordienko[a], Alexander Burlachenko[a]

[a]*Institute of Strength Physics and Materials Science, Siberian Branch of Russian Academy of Sciences, Akademichesky pr. 2/4, Tomsk 634055, Russia*

Abstract

For 1high-nitrogen Fe-19Cr-21Mn-1.5V-0.3C-0.9N (wt. %) steel water-quenched from the different solution-treatment temperatures (1100ºC and 1200ºC, 1h), the tensile mechanical properties and fracture micromechanisms were investigated in a temperature range of 77K to 673K. Increase in quenching temperature (QT) provides a partial dissolution of precipitates and increases a solid-solution hardening effect in the steel. A yield strength, tensile strength, strain-hardening coefficient and plasticity are QT-dependent characteristics. Independently on QT and test temperature, steel specimens fracture in ductile transgranular mode except for 77K-temperature, where dimples and some cleavage components are observed on fracture surfaces. The variation in QT allows one to decrease the fraction of cleavage component: 8% for QT=1100ºC and 25% for QT=1200ºC.

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Keywords: High-nitrogen steels; tensile properties; ductile fracture; brittle fracture; cleavage

* Corresponding author. Tel.: /
E-mail address: elena.g.astafurova@gmail.com

Reference toughness – a pragmatic tool to estimate ductile-brittle transition temperatures

Sakari Pallaspuro[a,b,*], Saara Mehtonen[c], Jukka Kömi[a], Zhiliang Zhang[b], David Porter[a]

[a]Materials and Production Engineering, Centre for Advanced Steels Research, University of Oulu, Finland
[b]Department of Structural Engineering, Faculty of Engineering Science and Technology, NTNU, Norway
[c]SSAB, Raahe, Finland

Abstract

Recent advances show that tough as-quenched ultra-high-strength steels in fully and partially martensitic conditions demand proper control of the effective coarse grain size, which is the key microstructural parameter controlling the toughness in the ductile-brittle transition region. The most effective way to reduce this grain size and texture components detrimental to toughness with thermomechanically rolled steels is to apply a high level of austenite pancaking. The effective coarse grain size ($d_{80\%}$) can be used to reliably estimate impact toughness transition temperatures. Adding the fraction of {100} cleavage planes close to the specimen notch/crack plane further improves these estimates. A recent straightforward semi-physical model consists of just two parameters, the first term describes the temperature-dependency of a local brittle fracture, and the second term relates to the size of these locally cleaved areas. Here, we present the concept *reference toughness* and study its applicability to the estimation of both impact toughness and fracture toughness transition temperatures. Fractographic evidence demonstrates that failure initiation is a complicated interaction between large grains and large brittle inclusions. With locally varying, inhomogeneous microstructural properties, the failure is likely to initiate and propagate when a large particle locates in a coarse-grained matrix, whose dimensions are in line with the effective coarse grain size. Application of these microstructure-based estimates of the impact toughness and fracture toughness transition temperatures can further assist the design and production of steels with lath-like microstructures.

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Keywords: Ductile-brittle transition; Stress intensity; Fracture toughness; Impact toughness; Grain size; Characterization

* Corresponding author. Tel.: /
E-mail address: sakari.pallaspuro@oulu.fi

Features of the hydrogen-assisted cracking mechanism in the low-carbon steel at ex- and in-situ hydrogen charging

E.D. Merson[a,*], P.N. Myagkikh[a], V.A. Poluyanov[a], D.L. Merson[a], A. Vinogradov[b]

[a]*Institute of Advanced Technologies, Togliatti State University, Belorusskaya str. 14, Togliatti 445667, Russian Federation*
[b]*Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology -NTNU, N-7491 Trondheim, Norway*

Abstract

Hydrogen embrittlement has been intensively studied in the past. However, its governing mechanism is still under debate. Particularly, the details of the formation of specific cleavage-like or quasi-cleavage fracture surfaces related to hydrogen embrittled steels are unclear yet. Recently it has been found that the fracture surface of the hydrogen charged and tensile tested low-carbon steel exhibits quasi-cleavage facets having specific smoothly curved surface, which is completely different from common flat cleavage facets. In the present contribution we endeavor to shed light on the origin of such facets. For this purpose the notched flat specimens of the commercial low carbon steel were tensile tested using ex- and in-situ hydrogen charging. It is found that in the ex-situ hydrogen charged specimens the cracks originate primarily inside the specimen bulk and expand radially form the origin to the specimen surface. This process results in formation of "fisheyes" – the round-shape areas with the surface composed of curved quasi-cleavage facets. In contrast, during tensile testing with in-situ hydrogen charging, the cracks initiate from the surface and propagate to the bulk. This process results in the formation of the completely brittle fracture surface with the quasi-cleavage morphology - the same as that in fisheyes. The examination of the side surface of the in-situ hydrogen charged specimens revealed the straight and S-shaped sharp cracks which path is visually independent of the microstructure and crystallography but is strongly affected by the local stress fields. Nano-voids are readily found at the tips of these cracks. It is concluded that the growth of such cracks occurs by the nano-void coalescence mechanism and is responsible for the formation of fisheyes and smoothly curved quasi-cleavage facets in hydrogen charged low-carbon steel.

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Keywords: Hydrogen embrittlement; fracture surface; quasi-cleavage

* Corresponding author. Tel.: /
E-mail address: Mersoned@gmail.com

Effect of hydrogen charging current density on hydrogen concentration and hydrogen-induced defects in the low-carbon steel

Evgeniy Merson[a,*], Vitaliy Poluyanov[a], Pavel Myagkikh[a], Dmitriy Merson[a], Alexei Vinogradov[a]

[a] *Institute of Advanced Technologies, Togliatti State University*

Abstract

Cathodic hydrogen charging is widely used as the laboratory method for infusion hydrogen (with different concentrations) into steels and alloys. However the contradictory results have been reported with regard to the relationship between the electrolysis parameters such as the current density and the resulting hydrogen concentration even in similar materials, e.g. steels. Large errors can arise due to hydrogen-induced defects which are produced during hydrogen charging and are served as hydrogen traps. Thus in the present study both the as-received hot-rolled and vacuum annealed specimens of low-carbon steel grade S235JR were hydrogen charged at current densities i varying in the wide range from 20 to 600 mA/cm^2. The concentration of mobile hydrogen CHdif as well as desorption curves were evaluated by the thermal desorption analysis. The hydrogen-induced defects including blisters and hydrogen-induced cracks (HIC) were also quantitatively characterized. It is found that the relationship between the concentration of mobile hydrogen and the current density has a sigmoidal shape with three distinct regions: (i) – nearly linear and relatively slow growth of CHdif at i<ib, where ib is the current density of the blistering initiation, (ii) – profuse blistering and rapid growth of CHdif at ib<i<is, (iii) – constant level of CHdif and amount of blisters at i>is. The value and the growth rate of CHdif in these regions, as well as the value of ib depend strongly on the microstructure and the strength of steels. In contrast the value of is is independent of material properties and is presumably conditioned by the electrolyte composition. The rapid growth of CHdif in the range ib<i<is is mainly controlled by blistering accompanying by the hydrogen trapping inside HICs and at dislocations associated with the blisters. Financial support from the Russian Foundation for Basic Research (grants-in-aid 17-08-01033) is gratefully acknowledged

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Keywords: Cathodic hydrogen charging, hydrogen concentration, hydrogen-induced defects, thermal desorption analysis

* Corresponding author. Tel.: /
E-mail address: Mersoned@gmail.com

Analysis of fatigue crack configuration influence on fatigue life

Masataka Aibara[a,*], Motomichi Koyama[b], Shigeru Hamada[b], Hiroshi Noguchi[b]

[a]*Graduate School of Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka, 819-0395, Japan*
[b]*Faculty of Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka, 819-0395,Japan*

Abstract

When a crack initiates and grows in a plain specimen under constant cyclic load amplitude, fatigue crack growth behavior is not reproducible. The fatigue crack length l_0 when the scatter of the fatigue crack growth rate converges is reported by observing the crack growth behavior on the specimen surface. The l0 is reported that it is approximately six times as long as the grain size in carbon steels. However, the crack shape of the inside is not observed and we considered that the three-dimensional irregular fatigue crack front shape affects the fatigue crack growth behavior on the specimen surface. Furthermore, the physical meaning and controlling factors of the l0 is still uncertain. Therefore, in this study, we propose two factors that affect the local fatigue crack growth rate: local microstructural and mechanical factors. The former causes a variation of the three-dimensional fatigue crack front shape, and the fatigue crack front shape synergistically affects the mechanical condition at the crack tip. Then we investigated the stress intensity factor values along the tip of the crack including a part of the locally grown crack front. And we propose a concept of force caused by a stable growth part which prevents local growth parts from growing.

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Keywords: Fatigue crack growth simulation; stress intensity factor; finit element method; crack front shape;

* Corresponding author. Tel.: /
E-mail address: masatakanike0711@gmail.com

Proposal and verification of novel fatigue crack propagation simulation method by finite element method

Temma Sano[a,]*, Daisuke Sasaki[b], Motomichi Koyama[c], Shigeru Hamada[c], Hiroshi Noguchi[c]

[a]*Graduate School of Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka, Fukuoka 819-0395, Japan*
[b]*National Institute of Technology, Kurume College, 1-1-1 Komorino, Fukuoka, Fukuoka 830-8555, Japan*
[c]*Faculty of Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka, Fukuoka 819-0395, Japan*

Abstract

In this paper, we propose and verify a novel method to simulate crack propagation without propagating a crack by finite element method. We propose this method for elastoplastic analysis coupled with convection-diffusion. In the previous study, we succeeded in performing elastoplastic analysis coupled with convection-diffusion of hydrogen for a material with a crack under tensile loading. This research extends the successful method to fatigue crack propagation. In convection-diffusion analysis, in order to simulate the invasion and release of elements through the free surface, the crack tip is expressed by using a notch with a sufficiently small radius. Therefore, the node release method conventionally used to simulate crack propagation cannot be applied. Hence, instead of crack propagation based on an analytical model, we propose a novel method that can reproduce the influence of the vicinity of the crack tip on a crack. We moved the stress field near the crack tip in the direction opposite to that of crack propagation by an amount corresponding to the crack propagation length. When we extend the previous method to fatigue crack propagation simulation, we must consider the difference in strain due to loading and unloading. This problem was solved by considering the strain due to loading as a displacement. Instead of moving the strain due to loading, we moved the displacement. First, we performed a simple tensile load analysis on the model and output the displacement of all the nodes of the model at maximum load. Then, the displacement was moved in the direction opposite to that of crack propagation. Finally, the stress field was reproduced by forcibly moving all the nodes by the displacement amount. The strain due to unloading was reproduced by removing the displacement. Furthermore, we verified the equivalence of the crack propagation simulation and the proposed method.

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Keywords: Finite element method; hydrogen diffusion; fatigue; crack propagation

* Corresponding author. Tel.: /
E-mail address: r.sn677@gmail.com

Thermo-mechanical model of steam injection in porous media

A. Kostina[a,*], M. Zhelnin[a], O. Plekhov[a]

[a]*Institute of continuous media mechanics of the Ural branch of Russian academy of science, Ac.Koroleva st.,1, Perm, 614013, Russia*

Abstract

The work is devoted to the development of a coupled thermo-mechanical model of a steam injection effect on a stress-strain state and failure of a reservoir. Steam assisted gravity drainage method is widely used for a heavy oil recovery. Injection of the hot steam significantly alters the temperature of the reservoir, which, in turn, can induce failure of the formation and surrounding rock. Therefore, the accurate simulation of this process should include simultaneous consideration of a mechanical (plastic deformation and failure) and physical (phase transition) processes. The main feature of the proposed thermo-mechanical model is introduction of an additional parameter characterizing evolution of the structural defects in the considered media. A three-dimensional numerical simulation of the steam injection into a sandstone reservoir demonstrates application of the proposed model.

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Keywords: SAGD; mesoscopic defects; porous media; thermo-mechanical coupling

* Corresponding author. Tel.: /
E-mail address: kostina@icmm.ru

A hydrogen embrittlement model based on hydrogen-microvoid interactions

Haiyang Yu[a], Jim Stian Olsen[b], Jianying He[b], Edmund Tarleton[a], Alan Cocks[a], Zhiliang Zhang[b,*]

[a]*University of Oxford*
[b]*Norwegian University of Science and Technology*

Abstract

Hydrogen-microvoid interaction was systematically studied recently, and hydrogen was found to have strong influence on microvoid process, either by enhancing the internal necking failure mode or by triggering an internal shearing failure mode which is otherwise impossible. Therefore, a hydrogen fracture locus consists of an internal necking failure branch and an internal shearing failure branch. In this work, a parametric study on the hydrogen failure loci with different hydrogen concentrations is first performed using hydrogen diffusion coupled unit cell approach, and it is found that both the necking and the shearing branches can be normalized, indicating the effect of hydrogen on microvoid failure strain can be decoupled from that of stress triaxiality. This gives rise to a parameterized hydrogen failure criterion, which inherently captures the transition of failure mode from internal necking to internal shearing with the increase of hydrogen concentration. This criterion is then used for hydrogen failure prediction, with the hydrogen effect on flow stress described by the Gurson model. Further, this model is applied to predict failure in hydrogen pre-charged smooth, notched and circumferentially pre-cracked tensile bars, and both failure initiation site and failure mode are well captured.

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Keywords: Hydrogen embrittlement, microvoid process, unit cell analysis, Gurson model

* Corresponding author. Tel.: /
E-mail address: zhiliang.zhang@ntnu.no

Modelling of hydrogen embrittlement with a discrete dislocation plasticity coupled cohesive zone approach

Haiyang Yu[a], Edmund Tarleton[a], Alan Cocks[a,*]

[a] *University of Oxford*

Abstract

The underlying mechanism of hydrogen embrittlement has been under debate over decades. Among various theories accounting for this phenomenon, the hydrogen induced decohesion (HID) mechanism and the hydrogen enhanced localized plasticity (HELP) mechanism have been the most popular up to now. In recent experiments, intensive dislocation activity was observed beneath inter-granular and quasi-cleavage fracture surfaces, indicating a synergistic effect of these two mechanisms. In this work, a hydrogen embrittlement modelling framework reflecting such effect is established, with material flow behavior described by discrete dislocation plasticity and material separation handled by cohesive zone simulation. The cohesive strength of the material is assumed to be a decreasing function of hydrogen concentration, corresponding to the HID mechanism. Meanwhile, the effect of hydrogen on plasticity is taken into account by considering hydrogen atoms as Eshelby inclusions which exert extra stress fields and thus influence dislocation dynamics. Two limiting cases regarding hydrogen diffusion, the fast diffusion scenario with an extremely large diffusion coefficient and the slow diffusion scenario with an extremely small diffusion coefficient, are investigated. The results obtained under this new framework shed light on the recently proposed hydrogen-enhanced plasticity-mediated decohesion mechanism.

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Keywords: Hydrogen embrittlement, discrete dislocation plasticity, hydrogen induced decohesion, hydrogen enhanced localized plasticity

* Corresponding author. Tel.: /
E-mail address: alan.cocks@eng.ox.ac.uk

Intrinsic ductility as a precursor to ductile fracture

Predrag Andrić[a,]*, William Curtin[a]

[a]*Ecole Polytechnique Fédérale de Lausanne*

Abstract

A crystalline material is intrinsically ductile under Mode I loading if an atomically sharp crack emits dislocation(s) and blunts rather than propagating and reaming sharp. A sharp crack in loaded material emits dislocation if the critical stress intensity factor for dislocation emission K_{Ie} is smaller than the critical stress intensity factor for Griffith cleavage K_{IC}. Intrinsic ductility is usually estimated by the Rice theory where K_{Ie} depends on the unstable stacking fault energy. Atomistic simulations showed this theory to be reasonable, but not highly accurate in predicting K_{Ie}. An analysis of the energy change where the actual nucleation takes place reveals that the emission in Mode I is always accompanied by the surface step creation, a feature absent in the Rice theory. Here we present a new theory for dislocation emission, based on the mechanical instability at the crack-tip, which naturally includes for the step creation. Similar analysis, applied for predicting the second partial dislocation emission in fcc metals, explains why atomistic simulations always show twinning rather than full dislocation emission at T=0K. The new theory is quantitatively validated against molecular statics simulations across a wide set of materials described with various pair-potentials, and EAM potentials.
We further investigate overall fracture toughness using Coupled Atomistic Discrete Dislocation (CADD) multiscale method. CADD enables us investigating the influence of the far-field plasticity on the crack-tip that is modeled as a fully atomistic region. For describing the atomic interaction in the crack-tip region we use recently developed pair-potentials that enable us to switch the material from intrinsically ductility to brittle by varying the unstable stacking fault energy, while the surface energy and the elastic constants are held constant. Within the method and materials described we will be able to correlate the influence of the intrinsic ductility on overall fracture toughness.

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Keywords: Fracture toughness, ductility, dislocations, molecular statics simulations

* Corresponding author. Tel.: /
E-mail address: predrag.andric@epfl.ch

On fracture modes of thermally-cycled plasma-sprayed MCrAlY+YSZ thermal barrier coatings: the role of the bond-coat interfacial features in the crack initiation phase

Karel Slámečka[a,*], Petr Skalka[a], Ladislav Čelko[a], Jaroslav Pokluda[a]

[a]*Brno University of Technology*

Abstract

Plasma-sprayed thermal barrier coatings (TBCs) are thermally-sprayed multilayer coatings used to protect various high-temperature components against heat and oxidation. These coatings find their application mainly in power generation devices, most notably in land-based and aircraft gas turbines. While TBCs in the land-based turbines are operated predominantly under quasi-static isothermal loading, in which case the oxidation of the metallic bond-coating is the main cause of their failure, the TBCs operated in the aircraft engines mostly experience thermal cycling fatigue. Under such conditions, the cracks initiated at the oxidised metallic interface or at the pores and at the cracks present within the ceramic top-coating are the main reason for their failure.
In this contribution, the critical locations in TBCs are discussed based on the recent 3D FE numerical simulation of thermal loading of a typical, commercially used double-layer MCrAlY + YSZ TBC system. In particular, the work focuses on the role of the common interfacial features (i.e. waviness and roughness peaks and valleys of the bond-coat) in the initiation of cracks in various oxidation stages. The major experimentally observed crack initiation mechanisms (i.e. initiation of cracks in the ceramic top-coat and cracking along the interface between the produced oxide layer and the MCrAlY bond-coat, are discussed based on the results obtained using both intact and pre-cracked TBC models. The study summarizes the fact that one of the important factors in the current development of modern aircraft plasma-sprayed TBC system that we need to fully understand and deploy is the bond-coat surface topography effect.

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Keywords: Thermal barrier coatings, thermal stresses, bond-coat texture

* Corresponding author. Tel.: /
E-mail address: k.slamecka@gmail.com

Physical explanation of the critical distance theory and a link with structure of material

A. Vedernikova[a,]*, A. Kostina[a], A. Petrova[b], O. Plekhov[a]

[a]ICMMUrB RAS, Academika Koroleva st, 1, Perm 614013, Russia
[b]IMP UB RAS, S. Kovalevskaya st, 18, Yekaterinburg 620137, Russia

Abstract

The Theory of Critical Distances (TCD) is a group of methods for prediction of materials failure with accounting effect of stress concentration. The work is devoted to the physical explanation of the critical distance theory, in particular the value of the critical length L, on the base of the original statistical-thermodynamic model of the evolution of defects proposed ICMM UB RAS. It has been shown that localization of the defect ensemble can be observed when existence of the area where stresses are higher than ultimate tensile strength and the spatial size of this area is equal to the half of the critical distance. Optical microscopy based structural analysis of fracture surfaces of specimen shows that annular area equal a critical distance value is characterized more smooth macro-relief then macro-relief from the central area, which have rough structure with ridges and macrocracks.

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Keywords: Theory of critical distances, model of the evolution of defects, structural analysis;

* Corresponding author. Tel.: /
E-mail address: terekhina.a@icmm.ru

Crack resistance to environment-assisted brittle fracture of tram rails

Michał Kawiak[a,*], Aleksander Ballitskii[b], Ryszard Kawiak[a]

[a]*West Pomeranian University of Technology in Szczecin*
[b]*Karpenko Physico-Mechanical Institute, National Academy of Sciences*

Abstract

The effects of constant development in the realm of building tram and railway tracks are the following: large degree of safety in human and cargo traffic, increased passenger comfort, higher speed of trains and trams, greater permissible mass of transported cargo, lower operating costs, etc. Still, the greater the speed of rail vehicles and the mass of cargo, the higher the dynamic load transmitted by the rails. It can happen that a rail will crack under the influence of such loads. Fortunately, cases of rail fracture resulting in a crash that involves people are very rare. After each such event, a thorough examination is done in order to determine what caused the crash and what has to be done in order to prevent it from happening again. Apart from loads, factors conducive to railway and tram rail cracking include properties of rails and environment in which they are in operation. The article will discuss tests for resistance to brittle cracking of tram rails, which constitutes a continuation of the tests presented in article.
The scope of railway and tram rail tests that are required before rails can be installed in a track is stipulated in the EN 13674-1 and EN 14811+A1 norms. The paper will show that, currently, these tests prove insufficient. The fact is especially prominent in the case of tram rails, since it is not possible to determine their resistance to brittle cracking on the basis of the recommended tests. The authors considered it advantageous to determine the resistance to brittle cracking of tram rails made of R260 steel. It was borne in mind that trams going on a newly-built track in Szczecin move at a high speed, i.e. 70 km/h.
The cracks appear and propagate both parallelly and perpendicularly to the axis of a rail. In this paper, the value of the stress intensity coefficient of the tram rails made of R260 steel was determined on compact specimens featuring preliminary fatigue cracks parallel or perpendicular to the axis of the rail, isolated form rail head or web. Resistance of rails to brittle cracking can decrease during operation due to the influence of corrosive environment. In some cases, it can lead to an increase of the content of hydrogen in the rail material. The paper will present results of tests for stress intensity coefficient conducted on the specimen before and after hydriding.

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Keywords: Brittle cracking, tram rail, hydrogen embrittlement, fracture testing

* Corresponding author. Tel.: /
E-mail address: michal.kawiak@zut.edu.pl

An implicit criterion of fracture growth direction for 3D simulation of hydraulic fracture propagation

V.N. Lapin[a,b,*], S.G. Cherny[a,b]

[a]Institute of Computational Technologies SB RAS, Lavrentiev av., 6, Novosibirsk, 630090, Russia
[b]Novosibirsk State University, Pirogova st., 2, Novosibirsk, 630090, Russia

Abstract

Validation of the previously proposed implicit criterion of fracture propagation was carried out. The implicit criterion at each step of the propagation considers the rock stress state both before and after the propagation. It is based on the assumption that the fracture tends to propagate in the direction where II and III modes of stress intensity factor (SIF) are zero. Since in most cases both conditions cannot be satisfied simultaneously, the values of the SIF modes II and III are combined in one function and are integrated along the whole front. A few possible propagation directions are considered at each step of the propagation and the one is chosen to provide the minimum of the integral. The criterion parameters was chosen using the comparison with experiment results and semi analytical formulas obtained from three point bend test with twisted fracture.

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Keywords: Hydraulic fracturing, fracture growth direction, mixed mode

* Corresponding author. Tel.: /
E-mail address: lapin@ict.sbras.ru

Debond predictions using finite fracture mechanics along elastic interfaces by a FEM code

Mar Muñoz-Reja[a,*], Luis Távara[a], Vladislav Mantič[a]

[a]*University of Seville*

Abstract

A failure model for interfaces between solids is developed and tested. The undamaged interfaces are modelled by a spring distribution, where the normal and shear tractions are proportional to the normal and tangential relative displacements, while along the suddenly broken interface parts tractions vanish expect for compressive normal tractions, such model being referred to as Linear Elastic-Brittle Interface Model (LEBIM). Nevertheless, in the original LEBIM formulation the critical stress and the fracture toughness are dependent on each other. Therefore, in some cases, LEBIM is not able to properly characterize the behaviour of the interface. To solve this problem the Finite Fracture Mechanic (FFM) approach is used. In the FFM framework, both the interface strength and fracture toughness criteria are imposed as independent conditions for crack onset and growth. Thus, the fracture toughness and critical stress can be uncoupled. The present FFM criterion using LEBIM was already implemented in a Boundary Element Method (BEM) code, and it has proven to be a suitable numerical tool. Despite of this, the BEM code is restricted to a small number of degrees of freedom. To circumvent this difficulty, the FFM criterion for LEBIM is implemented in the commercial FEM code ABAQUS through the user-defined subroutine UMAT and a Python code. This tool can call ABAQUS commands and solve different linear elastic scenarios, needed to apply the FFM criterion. The obtained numerical results are compared with some analytical studies, and previous numerical results using BEM. All obtained results show a good agreement.

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Keywords: Interface crack, linear elastic brittle interface model, finite fracture mechanics, fem, composites

* Corresponding author. Tel.: /
E-mail address: mmunozreja@us.es

The influence of aggregate grain size on the parameters of acoustic emission signals obtained from a three-point bending test on concrete specimens degraded by high-temperatures

Libor Topolář[a,]*, Šárka Keprdová[a], Luboš Pazdera[a]

[a]*Brno University of Technology, Faculty of Civil Engineering, Veveří 331/95, Brno 602 00, Czech Republic*

Abstract

One of the advantages of concrete when compared to other building materials is its fire resistance. Fire resistance of concrete structures depends on the thermal, mechanical and deformation properties of the used concrete. Some concrete structures can be exposed to extreme temperature conditions (e.g. concrete structures in nuclear power plants or in tunnels during fires). This paper presents the measurement results of a three-point bending test on three different mixtures of concrete specimens that have been exposed to high temperatures. The concrete specimens were heated in a programmable laboratory oven at a heating rate of 5 °C/min and were exposed to the following temperatures: 400 °C, 600 °C, 800 °C, 1000 °C and 1200 °C. The heating was maintained for 60 minutes. The obtained results indicate that the comparison of the absolute measured values is not sufficient. For this reason, the comparison of the individual mixtures is carried out using the relative values, which more clearly demonstrate the degree of damage to the concrete samples caused by exposure to elevated temperatures.

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Keywords: Acoustic emission method; three-point bending test; concrete; high-temperature;

* Corresponding author. Tel.: /
E-mail address: Libor.Topolar@vutbr.cz

Estimation of fracture toughness of metallic material by using instrumented flat-end shaped indentation test

Woojoo Kim[a,*], Junyeong Kim[b], Seunghun Choi[a], Dongil Kwon[a*]

[a]*Seoul National University*
[b]*LG Electronics*

Abstract

Structure integrity assessment requires knowing the structure's mechanical properties. Among them, fracture toughness, the ability to resist crack growth, is a key parameter in material failure. However, fracture toughness testing currently requires specimens of a specific shape and a complex test procedure and is particularly difficult to apply to structures that are in operation. Therefore, non-destructive testing (NDT) studies have been carried out to predict the fracture toughness value of structures in operation. Instrumented indentation testing, a NDT method, can evaluate the mechanical properties with a simple loading-unloading process, making it easy to diagnose the condition of the operating structure. In this study, we propose models to predict fracture toughness values by using instrumented indentation testing with a flat-ended cylindrical indenter. Brittle and ductile fracture models are suggested for indentation testing based on similarity between indentation test and fracture toughness test situation. A virtual crack initiation point is assumed in each model, and the indentation load-depth curve is normalized to find the critical indenter radius size satisfying the thickness condition. Finally, evaluation of fracture toughness using the indentation test was performed for several commercial metallic materials and the results give accuracy within 20% of conventional fracture toughness testing.

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Keywords: Instrumented indentationtest, fracture toughness, contact mechanics, non-destructive test, nuclear power plant, metallic material

* Corresponding author. Tel.: /
E-mail address: energy88@snu.ac.kr, dongilk@snu.ac.kr

Dynamic measurement of CTOA of unstable ductile fracture of high pressure gas pipelines

Hikaru Yamaguchi[a], Takahiro Hosoe[a], Kazuki Shibanuma[a], Shuji Aihara[a,*]

[a]*The University of Tokyo, 7-3-1, Hongo, Bunkyo, Tokyo, 113-8656, Japan*

Abstract

Demand for natural gas is increasing worldwide and pressure and diameter of gas pipelines are increasing. In such high-pressure gas pipelines, prevention of unstable ductile fracture is an important issue. Crack tip opening angle (CTOA) is widely used for fracture criterion of unstable ductile fracture, and measured by Drop Weight Tear Test (DWTT). But, measuring CTOA during dynamic crack propagation in pipe burst is very limited. Therefore, in this study, we measured CTOA in a pipe burst test. The crack propagation was photographed by high-speed camera. The CTOA values by the DWTT and the burst tests were found somewhat different. A care should be taken when using CTOA value obtained by DWTT for analyzing dynamic crack propagation behavior in pipelines.

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Keywords: Unstable ductile fracture; crack tip opening angle; drop weight tear test; pipe burst test

* Corresponding author. Tel.: /
E-mail address: aihara@fract.t.u-tokyo.ac.jp

The experimental and theoretical study of plastic deformation in the fatigue crack tip based on method of digital image correlation

A. Vshivkov[a,]*, A. Iziumova[a], A. Zakharov[b], V. Shlyannikov[b], O. Plekhov[a]

[a]*Institute of Continuous Media Mechanics Russian Academy of Sciences Ural Branch, Academika Koroleva st, 1, Perm, 614013, Russian Federation*

[b]*Kazan Scientific Center of Russian Academy of Sciences, Lobachevskogo str. 2/31, Kazan, 420111, Russian Federation*

Abstract

This work is devoted to the experimental study of strain distribution at crack tip using digital image correlation technique. The real strain fields were compared with an elastic solution for verification of a hypothesis about link of the elastic-plastic and elastic strain fields at crack tip using the coupling between Young's modulus and the secant plasticity modulus. The precracked plane specimens of titanium alloy VT1-0 with a thick of 1 mm were used in experimental program. The method of digital image correlation based on system StrainMaster was used for measurement the plastic deformation with spatial resolution up to 1 mkm. The strain field was obtained for different crack length and different biaxial coefficient was obtained using biaxial testing machine Biss BI-00-502. Numerical simulation of deformation fields at the fatigue crack tip was done. A qualitative correspondence between the theoretical, calculation and experimental results has been shown.

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Keywords: fatigue, crack, deformation, digital image correlation;

* Corresponding author. Tel.: /
E-mail address: vshivkov.a@icmm.ru

Characterization of J-R curves of a HSLA-steel and an alloy 52 DMW with SE(T) specimens

S. Lindqvist[a,*], T. Seppänen[a]

[a]*VTT, Kemistintie 3, Espoo and 02150, Finland*

Abstract

The J-R curves determined with high constraint specimens can be overly conservative for structural integrity analyses of cracks in pipes and pressure vessels. In this investigation, J-R curves are determined experimentally with low-constraint single edge tension (SE(T)) specimens of a HSLA-steel and an Alloy 52 dissimilar metal weld (DMW) and the quality of the data is analysed. The results show that the CANMET crack length prediction gives a good fit to the measured data within the validity limits of the prediction, the stress in the remaining ligament does not exceed the true tensile strength, and the increase in the J-R curve due to loss of constraint was predicted analytically.

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Keywords: Dissimilar metal weld; SE(T); constraint; J-R curve; tearing resistance; fracture toughness

* Corresponding author. Tel.: /
E-mail address: sebastian.lindqvist@vtt.fi

Deformation and failure of titanium alloy under tensile dynamic loading

Anastasiia Chevrychkina[a,*], Alexey Evstifeev[a]

[a]Saint-Petersburg State University

Abstract

The behavior titanium alloy Ti–6Al–4V was investigated in quasistatic and dynamic uniaxial tension tests at nominal strain rates range of 0.001 - 1000 1/s. Dynamic investigation were carry out at drop tower impact system. The effect of strain rate dependence of deformation process under tension was considered. Incubation time approach was used for numerical analysis of experimental data.

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Keywords: High strain rates, titanium alloy, incubation time

* Corresponding author. Tel.: /
E-mail address: Anastasiia.Che@gmail.com

Theoretical and experimental research of mechanical behavior of viscoelastic highly-filled polymers during complex harmonic loads

Andrey Yankin[a,]*, Roman Bulbovich[a]

[a] *Perm National Research Polytechnic University, Perm, Russia*

Abstract

Highly-filled polymer composites are widely used in important aerospace structures and other industries. The solid propellant (fuel) is a typical highly-filled polymer. Solid propellant structures resist complex dynamic and static loads. For example, storage of a motor is the static load; transportation and pressure change inside a combustion chamber are dynamic loads. In this case, finished products (motors) are subjected to complex harmonic oscillations under different temperatures. The aim of this research is to develop methods for conducting the dynamic experiment, to define viscoelastic parameters of highly-filled polymer composites under stationary complex harmonic loads, and to identify the mathematical model for calculating the stress-strain state of viscoelastic aerospace structures. Linear and nonlinear integral representations of stress and strain for mechanical behavior description of the viscoelastic materials were presented. The general description of a method to mathematical model nonlinear viscoelastic behavior was accomplished by Volterra using an earlier representation developed by Frechet (Volterra-Frechet integral series). Simple nonlinear phenomenological mathematical model based on complex parameters for describing the viscoelastic material behavior under stationary complex harmonic loads (under various values of frequencies and small strain amplitudes) were presented by using the Volterra-Frechet integral series . This mathematical model was analyzed. Mathematical model identification procedure for describing the behavior of the viscoelastic material under complex harmonic load was developed. Polynomials to describe dependencies of the viscoelastic parameters on frequency and temperature were proposed by using a time-temperature superposition. An experimental design was developed and experiments were conducted. Mathematical model constants were found. Model adequacy was checked. Additional complex uniaxial and biaxial experiments were conducted. The experimental design did not include these additional experiments. Predictive ability analysis of the developed model was checked by using these additional experiments.

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Keywords: Highly-filled polymer, viscoelastic composites, uni- and biaxial complex harmonic load

* Corresponding author. Tel.: /
E-mail address: yas.cem@yandex.ru, dekan_akf@pstu.ru

Fatigue crack initiation and propagation in auxetic porous structures

B. Nečemer[a,]*, J. Kramberger[a], S. Glodež[a]

[a]*University of Maribor, Faculty of Mechanical Engineering, Smetanova 17, 2000 Maribor, Slovenia*

Abstract

The investigation of fatigue behavior of auxetic porous structure made of Al-alloy 7075-T651 is presented in this study. The complete fatigue process of analyzed porous structure is divided into the crack initiation (Ni) and crack propagation (Np) period where the total fatigue life (Nt) is defined as: Nt = Ni + Np. The crack initiation period, Ni, is determined using strain life approach in the framework of FE-Safe computational code where elastic-plastic numerical analysis is performed to obtain the total strain amplitude in the critical cross section of the porous structure. The number of stress cycles, Np, required for the crack propagation from initial to the critical crack length is also numerically determined using finite element model in the framework of Abaqus computation FEM code. The Maximum Tensile Stress (MTS) criterion is considered when analyzing the crack path inside the porous structure.

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Keywords: Auxetic porous structures; fatigue crack initiation; fatigue crack propagation, numerical analysis

* Corresponding author. Tel.: /
E-mail address: branko.necemer@um.si

The study of physically short crack behaviour of FGH96 based on in-situ testing method combined with DIC

Yi Shi[a,*], Xiaoguang Yang[a], Guolei Miao[b], Duoqi Shi[a]

[a]*Beihang Unviersity, Beihang, China*
[b]*Chengdu Holy Industry & Commerce Corp.LTD, Lichun, China*

Abstract

In this paper, we aimed to study the short fatigue crack growth behavior of FGH96 at room temperature combined with the Digital Image Correlation Method (DIC Method). FGH96, a Chinese made powder metallurgy nickel based superalloy, is applied in advanced gas turbine discs due to its excellent mechanical properties. We first set up an in-situ observation system based on the loading system of hydraulic servo testing machine. Compared with the traditional surface replica method, the in-situ test combined with DIC technique provides more information such as the evolution of strain field at the crack tip under the cyclic loading. Then we used the SENT specimens with different notch sizes to obtain the crack growth rate of short crack and long crack. The surface of one SENT was etched to reveal microstructure and form natural speckle for DIC analysis, while other specimens were sprayed with black paint for speckle. The test shows the similar result that short cracks grow faster than large cracks at the same stress intensity factor (below or above the threshold), and the difference between the crack growth rate decreases with the increase of SIF. However, the curve of crack growth rate also exhibits the 'step-like', which is relevant to the 'block' at the tip in the process of damage. Once the strain accumulates to a certain level, the block will fail and thus the crack tip advance to a new virgin block. Meanwhile, the captured pictures reveal that the crack path shifts between transgranular and intergranular due to the unevenly distribution of the grain barriers. The contour of strain field also helps us reveal the deformation in the crack growth.

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Keywords: Short crack, crack growth rate, Digital Image Correlation, strain field, grain barrier

* Corresponding author. Tel.: /
E-mail address: shiyi_sepe@buaa.edu.cn

Effects of molecular orientation and loading rate on the essential work of fracture properties of PET film

Min-Seok Choi[a], Byoung-Ho Choi[a,*]

[a]Korea University, Seoul, South Korea

Abstract

For the sake of weight saving in the automotive industry, composite materials based on engineering plastics have been developed to replace steel. Among many engineering plastics, thermoplastics are considered as good substitutes. Due to their weak strength, rigidity and low heat resistance, there are some problems to use in the industrial field. However, some kinds of additives such as fillers, nanoparticles could improve weaknesses and some advantages such as easy-processibility and recyclability could make them used widely. In this study, essential work of fracture (EWF) tests for commercial polyethylene-terephthalate (PET) films were conducted as a basic study to commercialize an underbody shield component for protecting battery pack of an electric vehicle made of PET.
There are some conventional tests to measure fracture toughness; to find stress intensity factor, KIC, energy release rate (ERR) in LEFM and to consider crack tip opening displacement (CTOD), J-integral in EPFM. However, there are limitations to apply these methods to some kinds of structures with thin thickness and large ductility. An alternative test, the EWF test, was suggested that total energy to fracture is measured from force-displacement curves and divided into two parts; essential work of fracture consumed to create a new surface and non-essential work of fracture consumed to create plastic region around a crack. To find out effects of melt flow direction EWF tests were conducted with two different kinds of specimens; TD-notched and MD-notched specimens. Also three kinds of strain rates were selected and compared one another.

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Keywords: PET film, essential work of fracture, fracture toughness

* Corresponding author. Tel.: /
E-mail address: choims9179@korea.ac.kr

Microstructure analyses and multiscale stochastic modeling of steel structures operated in extreme environment

Valeriy Lepov[a,]*, Albert Grigoriev[a], Mbelle Samuel Bisong[b,c,d], Valentina Achikasova[a], Kyunna Lepova[a], Anastasia Ivanova[a], Nikolay Balakleiskii[e], Boris Loginov[e], Artem Loginov[f]

[a]*V.P.Larionov's Institute of Physical-Technical Problems of the North SB RAS, Yakutsk-677980, Oktyabrskaja, 1, Russia*
[b]*University of Dschang, Dschang, Cameroon*
[c]*Ammosov's North-Eastern Federal University, 58, Belinskogo, 677000, Yakutsk, Russia,*
[d]*ENSET Douala, 15025 Douala, Cameroon*
[e]*Moscow Institute of Electron Technology (Technical University), 10100 Moscow, Russia*
[f]*M.V.Lomonosov's Moscow State University, 10100 Moscow, Russia*

Abstract

The article primarily is concerned with the problem of damage accumulation and fracture modeling for steel structures operated at low temperature conditions. The inhomogeneity of the weld joints is other issue associated with the need to examining the microstructure and defects in steel at different scale levels. The next problem is that, extreme environment contains not only the extreme temperature conditions but phase transitions also, fluctuations in temperature, inappropriate in service and repair. Last factors have stochastic behavior and are even uncertain in nature. So these problems are observed and discussed in this paper as theoretical and experimental for building the multiscale model of structural damage accumulation, taking into account the following: the inhomogeneity of the weld, the low-temperature brittle-ductile transition for bcc steels, and the uncertainty factors estimation concept. The applications describe the locomotive tire lifetime estimation at low temperature conditions. The modeling approach is based on Kachanov-Rabotnov structural damage accumulation theory and stochastic crack growth modeling. Bayesian probability approach has been used for uncertainty factor estimation. The experimental part includes the internal friction study of low temperature transition mechanism for bcc steel, the mechanical tension and impact toughness tests for locomotive tire steel, and the low-cycling testing and microhardness estimation of mechanical properties for welded steel probes. The experimental testing shows the impact toughness drop at low temperature. The microstructural study for weld joints reveals the small cracks in heat affected zone, so the size and distance between such defects are used for stochastic modeling visualization of crack propagation and crack velocity estimation. The revealing mechanisms and proposed relationships could be used for theoretical and numerical modelling of damage accumulation and fracture in welded steel structures and machines.

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Keywords: Weld joint; fracture mechanics; impact toughness; microstructure; microhardness; extreme environment; ductile-brittle transition; multiscale modeling

* Corresponding author. Tel.: /
E-mail address: lepov@iptpn.ysn.ru

The heat dissipation at fatigue crack tip under mix mode loading

O. Plekhov[a,*], A. Vshivkov[a], A. Iziumova[a], A. Zakharov[b], V. Shlyannikov[b]

[a]*Institute of continuous media mechanics of the Ural branch of Russian academy of science, Ac.Koroleva st.,1, Perm, 614013, Russia*
[b]*Kazan Scientific Center of Russian Academy of Sciences, Lobachevskogo str. 2/31, Kazan, 420111, Russia*

Abstract

The cruciform plane specimens of titanium alloy VT1-0 with a thick of 1 mm were tested to study temperature evolution under fatigue crack propagation. The original contact sensor of heat flow and method of infrared thermography were used to analyze the dissipated energy from crack tip during fatigue tests. A series of experiments was carried out to study the propagation of a fatigue crack under biaxial loading with different biaxial coefficient. It has been shown that heat dissipation caused by fatigue crack propagation under Paris regime can be divided into two stages both under uniaxial and biaxial loading conditions.

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Keywords: energy dissipation; crack propagation; infrared thermography; mix mode loading

* Corresponding author. Tel.: /
E-mail address: poa@icmm.ru

Electrochemical fracture analysis of in-service natural gas pipeline steels

Hryhoriy Nykyforchyn[a,*], Oleksandr Tsyrulnyk[a], Olha Zvirko[a]

[a]*Karpenko Physico-Mechanical Institute of the National Academy of Sciences of Ukraine, 5, Naukova St., Lviv 79060, Ukraine*

Abstract

Long-term operation of natural gas transit pipelines implies aging, hydrogen-induced and stress corrosion cracking and it causes hydrogen embrittlement of steels, degradation of mechanical properties associated to a safe serviceability of pipelines, and failure risk increase. The implementation of effective diagnostic measures of pipelines steels degradation would allow planning actions in order to reduce a risk of fracture.

In this paper, a new scientific and methodical approach based on the electrochemical analysis of fracture surface for evaluation of in-service degradation of operated pipeline steels was developed. It was suggested that carbon diffusion to grain boundaries and to defects inside grains, intensified by hydrogen, under long-term operation led to formation of nanoparticles of carbides, which resulted in intergranular cracking of operated pipeline steels under service and their transgranular cracking under impact toughness testing. Therefore, fracture surface was enriched by carbon compounds, and electrochemical characteristics were sensitive to this. In-service degradation of ferrite-pearlite pipeline steels was accompanied by a sharp shift in open-circuit potential of the fracture surface (brittle fracture) of specimens after impact toughness tests compared with that of polished steel surfaces. A significant difference between potentials of the fracture surface and the polished steel surface (over 60 mV in 0.3% NaCl solution) of specimens made of ferrite-pearlite pipeline steels observed after their long-term operation was evidently due to the increased content of carbon compounds on the fracture surface. Mechanism of ferrite-pearlite pipeline steels embrittlement under operation consisted in carbides enrichment not only grain boundaries, but also intragranular defects, has been revealed, as it is indicated by an increase of carbon content on transgranular fracture surfaces determined electrochemically.

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Keywords: Pipeline steel; hydrogen assisted degradation; electrochemical analysis; fracture surface; brittle fracture resistance

[*] Corresponding author. Tel.: /
E-mail address: nykyfor@ipm.lviv.ua

ECF22 - Loading and Environmental Effects on Structural Integrity

The influence of grain size on cleavage crack propagation resistance in ferritic steels

Yuta Suzuki[a,*], Takuhiro Hemmi[a], Fuminori Yanagimoto[a], Hiroyuki Shirahata[b], Kazuki Shibanuma[a]

[a]*Department of Systems Innovation, the University of Tojyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo, Japan*
**Plate & Shape Research Lab., Steel Research Laboratories, Nippon Steel & Sumitomo Metal Coopreration, 20-1 Shintomi, Futtsu-shi, Chiba, Japan*

Abstract

Cleavage crack propagation in steels occurs suddenly and at high speed, and has a risk of giving structures crucial damage. Thus, it is a phenomenon to be prevented absolutely. It is well known that microstructures, for example grain size or orientation, make a substantial contribution to material resistance to cleavage fracture, but the effect of microstructures on mechanism of fracture is practically hardly elucidated at the present moment. This study firstly carried out arrest tests to evaluate the relation between cleavage crack propagation and grain size that was the most basic characteristic of microstructures, and experimented to describe the elementary process on the microscopic mechanism. The numerical analysis model was developed to express the results of these experiments, and showed that the larger grain size was, the larger cleavage crack propagation resistance was.

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Keywords: Cleavage; crack propagation; arrest toughness; microstructure; XFEM;

[*] Corresponding author. Tel.: /
E-mail address: suzuki@struct.t.u-tokyo.ac.jp

A study on failure of double-layer thermal barrier coatings subjected to uniaxial compression tests using acoustic emission analysis and digital image correlation

Marcel Adam[a,]*, Christian Kontermann[a], Matthias Oechsner[a*]

[a]*Chair and Institute for Materials Technology, Technical University Darmstadt, Grafenstr. 2, 64283 Darmstadt, Germany*

Abstract

The failure behavior and fracture process of double-layer thermal barrier coatings under uniaxial compressive substrate loading has been investigated. Coating systems containing GZO with low and high porosity (LP, HP) were fabricated to examine the influence of microstructure on failure behavior and strain energy. An YSZ-HP single-layer system serves as a reference. All ceramic coatings were deposited via atmospheric plasma spraying (APS) on cylindrical rods and turbine blade-shaped specimens made from CoNiCrAlY (LCO-22) coated, nickel-based, single crystal superalloy (PWA 1483). Prior to compression tests, isothermal pre-oxidation at 1050 °C and dwell-times of 100, 500 and 1.500 hours, as well as cyclic annealing tests between 50 and 1050 °C up to 500 cycles were performed, to study the effects of thermal ageing on strain energy to failure. In-situ acoustic emission (AE) measurements provides quantitative information about the failure processes under compressive substrate loading. A stereo camera system monitors the three-dimensional displacements and the surface fracture processes. For as-sprayed coatings, strain to failure of the investigated GZO/YSZ systems is comparable to the referenced single-layer TBC. AE analysis indicates coating failure at earlier stages and less substrate loads after thermal ageing with increasing dwell-time. Consequently, the pre-oxidation leads to reduced strain to failure values in all investigated coating systems. Digital image correlations (DIC) suggests that the failure behavior of as-sprayed GZO/YSZ coatings is similar to the referenced YSZ system. However, a different behavior was observed for pre-oxidized coatings, where cracking and spallation of GZO occurs predominantly.

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Keywords: Gadolinium zirconate; double-layer; thermal barrier coating; acoustic emission; digital image correlation

* Corresponding author. Tel.: /
E-mail address: adam@mpa-ifw.tu-darmstadt.de

ECF22 - Loading and Environmental Effects on Structural Integrity

Methods for complex cracked body finite element assessments

Moritz Lessmann[a,*], John Sawyer[a], David Knowles[a,b]

[a]*Atkins, The Hub, 500 Park Avenue, Aztec West, Almondsbury, Bristol BS32 4RZ, UK*
[b]*University of Bristol, University Walk, Clifton BS8 1TR, UK*

Abstract

This paper presents approaches developed to allow consistent best practice assessments for complex 2/3D defects in engineering structures subjected to primary loading and secondary thermal stresses. Methods are outlined and discussed with reference to recent two- and three-dimensional cracked body analyses of components which have been undertaken to determine tolerable defect sizes and inform sub-critical crack growth calculations. The analyses considered a range of postulated semi-elliptical, through-wall and fully circumferential defects in pressure systems. Mixed element type meshing strategies with tied contact in combination with multiple node transformation techniques around the defect front were employed during mesh generation. This facilitated highly refined meshes along the defect front which were required to accurately model extensive plastic deformation in the region of interest. Displacement driven thermal load cases required detailed assessment with multiple elasto-plastic material models, since lower bound properties do not necessarily provide the most conservative results for displacement controlled load cases. The elasto-plastic J-Integral analyses were, as expected, shown to provide significant benefit over application of the more conservative Failure Assessment Diagram (FAD) approach. The undertaken assessments were validated against analytical solutions and historic inspection evidence and showed good agreement. In summary the adopted modelling techniques released conservatisms and permitted detailed assessment of complex geometries and load cases.

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Keywords: Crack body modelling, crack meshing, FAD, J-Analysis

[*] Corresponding author. Tel.: /
E-mail address: Moritz.lessmann@atkinsglobal.com

A numerical simulation model of microscopic cleavage crack propagation based on 3D XFEM

Kazuki Shibanuma[a,*], Yuta Suzuki[a], Kazuya Kiriyama[a], Takuhiro Hemmi[a], Hiroyuki Shirahata[a]

[a]Department of Systems Innovation, the University of Tojyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo, Japan
[b]Research into Artifacts, Center for Engineering, 5-1-5, Kashiwano-ha, Chiba, Japan

Abstract

We proposed a model of cleavage crack propagation in steel based on the extended finite element method (XFEM). In the proposed model, the geometry of the polycrystal is modeled independently from the finite element mesh, as well as the crack shape. As the fracture criterion of the cleavage crack propagation, the cleavage plane was formed on the {1 0 0} plane of the grain where the maximum normal stress was applied. As validation of the proposed model, the numerical simulation results of fracture surface morphology were compared with the SEM observation results obtained from the specimen of crack arrest test. The result shows that the proposed model can successfully simulate complicated microscopic cleavage crack propagation behaviors, such as micro-branching and wraparound of cracks.

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Keywords: XFEM; cleavage crack propagation;

* Correpsonding author. Tel.: /
E-mail address: shibanuma@struct.t.u-tokyo.ac.jp

Influence of printing direction on the mechanical properties of the additive manufactured polymeric components

Saeed Doagou Rad[a,*], Ali Davoudinejad[a], David Bue Pederson[a], Aminul Islam[a], Guido Tosello[a]

[a]*Technical University of Denmark, Lyngby, Denmark*

Abstract

Additive manufacturing (AM) of the components has provided novel opportunities for science and industry. Vat photopolymerization 3D printing of the polymeric parts has enabled precise manufacturing of the components with micro features. The involved processing parameters in this production method influence the properties of the components effectively. However, their influence on the functionality of the components has yet to be understood. In this study, the influence of the 3D printing direction on the mechanical and fracture behavior of the produced specimens is investigated. Micro tensile bars are produced under different applied directions of the photopolymer printing through a Vat photopolymerization method. The samples are positioned in different angles to acquire different arrangements of polymer layers. Acquiring the samples consisting different layer arrangements enables a full scope characterization of the properties. The mechanical properties of the produced specimens such as elastic modulus, tensile strength, elongation at break are characterized and studied in detail. The results show that changing the direction of the printing lead to up to 25 % difference in the mechanical behavior. In fact, variation of the printing direction affects the bonding behavior between the consecutive polymeric layers. Furthermore, the area of polymer layers bonds subjected to the applied loads differs based on the processing parameters. The involved mechanisms in the variation of the results are also studied using optical and electron microscopies. The results of this study enable designers for AM to have a better understanding of the properties in complex structures.

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Keywords: Additive manufacturing, mechanical properties, polymer, micro components

* Corresponding author. Tel.: /
E-mail address: sadora@mek.dtu.dk

Computational simulation of abnormal fracture appearance in DWTT of X65 steel using micromechanical modelling

Gabriel Testa[a,*], Nicola Bonora[a], Domenico Gentile[a]

[a]*Univeristà degli Studi di Cassino e del Lazio Meridionale*

Abstract

In high-toughness line-pipe steels, abnormal fracture appearances are sometimes observed on drop weight tear test (DWTT) fracture surfaces, thereby posing many complications in properly evaluating DWTT properties. The abnormal fracture appearances occur either when cleavage fracture follows immediately after the initiation of shear fracture at the notch of DWTT specimen, or - and this is indicated as “inverse fracture” - when a cleavage fracture area occurs in the region impacted by the hammer after the initiation of cleavage fracture at the notch. For what concerns the first type, problems have been partly solved by inserting a static pre-crack, a fatigue pre-crack, an electron beam weld, or a chevron notch instead of a conventional pressed notch. In the latter type, however, solutions or alternatives to prevent or reduce the abnormality have not been presented yet. In this work, the occurrence of abnormal fracture appearances was investigated computationally using a modelling approach that combines the modified Beremin model (MBM) for cleavage fracture and the Bonora damage model (BDM) for ductile tearing. Numerical simulation results seem to confirm the possibility to predict material fracture appearances at different temperatures indicating in the temperature dependence of material model parameters a possible explanation of observed behavior in the experiments.

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Keywords: Fracture mechanics, continuum damage mechanics, Drop Weight Tear Test, Beremin approach

* Corresponding author. Tel.: /
E-mail address: gabriel.testa@unicas.it

High rate response and dynamic failure of aluminosilicate glass under compression loading

Sheikh Muhammad Zakir[a], Wang Zhen[a], Suo Tao[a,*], Li Yulong[a], Zhou Fenghua[b], Ahmed Sohail[a], Uzair Ahmed Dar[a]

[a]*School of Aeronautics, Northwestern Polytechnical University, Xi'an, 710072, Shaanxi, PR China.*
[b]*Ningbo University, Ningbo 315211, PR China.*

Abstract

The mechanical behavior of un-strengthened aluminosilicate (ALS) glass is studied experimentally by using modified Split Hopkinson pressure bar and electronic universal testing machine. The compression tests on glass specimens are performed at strain-rates in the range of 10^{-4} to $10^{2}\ s^{-1}$. The compression tests data revealed that ALS glass is strain-rate sensitive vis-à-vis the compressive strength of the glass. In dynamic compression tests, failure process of glass is investigated using a high-speed camera and the failure process in ALS glass is explicated with the associated stress-time history. The initiation of crack, development, and glass debris are discussed to explain the failure process of glass specimens. Test results showed that the axial splitting lead to final rupture of the glass. From both static and dynamic compression tests, the compressive strength, failure strain and energy absorption results for ALS glass specimens are also compared.

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Keywords: Aluminosilicate glass; compressive strength; high-speed photography; rate sensitivity; Split Hopkinson Pressure Bar (SHPB);

* Corresponding author. Tel.: /
E-mail address: suotao@nwpu.edu.cn

Geometrical and feature of size design effect on direct stereolithography micro additively manufactured components

A. Davoudinejad[a,*], L. C. Diaz Perez[b], D. Quagliotti[a], D. B. Pedersen[a], J.A. Albajez García[b], J.A. Yagüe-Fabra[b], G. Tosello[a]

[a]*Department of Mechanical Engineering, Technical Univ. of Denmark, Building 427A, Produktionstorvet, 2800 Kgs. Lyngby, Denmark*
[b] *Aragón Institute for Engineering Research, I3A-University of Zaragoza, C/Maria de Luna, 3, 50018, Zaragoza, Spain*

Abstract

Additive manufacturing (AM) is a suitable technique for the production of components with different geometries and complexity that cannot be easily fabricated with traditional manufacturing techniques. However, considering the manufacturing restrictions can clarify the feasibility of the designs to be produced by AM. In this context, this study investigates the capability and limitations, in terms of feature size and geometry, of the Vat Polymerization method by producing various micro components. In order to evaluate the AM machine capability, two test parts, one with hollow cylindrical and the other with hollow box shapes, with different size features have been designed. Different batches of samples were printed to find out the limit for micro polymer components manufacturing with different geometries. The variability of the results in a single print and different batch was also evaluated. The smallest printed feature of size with hollow shape was 630 µm for both geometries and the features smaller than 355 µm were completely solid.

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Keywords: Additive manufacturing; vat polymerization; micro manufacturing; stereolithography; polymer

* Corresponding author. Tel.: /
E-mail address: alidav@mek.dtu.dk

Numerical residual strength prediction of stationary shoulder friction stir welding structures

Ingo Scheider[a,*], Alessandro Barbini[a], Jorge Dos Santos[a]

[a]*Helmholtz-Zentrum Geesthacht, Geesthacht, Germany*

Abstract

The residual strength of dissimilar Aluminium panels joined by a stationary shoulder friction stir welding (SS-FSW) process is predicted by numerical simulation using finite elements and a cohesive zone model for crack propagation. The yield strength and strain hardening parameters within the stir and heat affected zones are derived from a tensile specimen cut out from the blank perpendicular to the weld seam. The identification is conducted by a hybrid numerical/experimental procedure with an inverse search by help of digital image correlation in order to get the strain field at the welded surface and to compare them to the numerical calculation. The crack propagation parameters are retrieved from specimens with crack in the stir zone and heat affected zone on either side. After this identification procedure, the fracture behavior of a coupon specimen with a crack crossing the weld is predicted.

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Keywords: Rresidual strength, cohesive zone model, welded structures, parameter identification, stress-strain curve

* Corresponding author. Tel.: /
E-mail address: ingo.scheider@hzg.de

Multi-axial high cycle fatigue criteria applied to motor crankshafts

Roberta Amorim Gonçalves[a], Marcos V. Pereira[a,*], Fathi A. Darwish[b]

[a]*Catholic University of Rio de Janeiro, Department of Chemical and Materials Engineering, Rua Marques de São Vicente 225, 22453-901 Rio de Janeiro – RJ, Brazil.*
[b]*Fluminense Federal University, Department of Civil Engineering, Rua Passo da Patria 156, 24210-240 Niteroi – RJ, Brazil.*

Abstract

A comparative study is made of the applicability of critical plane based multiaxial high cycle fatigue models to predicting the fatigue behavior of metallic materials. A number of models, namely Matake, McDiarmid, Carpinteri and Spagnoli, Liu and Mahadevan and Papadopoulos, were applied to fatigue limit states, involving synchronous fully reversed in-phase sinusoidal bend and torsion loading. The results obtained indicated a good predictive capability of the models with an average error index situated approximately between -5,5% and 4,5%. However, this average was limited to less than 3% for the latter three models. Finally, the critical plane orientation, which, for a given material, is characteristic of the proper model, is compared with that of the fracture plane, exclusively determined by the ratio between the shear stress and normal stress amplitudes.

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Keywords: Fully reversed loading; proportional loading; critical plane; fracture plane; error index.

* Corresponding author. Tel.: /
E-mail address: marcospe@puc-rio.br

Formation of slip bands in nano-polycrystalline copper sandwiched between nanoscale brittle materials

Takashi Sumigawa[a,]*, Takayuki Kitamura[a]

[a]*Kyoto University, Kyoto, Japan*

Abstract

The purpose of this study is to investigate the effects of a nano-scale stress field on fatigue damage in a nano-polycrystalline material under fully-reversed and high-cycle loading. A resonant fatigue experiment is carried out for a nano-cantilever specimen that has a nano-polycrystalline Cu thin layer sandwiched by Si, Ti and SiN. Crystallographic slip bands associated with extrusion/intrusion of about 30 nm width are formed on the Cu surface owing to the high-cycle fatigue loading. The slip bands appear only in particular grain though others possess slip systems with a higher Schmid factor. Detailed stress analysis, taking into account the Cu grains and dissimilar surrounding materials (Si, Ti, SiN), indicates that the grain where the slip bands are formed possesses a slip system with the highest resolved shear stress. Slip band formation during fatigue of a polycrystalline material in a nanoscale component is governed by the stress field in the grain. The stress, defined on the basis of continuum mechanics, is available as the governing quantity for slip band formation in fatigue of nanoscale materials with an understructure.

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Keywords: Nano-polycrystalline material, high-cycle fatigue, slip band, stress field, resolved, shear stress, copper

* Corresponding author. Tel.: /
E-mail address: sumigawa@cyber.kues.kyoto-u.ac.jp

Multi-parameter average strain energy density factor criterion applied on the bi-material notch problem

Jan Klusák[a,]*, Ondřej Krepl[a]

[a]CEITEC IPM, Institute of Physics of Materials AS CR, Žižkova 22, Brno 616 62, Czech Republic

Abstract

The stress field near a bi-material notch tip has the singular character. The power of singularity is lower in comparison to the case of a crack. The stress field can be described by the asymptotic stress series, in which each term contains generalized stress intensity factor and stress term exponent. The terms can be either singular or non-singular depending on the value of stress term exponent. The exponents are determined as solution of eigenvalue problem and depend on material properties and local geometry. The factors are calculated by analytical-numerical approaches and depend on global geometry and applied loading. The singular terms become unbounded when approaching the bi-material notch tip while the non-singular terms vanish. The non-singular terms increase precision in stress description on larger distances from the notch tip. The crack initiation conditions from the notch tip can be assessed by the average strain energy density factor (SEDF) criterion. In the case of bi-material notch problem, the crack can initiate in the direction of global minimum, the local minimum or the interface. The actual crack initiation load is calculated for each of abovementioned directions considering the individual fracture toughnesses. Contrary to the case of a crack, the direction of minimum of SEDF changes in dependence on the distance from the tip, therefore the average value over specific distance is used. The multi-parameter criterion considers singular and non-singular stress terms. Therefore in cases, when the specific distance is large, the non-singular terms provide means to improve precision of prediction of crack initiation parameters.

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Keywords: Generalized fracture mechanics, crack initiation, bi-material notch, stability criterion, strain energy density factor;

* Corresponding author. Tel.: /
E-mail address: klusak@ipm.cz

Residual stress estimation based on 3D DIC displacement filed measurement around drilled holes

Tomasz Brynk[a,*], Barbara Romelczyk- Baishya[a]

[a]*Warsaw University of Technology, Faculty of Materials Science and Engineering, Woloska 141 str. 02-507 Warsaw, Poland*

Abstract

Residual stress might influence noticeably fatigue strength and fracture behavior of materials, therefore accurate methods of its determination are desired. The most popular method up today is based on strain measurements resulted from material relaxation near the drilled hole. Tensometric rosettes of defined geometry are used for strain measurements in 3 or 6 positions around the hole. The method has some drawbacks related to its sensitivity to hole and rosette centers eccentricity, averaging strain from tensometers area, time consuming rosettes fixing procedures and calculations based on only a few strain readings. Tensometric rosettes might be replaced by non-contact optical displacement field measurements by means of Digital Image Correlation (DIC) giving much more information (hundreds or thousands of data points) for residual stress calculations. In the paper results of experiments concerning 3D DIC measurements usage for displacement field determination near the drilled hole in preloaded steel samples which afterwards were used as input data in the iterative procedure for the analytical model parameters fitting are presented. Details of testing stand allowing precise hole drilling without need of cameras used for DIC measurements movement during the drilling process and algorithm for inverse method calculations are described. Additionally, FEM model developed for introducing correction terms for blind hole case to the analytical model existing only for through hole instance is discussed.

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Keywords: Residual stress; Digital Image Corrleation (DIC); inverse method

* Corresponding author. Tel.: /
E-mail address: tomasz.brynk@pw.edu.pl

Creep behaviour of an ice-soil retaining structure during a shaft sinking

A. Kostina[a], M. Zhelnin[a,*], O. Plekhov[a], I. Panteleev[a], L. Levin[b]

[a]*Institute of Continuous Media Mechanics of the Ural Branch of Russian Academy of Science, Perm 614013, Russia*
[b]*Mining institute, Ural Branch of Russian Academy of Sciences, Perm 614007, Russia*

Abstract

The article is devoted to analysis of deformation of an ice-soil retaining structure during a vertical mine shaft sinking by applying the artificial ground freezing technique. The analysis was performed by finite element numerical simulation. Since frozen soils possess rheological properties, creep deformation of the ice-soil structure was considered. To determine the creep deformation, the Vaylov's constitutive relations was used. In the relations the creep behavior is described by the Norton-Bailey creep law and the volumetric creep strain is restricted to be zero. The wall thickness of the ice-soil structure was estimated by the Vaylov's formula that is widely used in structural design of potash mines. As a result of the study, it was established that for time required for the lining installation at large depths of the shaft sinking the creep deformation of the ice-soil structure exceeds admissible value guaranteeing safety of the excavation process.

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Keywords: Artificial ground freezing; mine shaft; creep deformation; numerical simulation

* Corresponding author. Tel.: /
E-mail address: zhelnin.m@icmm.ru

Experimental study of fragmentation of PMMA ring

Tianmi Li[a], Yuxuan Zheng[a,*], Fenghua Zhou[a]

[a]*Ningbo University, Ningbo, China*

Abstract

Expanding ring experiment is an important method for dynamic fragmentation of solid materials under 1D tensile loading. A New technique using liquid-driven expansion ring setup was developed for the dynamic tensile fracture and fragmentation testing of ductile/brittle materials. This technique was used to study the fragmentation properties of PMMA rings at different expansion velocities. From the observations of the fracture morphology and the residual internal cracks of the recovered fragments, it is concluded that the fracture of the rings is caused by the circumferential tensile stress. The ring expansion process was captured using ultrahigh speed camera. The specimen surface expansion rate was measured using laser interference device VISAR. The fracture strain of ring was captured using the strain gauge on the specimen. Preliminary results conducted on PMMA rings show that: (1) In the range of tensile strain rate 150~500 s-1, the dynamic failure strain of PMMA is lower than that under the quasi-static tension, which means that PMMA became brittle under higher strain rate loading; (2) Higher loading rates resulted in smaller fragments; (3) The "non-dimensional fragment size vs. strain rate" data fall between the theoretical fragmentation predictions for ductile material and brittle material.

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Keywords: PMMA, liquid-driven expanding ring, high rate tension, fragment size, brittle fracture

* Corresponding author. Tel.: /
E-mail address: zhengyuxuan@nbu.edu.cn

Multi-parameter average strain energy density factor criterion applied on the sharp material inclusion problem

Ondřej Krepl[a,]*, Jan Klusák[a]

[a]CEITEC IPM, Institute of Physics of Materials AS CR, Žižkova 22, Brno 616 62, Czech Republic

Abstract

The tip of a sharp material inclusion (SMI) embedded in a parent material is considered as the singular stress concentrator. The SMI tip is modelled as a special case of a multi-material junction. The singular stress behaviour is caused by the material mismatch and geometrical discontinuity. The power of singularity is lower in comparison to the case of a crack. The stress field can be described by the asymptotic stress series, in which each term contains generalized stress intensity factor and stress terms exponent. The exponents are determined as a solution of eigenvalue problem. The factors are calculated by combination of analytical and numerical approaches. The terms can be either singular or non-singular depending on the stress term exponent. When approaching the concentrator, the singular terms become unbounded while the non-singular terms vanish. The non-singular terms increase precision of stress description on larger distances from the point of singularity. In some cases they provide the only means to describe the stress field well. Because of the singular stress behaviour near SMI tip, this location is prone to crack initiation. The crack initiation conditions are calculated by the average strain energy density factor (SEDF) criterion. Contrary to the case of a crack, the direction of minimum of SEDF changes with distance from the singular point. Therefore, an averaged value over specific distance is used. If the specific distance is relatively large, the employment of non-singular terms in multi-parameter criterion can significantly improve the critical parameters prediction. Thanks to that e.g. the particle composite design can be optimized.

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Keywords: Generalized fracture mechanics, Crack initiation, Sharp material inclusion, Stability criterion, Strain energy density factor;

* Corresponding author. Tel.: /
E-mail address: krepl@ipm.cz

Influence of residual stress and heterogeneity on mechanical field at crack tips in safety end of nuclear power plant

Rui Guo[a,b,*], He Xue[a], Xiaoyan Gong[a]

[a] *Xi'an University of Science and Technology, Xian, China*
[b] *Brunel University, Kingston Lane, London UB8 3PH, UK*

Abstract

The welded residual stress is one of the main factors lead to stress corrosion cracking (SCC) in dissimilar metal welded joints of nuclear power plant safety end. Meanwhile, the material mechanical heterogeneity of welded joints makes the SCC crack tip mechanical fields more complicated. By means of theoretical analysis and Finite Element Method, the laws of stress and strain distribution at SCC crack tip under the interactive effect of residual stress and mechanical heterogeneity in nuclear power plant safety end were simulated and analyzed. The results show that due to the variation of the residual stress, the propagation of the SCC crack might even paused; Cracks adjacent to material interface might change their directions due to the heterogeneity of the welded structure.

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Keywords: Structural integrity; numerical simulation test; stress corrosion cracking; welding residual stress; heterogeneity

[*] Corresponding author. Tel.: /
E-mail address: larklork@gmail.com; b201403011@stu.xust.edu.cn

Fracture criterion for tested CFRP specimens under tension

A.A. Lukyanchuk[a,*], A.G. Kalinin[a], A.V. Pankov[a], Yu.A. Svirskiy[a]

[a]*Central Aerohydraudynamic Institute n.a. Prof. N.E. Zhukovsky (TsAGI), Russia*

Abstract

The development of the theory-experimental methodology to evaluate the fatigue life is one of the essential stages to substantiate the strength and to verify the certification of aircraft from the POV of fatigue and service lives.
To develop such a methodology, it is necessary to obtain the S-N curves for different stress ratios. However, the fatigue test by zero-to-tension stress cycle of an open-hole specimen manufactured of carbon fiber reinforced polymer (CFRP) until final fracture (broken into 2 parts) shows a big scatter of fatigue lives and sometimes it is impossible due to fibers long lives despite of fractured matrix. For example, in our research, the root-mean-square deviation of the logarithm of fatigue life S_{lgN} was in the range 0.7 ÷ 0.9. In order to obtain reliable resource characteristics of the structure, at this kind of dispersion values, a lot of time and material costs are required.
In order to solve this problem, the task was formulated to create a new fracture criterion, which will allow reducing dispersion of fatigue life. Our analysis showed that the fracture process starts from interlayer delamination at hole edge and propagates towards the outer side of specimen under test. The delamination initiation at the hole edge is proposed to be taken as failure initiation moment; then the data obtained are to be used to estimate the S-N curve. To fix the appearance of delamination, a special sensor was developed.
A method was developed to detect the delamination initiation while monitoring the transverse displacement near the free edge of hole. This method provided a drastic decrease of fatigue life scatter up to S_{lgN} = 0.2÷0.3 that is acceptable to estimate the fatigue life; at this, two modes of fracture process in CFRP are taken into consideration: initiation and propagation of delamination, which are characterized by different fracture mechanisms.

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Keywords: Carbon fiber reinforced polymer; open-hole specimen; delamination; fracture criterion; fatigue life; fatigue scattering parameter.

* Corresponding author. Tel.: /
E-mail address: andrey.lukyanchuk@tsagi.ru

Main mechanical factors affecting creep strain at crack tip of stress corrosion cracking in full life cycle

Yinghao Cui[a], He Xue[a,*], Shuai Wang[a], Xiaoyan Gong[a], Jianlong Zhang[a]

[a]*School of Mechanical Engineering, Xi'an University of Science and Technology, Xi'an 710054, China*

Abstract

Stress Corrosion Cracking (SCC) is a failure mechanism that is caused by environment, susceptible material and tensile strain at crack tip. The mechanical state at crack tip is one of the main factors affecting stress corrosion crack propagation rate in structural materials of nuclear power plants. To understand the effect of mechanical factor on creep strain on SCC crack growth rate in the light water reactor environments, the creep strain at crack tip in full life cycle is studied by elastic-plastic finite element method (EPFEM) in this paper. Study results indicate that it is suitable to use the creep strain in front of crack tip as a mechanical factor of SCC behaviors, and also show that wedging stress is the main mechanical factor affecting creep strain in micro crack stage, while external load are gradually becoming the main mechanical factor in long crack stage. Crack propagation rate is very slow in micro crack stage, and it will expand rapidly under the combined effect of residual stress and working load if there is an initial crack in the structural material.

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Keywords: Full life cycle; elastic-plastic FEM simulation; creep strain; nickel-based alloy 600

* Corresponding author. Tel.: /
E-mail address: xue_he@hotmail.com

Analytical prediction of fracture energy at meso-scale

Dinesh Kumar Samal[a], Sonalisa Ray[a,]*, T. Hemalatha[b]

[a]*Indian Institute of Technology Roorkee, India*
[b]*CSIR-Structural Engineering Research Centre, Chennai, India*

Abstract

Concrete is a three phase material comprising of aggregates, matrix and interface transition zone (ITZ) between the aggregate and matrix. In general, the microstructure of ITZ is different than that of bulk mortar and is considered to be the weakest link in concrete. It is important to understand the properties of ITZ and its effect on physical, mechanical and fracture properties of concrete. In this work, an attempt has been made to develop an analytical model to investigate the fracture properties of concrete namely, critical fracture energy while taking into account the effect of interfacial transition zone at mesoscopic level. The mathematical model has been developed from the fundamentals using the principle of dimensional analysis and theory of intermediate asymptotic. Various important parameters, which influence the fracture energy, are volume fraction and elastic modulus of constituents, maximum aggregate size and aggregate gradation, water to cement ratio and thickness of ITZ and have been considered in this study.
The proposed model has been calibrated and validated using the available experimental and numerical results from the literature. Results have shown that the fracture energy of concrete increase with the increase in aggregate size, volume of aggregates and transition zone thickness whereas decreases with the increase in elastic modulus of constituent phases. The effect of water to cement ratio on fracture energy of concrete has also been studied and presented in the paper.

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Keywords: ITZ, fracture energy, analytical model, dimensional analysis

* Corresponding author. Tel.: /
E-mail address: sonalisaray@gmail.com

Scaling laws for concrete under fatigue

Sonali Bhowmik[a], Sonalisa Ray[a,*]

[a]*Indian Institute of Technology Roorkee, India*

Abstract

Developments of scaling laws are crucially important for modeling an engineering phenomenon. Based on the type of physical problems scaling laws has been developed together with the concept of self-similarity. Scale effect should take into account when the size of an object reduces to extremely small-scale level. Therefore, scaling/power laws and similarity concepts have been considered to be important in nano mechanics during last decades. In case of quasi-brittle structures like concrete, cracking occurs in multi-scale level as small cracks in nano scale level coalesce and combine to form micro and subsequently, major crack. Therefore, it is necessary to have a clear understanding of cracking behavior at different length scales during the life cycle of concrete structures. Paris law is the one of the most widely used fatigue crack propagation law established for metallic structure in the power law form. Eventually, numerous researchers have carried out extensive experimental as well as theoretical studies in order to justify the applicability of the Paris law for brittle and quasi-brittle materials. In this work, an attempt has been made to understand the scale effect in crack growth rate at nano-scale level of concrete members when subjected to fatigue loading. A theoretical model has been developed based on an atomic fracture mechanics and energetic-equivalence framework. In this process, the fatigue crack propagation rate is assumed to be governed by thermally activated breakage of atomic bonds. Kramers' formula has been used to derive the breakage of atomic bond and nano particles. The energy dissipation in each cycle to grow a macro-crack is considered to be equal to the sum of the energy dissipations associated with the propagation of all the active nanoscale cracks inside the cyclic FPZ.

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Keywords: Scaling laws, fatigue, fracture energy, nano-scale

* Corresponding author. Tel.: /
E-mail address: sonalisaray@gmail.com

Fracture mechanisms of similar Ti6242 Linear Friction Welds under monotonic and cyclic loading

Garcia Juan-Manuel[a,*], Thilo Morgeneyer[a,*]

[a]*Centre des Matériaux, Mines ParisTech*

Abstract

Fracture mechanisms under monotonic and cyclic loading of similar Ti6242 Lin-ear Friction Welded (LFW) joints are studied. Ti6242 is near-titanium alloy with a nominal composition of 6% Al, 2% Sn, 4% Zr and 2% Mo. Titanium alloys are widely used in the aerospace industry in which there is a need to improve the buy-to-fly ratio, e.g. by the use of novel joining techniques. LFW is a recent solid state joining process that works as follows : A cantilever work piece is in contact with another following a linear oscillatory motion. After a few seconds of friction, a forge pressure is applied in order to achieve a target axial shortening. This process is very quick, auto-cleaning and presents few defects. Ti LFW joints could be exposed to high mechanical stresses. Thus mechanical properties and fracture mechanisms need to be known, yet few results are available. In the present work, cross-welded specimens are tested under monotonic and cyclic loading with a target fatigue life of 10^5 cycles. All tests are performed at room temperature in the as welded state. Fatigue life for specimens in the as EDM-machined state and with improved surface roughness are compared. Monotonic loading fracture using smooth samples takes place in the parent material showing titanium alloys classical ductile rupture. In contrast, under cyclic loading, fracture takes place on the weld line and its surroundings. The change in failure location is attributed to the residual stresses distribution. The fatigue strength for the targeted 105 cycles lifetime is enhanced with improved surface roughness.

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Keywords: Linear friction welding, titanium alloy, Ti6242

* Corresponding author. Tel.: /
E-mail address: juan-manuel.garcia@mines-paristech.fr, thilo.morgeneyer@mines-paristech.fr

Dynamic failure of glass rod under high speed Taylor impact loading

Xun Xiong[a], Zhen Xu[a], Yuxuan Zheng[a], Fenghua Zhou[a,]*

[a]*Ningbo University, Ningbo, China*

Abstract

In this paper we investigated the compressive failure of quartz glass rods vertically impacted on a rigid wall at high velocity (Taylor impact). The glass rod projectile was launched using a high-pressure gas gun. An ultra-high speed video camera was used to record the failure process of the glass rod. The impact created a compressive region in the rod. It was found that starting at the impact face, a failure zone developed in the compressive region and expands toward the far end of the projectile. The moving front of this failure zone can be viewed as a kind of "failure wave", which travels at the velocity of 2~4 mm/μs. The speed of the failure front increases with the compressive pressure, and may decrease with the propagation depth. Some times after the impact, a spallation failure zone developed and expands at the region of near the far end of the projectile. This spallation zone is attributed to the interactions between the unloading stress wave reflected from the free end of the projectile, and the longitude unloading wave initiated at the failure zone. Compared with the compressive failure zone in the impact end region, and the spallation zone in the free end region, relatively less damage was observed in the middle region of the projectile. The experimental observations can be explained from the stress wave analysis. Numerical simulations based on discrete element method have been conducted, providing results that are consistent qualitatively to the experimental observations.

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Keywords: Failure wave, Taylor impact, quartz glass rod, failure and fragmentation, numerical simulation

* Corresponding author. Tel.: /
E-mail address: Zhoufenghua@nbu.edu.cn

On the determination of characteristic fracture toughness quantities of micro- and nano-composites

Darjan Kozic[a,*], Markus Alfreider[b], Daniel Kiener[b], Otmar Kolednik[c]

[a]*Materials Center Leoben Forschung GmbH (MCL)*
[b]*Department Materials Physics, Montanuniversität Leoben*
[c]*Erich Schmid Institute of Materials Science, Austrian Academy of Sciences*

Abstract

Microelectronic components are assembled from a variety of materials with very different properties. Thin film stacks are often processed to produce these components. Single films in a stack typically do not exceed a thickness of a few micrometers. The strength of such small-scale materials is commonly higher than the strength of their bulk counterparts. Additionally, the materials become more brittle as their size is decreased. Fracture mechanical experiments for applications on the macroscopic scale are largely standardized, and a good understanding about the determination of the fracture toughness and the crack growth resistance is established. Basically, these measurements rely on the determination of the crack driving force (CDF) during crack growth initiation and during crack extension. The fracture mechanics testing of micro- and nanocomposites is much more complicated.
First of all, there are technical problems, such as the availability of the necessary apparatus for manufacturing of suitable specimen geometries, and the measurement of crack parameters during testing. The fracture behavior of thin film stacks has already been investigated. The studies used fracture mechanical experiments on micro-cantilever bending beams. Application of such geometry is straightforward as long as linear elastic fracture mechanics is applicable. This is not the case if elastic-plastic fracture mechanics must be applied. Secondly, fundamental problems have to be addressed. Due to material inhomogeneities, the CDF depends on the spatial material property and residual stress variation in the composite. We have recently achieved significant conceptual progress by applying the configurational force concept for the evaluation of the CDF in inhomogeneous materials. Thus, characteristic fracture toughness quantities of small-scale composites can be determined only by a combination of experiment, e.g. for measuring the critical load at the moment of crack growth initiation, and modeling, for calculating the CDF at the given crack tip position.

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Keywords: Microcomposites, fracture modeling, material inhomogeneity effect, crack driving force, configurational force concept

* Corresponding author. Tel.: /
E-mail address: darjan.kozic@mcl.at

Numerical simulation of thermal ageing effect on fracture behavior for CF8A cast stainless steels under very low cyclic loading conditions

Gyo Geun Youn[a], Hyun Suk Nam[a], Yun Jae Kim[a,*], Jin Won Kim[b]

[a]*Department of mechnical engineering, Korea University, Anam-dong, Sungbuk-gu, Seoul 136-701, South Korea*
[b]*Department of nuclear engineering, Chosun University, Seosuk-dong, Dong-gu, Gwangju 501-759, South Korea*

Abstract

In this paper, a method to predict the fracture toughness of thermally-aged CF8A under cyclic loading condition is proposed. The FE damage model based on multi-axial fracture strain energy is applied for the prediction. The predicted results are compared with the experimental data of C(T) specimens. The multi-axial fracture strain energy of unaged CF8A can be obtained from tensile and C(T) data under monotonic loading condition. Then, the multi-axial fracture strain energy of aged CF8A can be determined by introducing the concept of thermal ageing constant "C". From the determined multi-axial fracture strain energy of aged CF8A, the fracture toughness of aged CF8A is predicted under monotonic and cyclic loading condition. The predicted results show good agreement with experimental data.

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Keywords: fracture toughness; multi-axial fracture strain energy; low cycle fatigue; C(T) test; themal ageing constant; finite element method

[*] Corresponding author. Tel.: /
E-mail address: kimy0308@korea.ac.kr

Numerical analysis for the thermal ageing effect on fracture behaviors of CF8A pipes and piping systems under monotonic and very low cycle fatigue loading conditions

Gyo Geun Youn[a], Hyun Suk Nam[a], Yun Jae Kim[a,*]

[a]*Department of mechnical engineering, Korea University, Anam-dong, Sungbuk-gu, Seoul 136-701, South Korea*

Abstract

In this research, the effect of thermal ageing for CF8A is studied under displacement-controlled low cycle fatigue. Virtual tests of pipe and pipe system are considered and they have the same shape and loading conditions as the pipe and pipe systems tested in Battelle. Only material was changed from A106 Gr. B to CF8A. The pipe tests are four-point bending tests with three different load ratio (R= -1, 0, 1) having through-wall crack. The pipe system test also has through wall crack with seismic loading condition (PGA=1g). To simulate the cyclic loading and thermal ageing effect, multi-axial fracture strain energy based FE damage model and thermal ageing constant "C" was applied. From the simulation, it can be known from the virtual pipe test that crack growth rates of unaged and aged CF8A become similar when loading type is changed from monotonic to cyclic. Also, it is can be known from the virtual pipe system test that the crack growths of unaged and aged CF8A are almost same when the size of through-wall crack is 43.2o. However, the crack growth of unaged CF8A is almost 25% smaller that aged CF8A when the size of through-wall crack is 90o.

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Keywords: Fracture toughness, multi-axial fracture strain energy, low cycle fatigue, C(T) test, thermal ageing, thermal ageing constant,finite element damage analysis

* Corresponding author. Tel.: /
E-mail address: kimy0308@korea.ac.kr

An experimental and numerical investigation of the anisotropic plasticity and fracture properties of high strength steels from laboratory to component scales

Fuhui Shen[a], Junhe Lian[a,b,*], Sebastian Münstermann[a], Valentin Kokotin[c], Thomas Pretorius[c]

[a]Steel Institute, RWTH Aachen University, Inzestraße 1, 52074 Aachen, Germany
[b]Impact and Crashworthiness Lab, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
[c]thyssenkrupp Steel Europe AG, Kaiser-Wilhelm-Straße 100, 47166, Duisburg, Germany

Abstract

Experimental and numerical investigations on the plasticity, damage and fracture behavior of a pipeline steel were conducted in this study. Anisotropy effects on the plastic deformation and fracture properties of the material were taken into consideration by performing tests along different loading directions with respect to the rolling direction. Fracture behavior of the steel was characterized through conducting a comprehensive experimental program covering a wide range of stress states by using fracture specimens of various geometries along different loading angles. Besides the fracture experiments in the laboratory scale, the drop weight tear tests of full plate thickness along different loading directions were performed as well. The recently proposed evolving non-associated Hill48 model was adopted to describe the anisotropic hardening behavior of the investigated material. Finite element analysis on the fracture behavior of this material was performed by using a coupled damage mechanics model with triaxiality and Lode angle dependence. Through the hybrid experimental and numerical investigations, the influences of anisotropy on the plastic deformation and fracture behavior of the pipeline steel are analyzed.

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Keywords: Anisotropy, damage mechanics model, ductile fracture, high-strength steels.

* Corresponding author. Tel.: /
E-mail address: junhe.lian@iehk.rwth-aachen.de, lianjh@mit.edu

A mixed-mode controlled DCB test on adhesive joints loaded in a combination of modes I and III

Lukas Loh[a,*], Stephan Marzi[a]

[a]*Institute of Mechanics and Material-Research, Technische Hochschule Mittelhessen, Wiesenstrasse 14, 35390 Giessen, Germany*

Abstract

This work presents a novel test setup to determine the fracture behavior of adhesive joints subjected to mixed-mode I+III loading.
Common mixed-mode tests are mainly focusing on a combination of modes I and II and are limited to approaches derived from linear-elastic fracture mechanics with respect to the test evaluation. The novelty of the here proposed test is based on the principle of superposition of modes I and III, which holds in case of non-linear elastic fracture mechanics as well. The definition of modemixity in terms of contributions to J-integral from single modes allows controlling of mode-mix ratio during experiments. The mode-mixity can be prescribed arbitrarily and the test evaluation is possible also in case of crack propagation. As an outlook, that test setup could be used to study the dependency of fracture behavior on the load history. The experimental work deals with an elastic-plastic epoxy adhesive, SikaPowerR-498. The adhesives is investigated under several constant and variable mode-mix ratios.

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Keywords: Epoxides ;plastics; fracture mechanics; mechanical properties of adhesive; mixed-mode i+iii; fracture envelope

* Corresponding author. Tel.: /
E-mail address: lukas.loh@me.thm.de

Microstructure and tensile mechanical behavior of laser beam welded AA2198 joints - Effect of process parameters and post-weld heat treatment

Theano Examilioti[a,*], Stefan Riekehr[b], Josephin Enz[b], Nikolai Kashaev[b], Benjamin Klusemann[a], Nikolaos Alexopoulos[c]

[a]*Leuphana University of Lüneburg, Lünebur, Germany*
[b]*Helmholtz-Zentrum Geesthacht, Geesthacht, Germany*
[c]*University of the Aegean, Lesbos, Greece*

Abstract

One of the main interests of aerospace industries is to reduce the structural weight of aircrafts; this has resulted in the development of innovative, lightweight and high-strength Al-Li-alloys. Aluminum alloy AA2198 is a third generation Al-Li-alloy and has been developed for the fuselage and skin applications in aircraft structures. Laser beam welding (LBW) of AA2198 is a very promising method for joining aircraft structures, within several other processes. Laser beam welded joints are already been established in the aerospace industry, as they provide higher buckling strength and lower weight by replacing respective riveted differential structures. In the present work, the tensile mechanical behavior of AA2198 was examined on its base material (T3 condition) as well as on laser beam welded specimens. The material sheets had nominal thickness of 5.0 mm and were laser beam welded both with and without filler wire for comparison purposes. The Al-Si alloy AA4047 with 1.2 mm diameter was used as filler wire material. The effect of post-weld heat treatment (PWHT) on the tensile mechanical behavior of the base and welded material was investigated under different ageing conditions, namely under-ageing (UA), peak-ageing (PA) and over-ageing (OA). Specimens were examined in an optical microscope to investigate the morphology formation precipitation formation on fusion and heat affected zones. Fractography was undertaken by scanning electron microscopy (SEM) to obtain a correlation between the material structure and the respective tensile mechanical behavior. Additionally, electron back-scatter diffraction (EBSD) measurements were realized to gain information about grain structure and size in the region of the weld. Differences in microhardness measurements was revealed between fusion zone and heat affected zones of the welded joints. The effect of post-weld heat treatment on microstructure and tensile mechanical properties is also discussed.

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Keywords: Al-Li alloy, laser welding, heat treatment, tensile test

* Correpsonding author. Tel.: /
E-mail address: t.examilioti@aegean.gr

Beam to column flange connection: from elasticity to destruction (theory and experiment)

I. Shardakov[a,*], A. Shestakov[a], M. Son[b], A. Zemlanuhin[b], G. Kashevarova[b], I. Glot[a]

[a]*Institute of Continuous Media Mechanics Ural Branch of Russian Academy of Science, Perm, Russia*
[b]*Perm National Research Polytechnic University, Perm, Russia*

Abstract

Flange connections are the critical elements of metal structures, as they determine the whole structure rigidity and strength. In this paper, the results of experimental and theoretical studies are presented performed to evaluate the deformation behavior of the elements of metal beam-to-column flange connections. The experimental investigations were carried out on samples subjected to elastic and inelastic deformations up to their full failure. Displacements at the characteristic points of the samples were registered during the loading process. Relative deformations were measured at the points of stress and strain concentration. The data obtained at different scales accurately characterize the interrelations between the deformed elements, especially when the deformation becomes inelastic. The theoretical studies were concerned with the development of a mathematical model capable of providing an adequate description of elastic and inelastic stress-strain states in the elements of flange connections.

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Keywords: Flange connection; failure, load-carrying capacity; monitoring; simulation; experiment

[*] Corresponding author. Tel.: /
E-mail address: shardakov@icmm.ru

Applications of multi-channel photonic Doppler velocimetry for investigating the dynamic mechanical behavior of materials

Yongang Wang[a,*], Jun Liu[a], Yuanyuan Ding[a]

[a]Ningbo University. Ningbo, China

Abstract

The split Hopkinson pressure bar (SHPB) technique and the wave propagation inverse analysis (WPIA) technique are both used to experimentally investigate the mechanical behavior of materials at high strain rate. In the present paper, more attention is paid to develop new optical measurement approach of SHPB and WPIA by using multi-channel photonic Doppler velocimetry (PDV). Based on the particle velocities measured by PDV, the dynamic stress-strain curve of material is obtained in SHPB tests. The strain is determined by the radial particle velocity of specimen, and the stress is determined by the free surface particle velocity of the transmitter bar, respectively. The results obtained by new method coincide with those obtained by the conventional strain gauge measurements. The new method is non-intervening and insensitive to electrical noise, making it significantly more reliable than strain gauges. Using the oblique incidence of laser beam, a series of particle velocity wave propagation signals for long rod specimen are measured simultaneously. Based on the measurements of particle velocity profile, the dynamic constitutive response of PMMA material is determined by WPIA method. The comparison between dynamic stress-strain curve and the quasi-static one indicates that the strain rate effect must be taken into account for PMMA.

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Keywords: Dynamic mechanical behaviour, photonic doppler velocimetry, split hopkinson pressure bar

* Corresponding author. Tel.: /
E-mail address: wangyonggang@nbu.edu.cn

ECF22 - Loading and Environmental Effects on Structural Integrity

Evaluation of blistered and cold deformed ULC steel with melt extraction and thermal desorption spectroscopy

A. Laureys[a], L. Claeys[a], M. Pinson[a], T. Depover[a], K. Verbeken[a,*]

[a]Department of Materials, Textiles and Chemical Engineering, Ghent University (UGent), Tech Lane Ghent Science Park - Campus A, Technologiepark 903, B-9052 Gent, Belgium

Abstract

Hydrogen characterization techniques like melt extraction and thermal desorption spectroscopy (TDS) are useful tools in order to evaluate and understand the interaction between hydrogen and metals. These two techniques are used here on cold deformed ultra-low carbon (ULC) steel with and without hydrogen induced damage. The material is charged electrochemically in order to induce varying amounts of hydrogen and variable degrees of hydrogen induced damage. The aim of this work is to evaluate to which extent the hydrogen induced damage would manifest itself in melt extraction and TDS measurements.

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Keywords: Ultra-low carbon steel, melt extraction, thermal desorption spectroscopy, blisters, cold deformation

* Corresponding author. Tel.: /
E-mail address: Kim.verbeken@ugent.be

Characterization of the ductile and brittle failure of thin-walled tubular materials

Camille Caisso[a,*], Nicolas Jacques[a,*], Younes Demmouche[a], Harold Fresnel[a], Aboulgihit El Malki Alaoui[a]

[a]*ENSTA Bretagne, France*
[b]*Autoliv-Livbag, France*

Abstract

Airbag gas generators used in the automotive industry are often made of tubular materials. To assess the fracture toughness of these generators, Gurson-Tvergaard-Needleman (GTN) model and the Beremin model are used to describe respectively the ductile and brittle fracture stages. The present work deals with the characterization of the ductile and brittle fracture of tubular materials. An experimental program has been carried out on specimens machined from tubes made of low-carbon high-strength steel. Double Edge Notched tensile samples with two symmetric circular cutouts and different notch radii were used in order to obtain different values of stress triaxiality (ranging from 0.33 up to 0.576). A specific holding system was designed to adapt these samples on conventional tensile machines. Using finite element computations and inverse analysis, the results of the fracture tests have been used to identify parameters of the GTN model. To study the ductile to brittle transition of tubular materials, a specific Charpy impact test has been developed. The specimens are ring-shaped with a diameter of 30 mm, a thickness of 2 mm and a width of 5 mm. Two symmetric V-notches are machined in the samples. The Charpy test has been applied on two grades of steel at temperatures ranging from -160°C to 20°C. In both cases, the ductile to brittle fracture transition was observed. The aim of this part is to identify the parameters of the Beremin model from the fracture energy measurements.

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Keywords: Ductile fracture, ductile to brittle transition, tubular materials

* Corresponding author. Tel.: /
E-mail address: camille.caisso@ensta-bretagne.org, Nicolas.jacques@ensta-bretagne.fr

Study of the effect of anatomical location and presence of bone marrow on mechanical properties of porcine trabecular bone at several strain rates

Juan Diego Silva-Henao[a,]*, Juan Pablo Casas-Rodríguez[a], Roberto Javier Rueda-Esteban[a], Alejandro Marañon-Leon[a]

[a]*Universidad de Los Andes, Colombia*

Abstract

Previous studies have demonstrated that mechanical properties of trabecular bone are highly dependent on specific anatomic location due to variations in porosity, density and local trabecular orientation. This work presents the mechanical properties of trabecular bone samples from several anatomic locations at several strain rates and the effect induced by bone marrow. Whole bones were obtained from porcine individuals whose age, sex, weight and breed were fully known before death. These were then weighted and measured for further specimen control prior to test subject acquisition. Samples were tested, with and without bone marrow, at several strain rates using three different tests devices: a conventional constant strain rate apparatus for low strain rates, a Drop Weight Impact Test device for the intermediate regime and a PMMA Split Hopkinson Pressure Bar System for high strain rates. Maximum elastic stress, plateau stress, energy absorption and modulus of elasticity were calculated. The results of this experimentation show that mechanical properties fluctuate within the distal metaphysis of the bone depending on the anatomical location as well as strain rate. Similarly, the presence of bone marrow improves the mechanical behavior of cancellous bone samples particularly at high strain rates were viscous effects were more prevalent. Further research needs to be conducted in order to fully comprehend how intraarticular injuries occur, however the results presented in this study can work as base for computational studies of complex bone fractures.

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Keywords: Dynamic loading, biological materials, quasi-static loading, trabecular bone, train rate, trabecular orientatio

* Corresponding author. Tel.: /
E-mail address: jd.silva248@uniandes.edu.co

The evolution of damage under static loading of carbon steels with different structure

Marat Tyutin[a,]*, Ludmila Botvina[a], Ivan Sinev[a]

[a]*A.A. Baikov Institute of Metallurgy and Materials Science, Russian Academy of Sciences*

Abstract

In the study, we investigated the interrelation of physical parameters of non-destructive testing (coercive force, eddy current parameter, self-magnetic field intensity and acoustic emission parameters) with characteristics of real damage (relative area of the damaged surface, the concentration criterion), estimated at static tension of specimens made of carbon 0.2%C and 0.45%C steels with keyhole stress concentrators. It was established that the achievement of characteristic stresses – the yield strength and ultimate strength – affect the magnetic and acoustic parameters. When the yield strength is reached, kink in the dependences of the physical characteristics is observed, accompanied by a fall in the acoustic emission b-value. Near the ultimate strength, there is a local drop in the b-value and coercive force, and then a sharp decrease in the eddy current parameter and coercive force in the steel 0.2%C specimen, followed by an acoustic emission gap before the fracture is observed. The real damage estimation was carried out by studying the microcracks patterns at various stages of deformation of specimens from 0.2%C and 0.45%C steels. The increase in damage during the tension was characterized by a change in such damage parameters as concentration k-criterion and the relative area of the damaged surface S* occupied by microcracks. According to the evaluation of the damage characteristics, three stages of fracture were identified, including the initiation of microcracks (stage I), their growth (stage II), and coalescence (stage III).

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Keywords: Nondestructive testing fracture, damage, acoustic emission

* Corresponding author. Tel.: /
E-mail address: tyutin@imet.ac.ru

Interrelation between mechanical, physical and damage parameters at fracture of carbon steels

Victor Levina[a,]*, Ludmila Botvina[a,]*, Marat Tyutin[a]

[a]A.A. Baikov Institute of Metallurgy and Materials Science, Russian Academy of Sciences, Moscow, Russia

Abstract

The purpose of this work is to establish the relationship between physical parameters (heat capacity, velocity and attenuation of ultrasonic waves, acoustic emission parameters, self-magnetic field intensity, coercive force, eddy current, electrical resistivity), mechanical properties of structural steels (yield strength, tensile strength, microhardness) and damage characteristics (length, total number of microcracks, relative area of damaged surface and plastic zone size). Specimens from structural steels 0.2%C, 0.45%C and 0.12C-18Cr-9Ni at various stages of static and cyclic loading were investigated.

The characteristics of the deformation and fracture localization are determined, the relationship between the physical parameters estimated, the plastic zone size and the microcrack concentration within zone at various stages of deformation are considered. At tension test, the physical parameters including heat capacity, microhardness, electrical resistivity, coefficient of ultrasound attenuation, the ratio of the self-magnetic field intensity to the velocity of longitudinal ultrasonic waves decrease with increasing distance from the notch tip. At fatigue testing we observed periodic change in microhardness, ultrasound attenuation coefficient, eddy current and electrical resistivity parameter associated probably with primary dislocation hardening at an early stage and the development of cracks at a later stage of fatigue. Assessment of material damage at different stages of cyclic loading is showed that the relative area of the damaged surface S* increases at a relative lifetime of N/Nf = 0.5. It correlates with an increase in the damage parameter (D) calculated using the velocity of ultrasonic waves, electrical resistivity and eddy current parameter. On the base of research of real damage of materials at static and cyclic loading physical parameters, which can be served as diagnostic characteristics were suggested.

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Keywords: Tension, fatigue, mechanical properties, heat capacity

* Corresponding author. Tel.: /
E-mail address: levin.vik@yandex.ru, botvina@imet.ac.ru

Characteristics of damage evolution in structural steels at different loading conditions

Victor Levina[a,]*, Ludmila Botvina[a]

[a]A.A. Baikov Institute of Metallurgy and Materials Science, Russian Academy of Sciences

Abstract

The kinetics of plastic deformation zone and microcrack accumulation in specimens from steels with different structure at various stages of tension, fatigue and mixed mode loading is studied. The microcrack length, the total number of microcracks, and the relative fraction of damaged surface are estimated and a correlation of these characteristics with both the magnitude of J-integral at tension loading, and the number of cycles at cycling loading is found. Cumulative number–length distributions of microcracks in the localized zone of fracture are plotted. The criteria of damage, fracture mechanics, percolation, and fractal dimension are estimated and used to distinguish the stages of fracture process. The influence of metal structure and loading conditions on multiple fracture kinetics is analyzed.
The concentration criterion of fracture characterizing the predominant mechanism of damage development at different stages of static and cyclic loading (accumulation at $k > 3$ or coalescence at $k < 3$) was estimated. Under cyclic loading of specimens of low-carbon steel, the power-law dependence of k-parameter on relative durability was found. Under static and cyclic loading of low-carbon steel, the exponential function approximating the cumulative microcracks' distribution curves at the initial loading stage changes by the power-law function at the pre-fracture stage. The power-law k-parameter dependences on both the damaged surface portion and the specific work of plastic deformation were found for the three structural steels under tension. During loading, the crack size in the plastic zone changes by two or more orders of magnitude, it allows to consider the process of damage accumulation in terms of the percolation theory using the concept of a percolation threshold for determining fracture stages. Some general regularities of defect accumulation on different scale levels were considered.

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Keywords: Damage, plastic deformation zone, length and number of microcracks, concentration fracture criterion, tension, fatigue, mixed mode loading, percolation threshold, fracture stages

* Corresponding author. Tel.: /
E-mail address: botvina@imet.ac.ru

Influence of ultrafine-grained structure produced by equal-channel angular pressing on the dynamic response of pure copper

Ivan Smirnov[a,*], Alexander Konstantinov[b]

[a]*Saint Petersburg University, 7/9 Universitetskaya nab., Saint Petersburg, 199034, Russia*
[b]*Lobachevsky State University of Nizhni Novgorod, 23 Prospekt Gagarina, Nizhny Novgorod, 603950, Russia*

Abstract

Metallic materials with a nanocrystalline or ultrafine-grained (UFG) structure can exhibit increased strength, albeit with reduced ductility. The behaviour of such materials under high-speed and impact loads has been insufficiently explored. This work presents experimental results on the dynamic response of UFG pure copper (99.95%) processed by equal-channel angular pressing (ECAP) in comparison with its initial coarse-grained (CG) structure. The yield strength in the case of compression tests of cylindrical samples and the energy consumed for deformation and fracture in the case of a three-point bending of a beam with a V-notch are considered. The UFG copper has higher yield strength in compression tests, but its sensitivity to the loading rate is significantly less than that of the CG initial material and depends on the number of ECAP passes. The UFG material shows higher impact toughness KCV and energy consumption for the entire process of deformation and fracture under impact three-point bending.

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Keywords: Ultrafine-grained; equal channel angular pressing; pure copper; dynamic compression; dynamic bending; yield stress; consumed energy.

* Corresponding author. Tel.: /
E-mail address: i.v.smirnov@spbu.ru

Elastic and dissipative properties of concrete under impact loads

I. Shardakov[a,*], A. Shestakov[a], I. Glot[a]

[a]*Institute of continuous Media Mechanics UB RAS, 1, Korolev Street, Perm, 614613, Russia*

Abstract

One of the most promising approaches for the diagnostic of reinforced concrete structures is vibration diagnostics which analyze natural vibrations and transient processes caused by impact loads. It concentrates on the evolution of the shock wave front passing through the structure. The results of measurements are analyzed based on mathematical simulation of the propagation of deformation wave in space and time. The presence of a defect in the structure causes changes in the shape, frequency composition and propagation time of the wave. The mathematical model is also used for determining the main parameters of experimental measurements: frequency range, actuator power and sensor sensitivity and their number and spatial location.
A theoretical and experimental approach is proposed to determine elastic and dissipative characteristics of concrete. In the framework of viscoelastic model, the deformation response of a concrete specimen to an impact load is analyzed. The numerical solution is obtained by the finite-element method using the ANSYS software. Based on this solution, structural scheme of experiments has been obtained. In experiments free vibrations of the specimen were excited. The deformation response was recorded with a laser vibrometer. A special iterative procedure ensuring the agreement between numerical and experimental results was developed. The proposed approach provides a high sensitivity of the vibrodiagnostic procedure to the appearance and development of defects in concrete structures.

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Keywords: Concrete, elastic and dissipative characteristics, vibrations, experiment and simularuin

* Corresponding author. Tel.: /
E-mail address: shardakov@icmm.ru

Fatigue crack propagation initiated at artificially made small defect in two different HAZ microstructures

Fidan Smaili[a], Tomaž Vuherer[a,*]

[a]*University of Maribor, Faculty of Mechanical Engineering, Smetanova ulica 17, 2000 Maribor, Slovenia*

Abstract

Weld joints consist of base material, heat affected zone (HAZ) and weld metal. Load carrying capacity of the weld joints depends on the weakest part of the microstructure in welded joint, especially at cyclic loading. Weld joint usually can consist small defects, which are much smaller of sensitivity of NDT methods for weld joint inspection. In those cases, small cracks often initiated from such defects, so the size of the defect in comparison to grain size is very important for early crack propagations. Defects and cracks originating on such condition can be declared as “microstructurally small” (smaller than grain) or “physically small” (size of just few grain) or long one (size 10 or 100 grains or more). Crack initiation from such defect and its early propagation are very different. Crack initiation and early crack propagation from artificially made defect (28 µm deep) by Vickers indenter were analyzed. Investigation reviled that threshold for FG HAZ is smaller than for the CG HAZ, but crack propagation in CG HAZ is higher in comparison to FG HAZ. Some cracks, which had been initiated, stopped to propagate in CG HAZ but in case of FG HAZ they propagated without stopping.

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Keywords: Weld joint; HAZ; defect; crack initiation; crack propagation

* Corresponding author. Tel.: /
E-mail address: tomaz.vuherer@um.si

Finite element prediction and validation of residual stress profiles in 316L samples manufactured by laser powder bed fusion

Richard J. Williams[a,]*, Paul A. Hooper[a], Catrin M. Davies[a]

[a]*Department of Mechanical Engineering, Imperial College London, SW7 2AZ, UK.*

Abstract

Laser powder bed fusion (LPBF) processes continue to grow in popularity and much progress has been made in recent years. However, due to the extreme thermal gradients present, significant residual stresses are inevitable and can be detrimental during component service. Critical to mitigating these stresses effectively is the ability to model the thermo-mechanical process accurately and efficiently. A simplified FE modelling methodology has been developed and applied to a cylindrical component built in both the horizontal and vertical orientations. The resulting distortion of the parts following a slitting process was compared with those predicted by the model and good agreement to within 5% was found. The final stress fields in the components were predicted by the model and then examined to assess the principal stresses driving the distortion and the causes of difference in results between the two build orientations.

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Keywords: Laser powder bed fusion; LPBF; residual stress; distortion; finite element modelling

* Corresponding author. Tel.: /
E-mail address: r.williams16@imperial.ac.uk

Relation between structure of metallic materials and fracture properties under conditions of solid particle erosion

S.A. Atroshenko[a,b,*], A.D. Evstifeev[b], Yu.V. Petrov[a,b]

[a]*IPME RAS, V.O., Bolshoy, 61, St.Petersburg, 199178, Russia*
[b]*SPbSU, Universitetskaya Embankment, 7/9, St.-Petersburg,199034, Russia*

Abstract

The fraction of the ductile component of the fracture surface after solid particle erosion for different materials was investigated. The minimum amount of viscous fracture on the fracture surface was observed in aluminum samples with the FCC lattice and very high stacking fault energy, and the maximum was found in copper samples with the same FCC lattice but small stacking fault energy. The percentage of viscous fracture in BCC steel samples is close in magnitude to titanium alloy with HCP + BCC lattice and they occupy an intermediate position between copper and aluminum samples.

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Keywords: Metallic materials, fracture properties, erosion;

[*] Corresponding auhor. Tel.: /
E-mail address: satroshe@mail.ru

Shock interaction of elements of the system "Striker - Gasket - reinforced concrete beam"

I.N. Shardakov[a,*], A.P. Shestakov[a], K.V. Sobyanin[a], I.O. Glot[a]

[a]*Institute of Continuous Media Mechanics of the Ural Branch of Russian Academy of Science, Perm, N614013, Russian Federation*

Abstract

Results obtained in this study are related to shock-wave vibrodiagnostics of reinforced concrete structures. The paper focuses on vibrodiagnostics procedure which causes no inelastic deformation in examined structure. The objective is to find local impact parameters for excitation of mechanical oscillations of a desired spectrum in the structure and to excite an elastic wave with required wavefront characteristics. Based on results of a numerical experiment performed on the basis of a mathematical model of dynamic elastic interaction of elements of "striker – gasket – reinforced concrete beam" system the duration of the impulse action on the beam was determined depending on various factors.

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Keywords: Concrete, vibration diagnostics, shock-wave method, elastisity

* Corresponding author. Tel.: /
E-mail address: shardakov@icmm.ru

Influence of inertia and material properties on discrete simulation of dynamic fracture of concrete

Josef Květoň[a,*], Jan Eliáš[a]

[a]Faculty of Civil Engineering, Veveri 95, Brno 602 00, Czech Republic

Abstract

It is well known that the material resistance to fracture increases with increasing strain rate. For relatively slow strain rates, the response is strongly dependent on the material fracture properties such as material strength or fracture energy, whereas with further increase of loading rate, the loading force is getting influenced predominantly by the material inertia. The response of the material changes with strain rate in the sense of loading force as well as character of the crack pattern. The contribution is focused on simulations of fracture experiments at various strain rates. Dynamical concrete fracture is simulated using mesoscale discrete model, i.e. a system of interconnected discrete particles. Material properties in the model are randomly distributed within the volume domain. Similar to quasi-static loading rates, the material randomness influences the dynamic fracture as well. Deterministic and probabilistic simulations are compared and the influence of material parameters and their strain rate dependence are discussed.

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Keywords: Strain rate effect; concrete fracture; dynamics; inertia influence; discrete model; spatial material randomness

* Corresponding author. Tel.: /
E-mail address: kveton.j@fce.vutbr.cz

Rupture of copper rings by a magnetic-pulse method over a wide range of loading times

S.A. Atroshenko[a,b,*], V.A. Morozov[b], V.M. Kats[b], D.A. Gribanov[a], Yu.V. Petrov[a,b]

[a]*Institute of Problems of Mechanical Engineering, 61 Bolshoj pr., V.O., Saint Petersburg 199178, Russia*
[b]*Saint Petersburg State University, 7/9 Universitetskaya Emb., Saint Petersburg 199034, Russia*

Abstract

This paper is devoted to investigations of copper ring samples loaded under high-strain-rate by magnetic pulse method. Three loading schemes are used to achieve strain rate up to 10^6 s^{-1}. The temporal dependence of strength in wide range of time is presented. Microstructure investigations of fracture surface and cross-section under these loading conditions were carried out.

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Keywords: High-strain-rate loading; ring samples; magnetic pulse loading; microstructure analysis

* Corresponding author. Tel.: /
E-mail address: satroshe@mail.ru

Effect of solid-solution and subsequent artificial ageing heat treatment on the fracture resistance of pre-corroded 2024 aluminum alloy specimens

Nikolaos Alexopoulos[a,*], Antonios Pasoudis[a], Alexis Kermanidis[b], Stavros Kourkoulis[c]

[a]*University of the Aegean, Greece*
[b]*University of Thessaly. Greece*
[b]*National Technical University of Athens, Greece*

Abstract

Structural integrity of aged aluminum structures is of major importance in aircraft structures. It is well known that the integrity of such aluminum structures is decreased due to several parameters, the most evident being fatigue, natural ageing as well as corrosion exposure. Each of the above parameter play a significant role on the decrease of remaining mechanical properties and their synergy could accelerate structural failure, e.g. Aloha accident. In the present work, the effect of solid solution heat treatment and subsequent artificial ageing on the fracture resistance of AA2024 is investigated. Additionally, the effect of pre-exposure to corrosion solution for the above different heat treatments will be studied. To this end, this work tries to give information on the synergy between natural ageing and corrosion resistance of AA2024. Tensile and fracture toughness specimens were machined from 3.2 mm nominal thickness sheets, according to specifications ASTM E8 and E561, respectively. The sheets were provided in T3 temper, that includes to some extent, stretching and natural ageing. Solid solution heat treatment for 30 min at 495°C was performed and quenching in water with ice <10°C followed. Three different artificial ageing temperatures was selected, namely 170, 190 and 210° C and the specimens were heat treated for different ageing times. Half of the specimens were tested immediately after artificial ageing heat treatment, while the rest were exposed to exfoliation corrosion exposure according to ASTM G34 specification. It can be noticed that solid solution heat treatment reduces essentially conventional yield stress Rp by approximate 100 MPa, while elongation at fracture Af and fracture toughness Kcr is increased by approximately 5 and 10%, respectively. This heat treatment dissolves any formed S-type precipitates on the grain boundaries during stretch-forming of the sheets. Different mechanical properties are obtained for artificial ageing conditions that all related with the nucleation and growth of the intermetallic precipitates. The effect of corrosion exposure on the above heat treated specimens is extensively discussed.

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Keywords: Heat treatment, corrosion, fracture

* Corresponding author. Tel.: /
E-mail address: nalexop@aegean.gr

Study of the dynamic fracture of hollow spheres under compression using the Discrete Element Method

A. Coré[a], J.-B. Koppa[a,*], J. Girardota[a,*], P. Viot[a]

[a]Arts et M´etiers ParisTech, CNRS, I2M Bordeaux, Esplanade des Arts et M´etiers, Talence 33400, France

Abstract

Hollow sphere structure (HSS) belongs to cellular solids that have been studied recently for its multiples properties. In our case, HSS aims to absorb soft impacts energy on an airliner cockpit. This structure is investigated because of its promises in term of specific energy dissipated (J.kg1) during impact. First of all, quasi- static and dynamic ($v = 5mm\ min^{-1}$ to $v = 2ms^{-1}$) uniaxial compression tests are conducted at room temperature on a single sphere (D = 30 mm). Rapid crack propagation (RCP) is observed to be predominant at macroscopic scale. The formalism of Linear Elastic Fracture Mechanics (L.E.F.M.) is therefore used to estimate the dynamic energy release rate GIdc. The crack tip location is measured during the crack propagation using a high speed camera. The Discrete Element Method (DEM) is used to simulate the dynamic fracture by implementing a node release technique to perform a generation phase simulation. The dynamic energy release rate can be determined using the experimentally measured crack history. In hollowed spherical structures the numerical results reveal a high proportion of energy dissipated through inertial effects as well as a dependence of the thickness of the skin over the range of 0.04 mm to 1.2 mm. At a crack tip velocity of 0.6 times the Rayleigh wave speed of the material, the dynamic correction factor is less than 0.05. Similar results have been shown for the longitudinal dynamic fracture of polymer pipes. The quantitative results of GIdc are in good agreement with the literature and the present model offers an alternative to the finite element method to simulate the rapid crack propagation.Its use reveals to be an interesting way to model the mechanical behavior of brittle materials.

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Keywords: Dynamic fracture; discrete element method; impact; hollow spheres

* Corresponding author. Tel.: /
E-mail address: jean-benoit.kopp@ensam.eu , jeremie.girardot@ensam.eu

Fracture analysis of 316L steel samples manufactured by selective laser melting

Catrin M. Davies[a,*], Olivia Withnell[a], Tobias Ronnerberg[a], Richard Williams[a], Paul A. Hooper[a]

[a]*Department of Mecahnical Engineering, Imperial College London, South Kensington Campus, London, SW7 2AZ.*

Abstract

Charpy impact and single edge notch bend, SEN(B), fracture tests have been performed on samples manufactured from selective laser melting 316L steel powder. Samples have been built in two orientations such that the crack plane was either parallel to the build layers (vertical) or normal to the build layers (horizontal). Generally it has been found that the fracture resistance of the horizontal samples is a factor of 3 higher than the vertical samples and that toughness has been consistently improved with heat treatment for the horizontal samples. However, from the limited number of tests performed, no affirmative trends were seen for the impact and fracture resistance of the vertical samples after heat treatment.

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Keywords: Selective laser metling, 316L, fracture toughness

* Corresponding author. Tel.: /
E-mail address: catrin.davies@imperial.ac.uk

Numerical and analytical modeling of crack path for three-dimensional mixed mode crack problem using global approach

S. El Kabir[a,*], F. Dubois[a], R. Moutou Pitti[b], N. Recho[c], Y. Lapusta[d]

[a]GC2D Laboratory, Limoges University, Civil Enginering Center, Egletons 19300, France
[b]Université Clermont Auvergne, CNRS, Institut Pascal, Clermont-Ferrand F-63000, France
[c]Université Clermont Auvergne, Institut Pascal, BP 10448, Clermont-Ferrand 63000, France
[d]SIGMA Engineering school, Institut Pascal, 63171 Aubière, France

Abstract

Civil engineering and mechanical structures are usually submitted to mixed mode loading. Consequently, a mixed mode crack path process occurs. In three-dimensional crack problem, the study of this problem is very important due to multiple problems that require more understanding of the corner point effect and the local effect due to the torsion mode (mode III) and also due to the necessity to take into account thickness effect. In order to study the mixed mode loading for three-dimensional crack problem, a new three-dimensional contour integral entitled M3D integral is modeled using global approach. Combining real and virtual mechanical displacement fields, this new integral is used to separate numerically mode I, mode II and mode III in the mixed mode ratio. In earlier research works, Moutou Pitti et al [1] have proposed a new specimen called Mixed Mode Crack Growth (MMCG), and El kabir et al [2] have studied numerically the stability of this specimen for various geometries in two-dimensional case. This work deals with numerical and analytical modeling to study the crack path stability in real three-dimensional case for mixed mode crack problem. Using MMCG specimen, the non-dependence of integration domain is presented, and the stability of the calculation of M3D Integral with respect to various geometries and thicknesses is shown for the opening mode (Mode I), the shear mode (Mode II), the out-of-plan shear mode (Mode III) and also for the mixed mode ratio by computing the energy release rate versus the crack length. Finally, the analytical generalization of the M3D-integral is done. That will allow to take into account the mixed-mode crack growth analysis coupling mechanical and thermal loads.

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Keywords: Crack path; MMCG specimen; 3D fracture; M_3D integral; energy release rate; mixed mode.

* Corresponding author. Tel.: /
E-mail address: soliman.el-kabir@unilim.fr

Study of strain-rate and temperature effect in ductile damage threshold and critical damage value for different damage models and its influence in orthogonal cutting simulations

Juan Camilo Osorio Pinzon[a,*], Juan Pablo Casas Rodriguez[a], Sepideh Abolghasem Ghazvini[a], Alicia Porras Holguin[a], Alejandro Marañon Leon[a]

[a]*Universidad de los Andes, Bogota, Columbia*

Abstract

Orthogonal cutting processes for ductile materials imposes severe plastic deformation, which involves ductile material failure at high strain-rates and the accompanying temperature rise. Plastic constitutive model parameters, ductile damage threshold and damage evolution are directly affected by the complicate interactions among the thermomechanical conditions during the cutting process. To perform FEM simulations, element removal and damage threshold are needed to perform an accurate cutting simulation taking into account plastic, thermodynamic and damage effects in the workpiece, since reasonable parameters estimation can potentially lead to reliable solutions for cutting force, thrust force, temperature rise and residual stress among others. This study presents the experimental results for damage threshold and critical damage values for various strain - rates and temperature conditions using two different test devices: a conventional quasi-static test apparatus and a drop weight impact device (DWIT) adapted for tensile tests, covering strain rates between 0.01/s to 10/s. Relationship between material damage threshold and critical damage value with strain – rate and temperature rise are presented, as well as their effects during orthogonal cutting FEM simulation and accurate chip thickness prediction. Experiments are carried to determine damage parameters for different damage model, taking into account various triaxiality factors and damage evolution using elastic modulus degeneration. Simulations are presented and compared with experimental results that show the importance of accurate damage parameter determination and damage model selection in cutting force prediction.

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Keywords: orthogonal cutting, temperature dependent, ductile damage, damage evolution, finite element simulation

* Corresponding author. Tel.: /
E-mail: jc.osorio10@uniandes.edu.co.

Crack growth in titanium alloy under ultrasonic loading

Valentin Tkachenko[a], Alexander Nikitin[b,]*, Ilia Nikitin[b]

[a]*Moscow Aviation Institute - National Research University, Moscow, 125993, Russia*
[b]*Institute for Computer Aided Design Russian Academy of Sciencies, Moscow, 123056, Russia*

Abstract

The ultrasonic loading is usually associated with a very high cycle fatigue problem of crack initiation. It has been shown many times by Shanyavskiy (2014), Nicholas (1999) and others that such high frequency loading may to cause'unexpected' in-service fatigue failures of turbo-jet elements, such as compressor disks and blades. Many different studies were carried out on the problem of crack initiation in different structural materials, Bathias and Paris (2004), Mayer (2013), even for titanium alloys McEvily et al. (2008), Nikitin et al. (2016). Nonetheless the problem of early fatigue crack growth under ultrasonic loading reminded outside of main scientific interests. In the resent years the interest to this subject is increasing Perez-Mora et al. (2015), Stanzl-Tschegg et al. (2016). This paper is focused on the problem of early crack growth in two-phases titanium alloy under ultrasonic loading. The first results of crack growth tests on VT3-1 (close to Ti-6Al-4V) titanium alloy and mathematical model for prediction of crack front evolution are presented. The results of mathematical modeling are comparing with a shape of fatigue crack at the fracture pattern for curvilinear crack front.

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Keywords: Failure Analysis; short-term overheating; steam tube

* Alexander Nikitin. Tel.: +79654365980.
E-mail address: nikitin_alex@bk.ru

Block copolymer and core shell rubber hybrid toughening of epoxy based carbon fibre reinforced composites

Andreas Klingler[a,*], Bernd Wetzel[a]

[a]*Institute for Composite Materials (IVW GmbH), Kaiserslautern, Germany*

Abstract

Epoxy based, carbon fibre reinforced composites (CFRP) are high performance materials for applications, which require a high strength and stiffness. However, these materials suffer from the inherently brittle nature of the thermosetting matrix. Therefore, various approaches exist to improve this adverse property by a modification of the resin system, e.g. by blending it with a second phase. For this purpose, new material concepts, such as self-assembling block copolymers (BCP) and core-shell rubber particles (CSR) have shown to be most efficient for toughening of epoxy resins without affecting the thermo-mechanical properties [1].

This study focussed on the application of these advanced types of modifiers in anhydride cured, epoxy based CFRP. It was shown that the mode II interlaminar fracture toughness, measured in a 3-point end notched flexure (3-ENF) setup, was strongly increasing for BCP/CSR toughened hybrid systems, due to an improved fibre-matrix adhesion. Furthermore, the phase separation behaviour of the acrylic BCP macromolecules was affected by the presence of the carbon fibres. Extensive dynamic mechanical thermal analyses (DMTA) of the matrix composites and the fibre reinforced systems verified the BCP phase separation behaviour. Microstructural and fractographic investigations by scanning electron microscopy identified structural features and toughening mechanisms such as plastic void growth, particle fracture and yielding of the matrix.

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Keywords: Block copolymers, fracture toughness, epoxy, carbon fibre reinforced composites, fibre-matrix adhesion

* Corresponding author. Tel.: /
E-mail: andreas.klingler@ivw.uni-kl.de

A three-dimensional local mechanical field around crack front for isotropic and orthotropic materials

Soliman El Kabir[a,*] Rostand Moutou Pitti[b], Frédéric Dubois[a], Naman Recho[b], Yuri Lapusta[c]

[a]*Limoges University*
[b]*Université Clermont Auvergne, Clermont Auvergne, France*
[c]*SIGMA Engineering school, Aubiere, France*

Abstract

Local approach is based on the definition of the mechanical fields close to the crack tip region. This approach allows us to determine the stress intensity factor and compliances. For plan problem, the description of the stress singularity along the crack tip is obtained using the Airy stress function. Most of the literature studies carried out deal with two-dimensional case (Rice's integral, Sih's fileds…) [1]. This paper deals with a novel approach description by complex variable method for three dimensional local mechanical fields close to the crack front for isotropic or orthotropic materials such as wood. A generalized formulation is developed to predict stress distribution along crack growth for orthotropic materials. An analytical study carried out is based on governing equations in static case. The compatibilities equations and Maxwell stress functions allow us to obtain the roots of characteristics equations. By introducing some assumptions, the stress distribution around the crack front line is obtained and compared to Sih's solution of stress for two-dimensional case [1]. The stress distribution is expressed in term of stress intensity factor using Irwin's expression for three modes. The expressions allowing to determine the stress intensity factor going from the stress distribution around crack tip for orthotropic materials are found. Using the stress mechanical field and the strain-stress relation for orthotropic materials, the displacement mechanical field can be easily addressed. The local approach is compared to global approach using three-dimensional J_3D integral by use of a numerical implementation [2].

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Keywords: Analytical formulation, local mechanical field, rhree-dimensional medium, stress intensity factor, orthotropic materials, 3D fracture, J_3D integral, energy release rate, wood

* Corresponding author. Tel.: /
E-mail: soliman.el-kabir@unilim.fr

Effect of the component properties on the creep life prediction of composites

Kirill Khvostunkov[a,*]

[a]*Lomonosov Moscow State University, Moscow, Russia*

Abstract

Failure time for composite is defined as a moment when solution of evolution equation has approach the critical value. This value is personal for every type of a composite. Evolution equation is based on the thermodynamic theory of Rice. Damage tensor for orthotropic composite is taken as symmetric tensor of the second rank and depends on damage of fiber (layer, inclusions), matrix and interface.

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Keywords: creep fatigue life prediction of compoistes, damage tensor, evolution equation

[*] * Corresponding author. Tel.: /
E-mail: khvostunkov@gmail.com

The effect of heat treatments on the microstructure and fracture toughness properties of drawn tungsten wires

Vladica Nikolić[a,*], Johann Reisch[b], Manuel Pfeifenberger[a], Reinhard Pippan[a]

[a]*Erich Schmid Institute of the Austrian Academy of Sciences, Leoben, Austria*
[b]*Max-Planck Institute for Plasma Physics in Garching, Garching, Austria*

Abstract

Together with the outstanding high-temperature mechanical and physical properties, the highest melting point of all the metals and thermal stability against recrystallization make tungsten (W) a very prominent material in high-temperature applications. Nevertheless, its applicability as a high-performance structural material is somewhat limited due to its typically brittle character at low temperatures and rather high ductile-to-brittle transition temperature. Among several ductilization strategies, one of the promising options is the development of W-fibre reinforced W-composite materials (Wf/W), where extrinsic toughening mechanisms can be used [1]. For a detailed failure analysis of such a composite material, it is essential to obtain a complete understanding of fracture behaviour of drawn tungsten wires which are used as a base material incorporated in the tungsten matrix.
This contribution is oriented towards the study of damage tolerance of pure and potassium doped W wires with the focus on the influence of different heat treatments. A scanning electron microscope equipped with an electron backscattered diffraction detector was used to determine the microstructure of the wire (grain shape, grain size distribution, grain boundaries nature) and analyse the texture. Annealing in temperature range from 900°C - 1600°C permits the investigation of the microstructural stability of the two investigated materials. The fracture experiments were performed at room temperature on both as-received and annealed wires, followed by a detailed characterization of the fracture surfaces. In order to investigate the anisotropic fracture properties, orientation sensitive experiments were conducted in two principle directions, with the crack propagation direction either parallel or perpendicular to the principal drawing direction. The relationship between responsible deformation mechanism and degree of deformation was explored by alternating the wire diameter between 50 and 150 µm.

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Keywords: Drawn tungsten wires, extrinsic toughening mechanisms, heat treatments effect, microstructural characterization, fracture toughness evaluation

[*] Corresponding author. Tel.: /
E-mail: vladica.nikolic@oeaw.ac.at

New experimental results for brittle fracture of V-notched TPB specimens

Adelaida Macías[a], Vladislav Mantic[a,*], Alberto Sapora[b], Luis Távara[a], Federico Paris[a]

[a]*Universidad de Sevilla, Sevilla, Spain*
[b]*Politecnico di Torino, Torino, Italy*

Abstract

The problem of determining the critical angle in edge V-notched structures is revisited providing new experimental results by a carefully prepared experimental campaign. Three series of V-notched Three Point Bending (TPB) specimens with different V-notch depths were carefully manufactured from polymethylmethacrylate (PMMA). These specimens were first measured paying an attention to the measurement of the key geometric parameters: the notch depth and angle and the notch-tip radius. The tested V-notch depths were about 0.2, 0.3 and 0.4 mm whereas notch-tip radii were about 0.01mm. Then, these TPB specimens were tested under displacements control in a universal testing machine. The aim of these tests was to identify the critical V-notch angle leading to the minimum critical load. In spite of certain dispersion of the experimental values for the critical load, they clearly indicate the existence of a minimum value for a V-notch angle greater than 30-40 degrees for all three tested V-notch depths. After characterizing the elastic and fracture properties of PMMA used, the theoretical predictions for the critical load values by the Coupled stress and energy criterion of Finite Fracture Mechanics are compared with these new experimental results.

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Keywords: brittle fracture, V-notch, critical notch-angle, notch-tip radius, Three-Point-Bending specimen, PMMA, Finite Fracture Mechanics

* Corresponding author. Tel.: /
E-mail address: mantic@us.es

Numerical and experimental identification of tensile strength properties of friction welded joints

Eric Heppner[a,*], Emlar Woschke[a]

[a]*Otto-von-Guericke-University, Magdeburg, Germany*

Abstract

The present work presents a numerical and experimental study characterizing the mechanical properties of pure aluminium to mild steel friction welded joints by considering the local microstructural morphology.
The rotary friction welding (RFW) belongs to the solid-state fusing processes which is now well established since it is highly productive, repeatable, and very economical. The RFW process is characterised by the means of creating a sound bond even for dissimilar material combinations. Accord to the process, the micro-structural changes along the joint appear caused by the frictional heat and deformation. The structural me-chanical response of the joint under tension is fundamentally related to the geometry and local mechanical properties of these zones. For that purpose, a numerical and experimental study is done to determine the tensile strength properties.

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Keywords: rotary friction welding, tensile behaviour, microstructure, hardness, FEM, constitutive modeling

* Corresponding author.
E-mail: eric.heppner@ovgu.de

Fracture energy dissipation for fiber composites with various interface and fiber strength distribution

Dmitriy Telitsyn[a,*], Kirill Khvostunov[a]

[a]*Lomonosov Moscow State University, Moscow, Russia*

Abstract

Creep fiber composite failure model for tension and bending conditions is suggested. Volumes of energy transformation and dissipation are estimated and numerically modelled. Effects of initial non-ideal interface coating on damage process is investigated.

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Keywords: fracture energy dissipation, fiber composite, damage of composite, non-ideal interface, creep fiber composite failure

* Corresponding author.
E-mail: khvostunkov@gmail.com

Critical plane and multiaxial criteria for in-phase and antiphase cyclic loading

B.A. Stratula[a,b], A.D. Nikitin[a,*], I.S. Nikitin[a]

[a]*Institute for Computer Aided Design of the Russian Academy of Sciences, Moscow, Russia*
[b]*Moscow Aviation Institute (National Research University), Moscow, Russia*

Abstract

Analytical solutions are obtained for determining of the critical plane orientation for a multiaxial stress state. This critical plane is the plane of initial development of fatigue damage under cyclic loading. The cases of in-phase and antiphase cyclic loading are considered for the classical fatigue range (low-cycle and high-cycle fatigue). Generalizations of the Findley fatigue criterion are proposed taking into account the orientation of critical plane for modes of very-high-cycle fatigue under in-phase and antiphase cyclic multiaxial loading. These generalizations are based on the similarity of the left and right branches of the bimodal fatigue curve. A procedure for determining the parameters of the generalized criterion is described according to the data of two uniaxial fatigue tests for tension-compression at various coefficients of the asymmetry of the cycle.

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*Keywords:*cyclic loading; fatigue fracture; criterion for a multiaxial stress state; critical plane; low cycle fatigue; very-high-cycle fatigue; durability of a structural element

* Corresponding author. Alexander Nikitin. Tel.: +79654365980.
E-mail address: nikitin_alex@bk.ru

ECF22 - Loading and Environmental Effects on Structural Integrity

Vacuum vs argon technology for hydrogen measurement

A.M. Polyanskiy[a] , V.A. Polyanskiy[b,c,*], K.P. Frolovab[,c], Yu.A. Yakovlev[b,c]

[a]*RDC Electron & Beam Technology, Ltd., Bronevaya str. 6, St. Petersburg 198188, Russia*
[b]*Peter the Great St. Petersburg Polytechnic University, Polytekhnicheskaya str. 29, St. Petersburg 195251, Russia*
[c]*Institute of Problems of Mechanical Engineering RAS, V.O. Bolshoy pr. 61, St. Petersburg 199178, Russia*

Abstract

Within the framework of this paper, we review the development of the problem of hydrogen diagnostic for metals. Metal sample enrichment techniques based on hydrogen vacuum extraction method used for a long time. Development of the industrial control technologies has led to the almost complete replacement of vacuum techniques with “atmospheric” ones. As a result systematic errors have occurred. These errors lead to multiple differences between certified and measured hydrogen concentration values for standard samples. In this paper, we analyze reasons of systematic errors genesis observed for hydrogen measurements while applying the thermal conductivity cell technique. As a result, we demonstrated that measurements resulting from samples heating and melting in the inert gas flow depend on its heat capacity and surface temperature of the melting pot. Due to this reason, one can obtain multiple errors and even negative values for measurements of a low hydrogen concentration.

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Keywords: hydrogen diagnostic; hydrogen analyzer; extraction in the inert gas flow; thermal conductivity cell

* Corresponding author. Tel.: +7-921-748-0637; fax: +7-812-321-4771.
E-mail address: vapol@mail.ru

Evaluation of plastic eta factors using key curve for cracked specimens employed in J − R curve testing: application on CT, SENB and SENT specimens

Yazid Madi[a,*], Christophe Leguyader[b], Jacques Besson[c]

[a]*EPF-Ecole d'ingénieures, Sceaux, France*
[b]*Air liquide, Paris, France*
[c]*Mines-Paristech, Paris, France*

Abstract

The experimental evaluation of J-integral is based on the equation: Jp = eta.Apl/(B(W−a)) where Apl is the area under the load (P) plastic displacement (Vpl) curve, B the specimen thickness and W − a the size of the uncracked ligamen. eta is a dimensionless function of the geometry, well established for Compact Tensile (CT) and Single Edge Notched Bend (SENB) specimens. To take advantage of the increased apparent toughness under low constraint, Single Edge Notched Specimen (SENT) specimens have been developed in the pipelines industry in order to have adequate resistance to large deformations such as caused by ground movement and used in "Strain-based design". In this study, the eta factor is computed using the key curve concept in order to generalize his application to a new sample, such as SENT specimens. The Key Curve Method (KCM), introduced by [Ernst et al., 1979, Ernst et al., 1981], is based on the assumption that the load can be expressed as an analytical function P(a, Vpl) = G(a/W) × H(Vpl/W) which separates the influence of the specimen geometry G from the nfluence of the material behavior H. This method (with some simplifications) justifies the existence of the eta factor and was used to derive both eta for CT and SENB specimens proposed in the ASTM E1820 standard. The KCM applied using Finite Element Analysis (FEA) following the following steps: i) simulation of samples for different a/W to get the Load-Displacement curves P—V , ii) evaluation of the compliance as a function of a/W, iii) determination of Load-Plastic displacement curves P—Vpl for the different values of a/W, iv) evaluation of functions G and H and v) determination of the expression of eta as a function of a/W. The evaluation of eta factor using KCM is finally compared and discussed with respect to the methodology proposed by [Cravero and Ruggieri, 2007] who directly calculate J-integral using FEA.

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Keywords: J-Integral, toughness, key curve, finite element analysis, CT, SENB, SENT

* Corresponding author. Tel.: /
E-mail address: yazid.madi@epf.fr

Numerical simulation of fracture in Ti-6Al-4V alloy for orthopedic applications

Ivana Cvijović-Alagić[a,*], Bojan Međo[b], Zorica Cvijović[b], Nenad Gubeljak[c], Marko Rakin[b]

[a]Institute of Nuclear Sciences „Vinča“, University of Belgrade, 11000 Belgrade, Serba
[b]Faculty of Technology and Metallurgy, University of Belgrade, 11120 Belgrade, Serbia
[c]Faculty of Mechanical Engineering, University of Maribor, 2000 Maribor, Slovenia

Abstract

The fracture behavior of implant Ti-6Al-4V alloy is essential for its service capability in orthopedic surgery. Therefore, it is very important to understand and predict the fracture resistance of this biomedical material. Although several micromechanical models have been developed for modeling the fracture behavior of metallic materials with ductile dimple fracture as predominant fracture mode, they have predominantly been applied to materials such as steels and aluminum alloys. Recently, efforts have been made to apply these micromechanical models to predict crack initiation and growth in two-phase titanium alloys. Due to the complex multiple fracture micromechanisms operative in these alloys, it is necessary to check the applicability of damage models on these materials. In the present study, the mechanical testing and numerical simulation are carried out to characterize the fracture behavior of an extra-low impurity (ELI) Ti-6Al-4V alloy solution treated below β transus temperature followed by water quenching in order to obtain the globular microstructure with 82 vol.% primary α and 18 vol.% β phase. The compact tension (CT) specimen is used for fracture testing. The crack tip opening displacement (CTOD) and strain distribution near the crack tip are measured on its surface by the digital stereometric method. The complete Gurson model (CGM) implemented in a finite element (FE) code ABAQUS is applied to predict the crack resistance (CTOD-R) curves and crack growth initiation (CTODi) values. A relatively good correlation between the experimental and results obtained by numerical simulation demonstrates the applicability of CGM for the prediction of fracture behavior in Ti-6Al-4V ELI alloy with given microstructure. The better agreement, in comparison with plane strain conditions, is achieved through a 3D ½ symmetrical FE model with appropriate FE size. The microstructural effects on the fracture mechanics parameter and fracture modeling are discussed.

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Keywords: Titanium alloy, fracture mechanics, finite elements, modeling, complete Gurson model

* Corresponding author. Tel.: /
E-mail: ivanac@vin.bg.ac.rs

The hydrogen trapping ability of TiC and V_4C_3 by thermal desorption spectroscopy and permeation experiments

T. Depover[a,*], E. Van den Eeckhout[a], K. Verbeken[a]

[a]*Department of Materials, Textiles and Chemical Engineering, Ghent University (UGent), Tech Lane Ghent Science Park - Campus A, Technologiepark 903, B-9052 Gent, Belgium*

Abstract

Hydrogen (H) presence in metals is detrimental as unpredictable failure might occur. Recent developments in material's design indicated that microstructural features such as precipitates play an essential role in potentially increasing the resistance against H induced failure. This work evaluates the H trapping characteristics for TiC and V_4C_3 by thermal desorption spectroscopy and permeation experiments. Two microstructural conditions are compared: as quenched vs. quenched and tempered, in which the carbides are introduced. The tempered induced precipitates are able to deeply trap a significant amount of H, which decreases the H diffusivity in the materials and removes some of the detrimental H from the microstructure. For microstructural design purposes, it is important to know the position of H. Here, H is demonstrated to be trapped at the carbide/matrix interface by modifying the tempering treatment.

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Keywords: thermal desorption spectroscopy, permeation experiments, hydrogen trapping, hydrogen diffusivity, carbides

* Corresponding author. Tel.: +32-9-331-0453;
E-mail address: Kim.verbeken@ugent.be

Corrosion resistance of 2024 aluminum alloy electron beam welded joints for different post weld heat treatments

Evangelia Dovletoglou[a,*], Vasilis Stergiou[b], Stavros Kouroulis[c], Nikolaos Alexpoulos[a]

[a]*University of the Aegean, 81100 Mytilene, Greece*
[b]*Hellenic Aerospace Industry, 11527 Athens, Greece*
[c]*National Technical University of Athens, 10682 Athens, Greece*

Abstract

During the last decades, several aluminum alloys were developed in order to improve the damage tolerance capabilities of aircraft structures. Nevertheless, aluminum alloy 2024 is still widely exploited in aircraft structures, thus proving that has improved fatigue, fracture toughness and resistance to corrosion properties. At the same time, welds are started to be used in aircraft structures used in order to improve the mechanical performance of differential riveted structures as well as to reduce manufacturing costs. Electron beam welding is an efficient process to weld metallic materials with extremely narrow welds so as to minimize any structural defects.
In the present work, the effect of corrosion exposure on the structural integrity of electron beam welded (EBWed) joints of AA2024 is investigated. Additionally, the effect of post-weld heat treatment (artificial ageing) as well the effect of subsequent corrosion exposure is studied. To this end, this work tries to give information on the synergy between natural ageing and corrosion resistance of AA2024 EBWed joints. Tensile and fracture toughness specimens were machined from 3.2 mm nominal thickness sheets, according to specifications ASTM E8 and E561, respectively. The sheets were provided in T3 temper, that includes to some extent, stretching and natural ageing. Electron beam welding was performed at Hellenic Aerospace Industry. Post-weld heat treatment was performed at 190oC and the specimens were heat treated for different ageing times. Half of the EBWed specimens were tested immediately after artificial ageing heat treatment, while the rest were exposed to exfoliation corrosion exposure according to ASTM G34 specification. It was noticed that EBW provides essential structural efficiency for the welded joints. Fracture toughness Kcr was hardly decreased for the EBWed joints. Post-weld heat treatment provides a powerful tool for tailoring strength and ductility properties according to the light-weight structural design rules. Artificial ageing increases the size and population of the S-type precipitates and especially at the fusion zone / heat affected zone interphase that is considered to be the weakest ligament of the welded joint. The effect of corrosion exposure on the above heat treated specimens is extensively discussed.

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Keywords: electron beam welding, tensile properties, fracture toughness

* Corresponding author. Tel.: /
E-mail address: dovletogloue@gmail.com

Plasticity and failure behavior modeling of high-strength steels under various strain rates and temperatures: from microstructure to components

Junhe Lian[a,b,c,*], Wenqi Liu[a], Ioanna Papadioti[d], Ilias Bellas[d], Sarath Chandran[e], Patricia Verleysen[e], Helmut Richter[f], Nikolaos Aravas[d], Sebastian Münstermann[a]

[a]*Steel Institute, RWTH Aachen University, Intzestraße 1, 52072 Aachen, Germany*
[b]*Impact and Crashworthiness Lab, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*
[c]*Department of Mechanical Engineering, Aalto University, Otakaari 4, 02150 Espoo, Finland*
[d]*Department of Mechanical Engineering, University of Thessaly, Leoforos Athinon, Pedion Areos, 38334 Volos, Greece*
[e]*Department of Materials Science and Engineering, Ghent University, Technologiepark Zwijnaarde 903, 9052 Zwijnaarde, Belgium*
[f]*thyssenkrupp Steel Europe AG, Kaiser-Wilhelm-Straße 100, 47166 Duisburg, Germany*

Abstract

The aim of this study is to establish an integrated material modelling approach across micro, macro and component scales for investigating the plasticity, damage and fracture behaviour of modern high-strength steels under various strain rates and temperatures. With the established communication between different scales, the approach ultimately provides a knowledge-based and efficient alternative for the damage-tolerant microstructure design to the conventional empirical rules. In this study, we will present the models working at different scales and the scaling strategy between them. For a more general application orientation than quasistatic and room temperature, the models are all formulated with strain rate and temperature dependency. All the models are calibrated by experiments on the corresponding scale and also validated by experiments not involved in the calibration procedure or tests from a higher length scale. As the ultimate goal of the approach is to guide the microstructure design, a fine-resolution digital representation of the microstructure is targeted in the study. In addition to the standard phase fraction, grain size and shape features, fine-tuning of the microstructural features, such as texture and misorientation distribution is also implemented into the synthetic microstructure model. The impact of these individual microstructure features and their combination on the macroscopic and component level performance is studied and the optimized microstructure for the desired improvement of the mechanical property can be identified by the proposed approach.

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Keywords: Structure integrity; Multiscale modelling; strain gradient theory, crystal plasticity, continuum damage mechanics models; damage and fracture

* Corresponding author. Tel.: +49-241-8092912; fax: +49-241-8095553.
E-mail address: junhe.lian@iehk.rwth-aachen.de

Corrosion-induced mechanical properties decrease of aeronautical Al-Li 2198 alloy for different tempers

Christina Charalampidou[a,*], Aggeliki Proiou[a], Stavros Kourkoulis[b], Nikolaos Alexopoulos[a]

[a]*University of the Aegean, 81100 Mytilene, Greece*
[b]*National Technical University of Athens, 10682 Athens, Greece*

Abstract

Third generation Al-Li alloys are increasingly used as structural materials for aerospace applications due to the excellent combination of reduced weight, high elastic modulus and high specific strength as well as improved corrosion resistance and good fatigue crack growth performance [1] The improved mechanical properties of these alloys are often attributed to the formation of several strengthening precipitates including δ (Al3Li), θ (Al2Cu), T1 (Al2CuLi) and S (Al2CuMg). Dispersoid particles such as β (Al3Zr) and Al20Cu2Mn3 were also observed [2]. However, these precipitates may influence the electrochemical behaviour of such alloys and increase the corrosion susceptibility. Corrosion damage leads to mechanical properties degradation of the material and must be taken into account for the assessment of the structural integrity of aircraft components. Nevertheless, the effect of corrosion on the mechanical performance of innovative AL-Cu-Li alloys is not often reported in the literature. For example, Guerin et al. [3] showed that the fatigue life of AA2050 presented higher reduction percentage at the T34 state than at T84 where intragranular corrosion takes place. Most of the published articles with regard to the newly developed AA2198 alloy are dealing with weldability, plastic deformation [4], fatigue [5] and fracture behaviour aspects [6].
In the present work, the corrosion evolution and effect on the residual mechanical properties of AA2198 in two different tempers will be investigated. The first temper is T3 condition (under-ageing) and the second is T8 condition (peak-ageing), each one used for high ductility and high strength properties, respectively. It is generally reported [7] that the 2xxx aluminium alloys in T3 condition have lower corrosion resistance than at the T6 and T8. Tensile and fracture toughness specimens were machined from aluminium sheets at T3 and T8 condition of nominal thickness of 3.2 mm. The specimens were exposed to exfoliation corrosion solution (EXCO) for different exposure times according to ASTM G34 specification and afterwards were mechanically tested in order to investigate the effect of temper on the corrosion resistance of this alloy. Fracture surfaces were examined using Scanning Electron Microscopy (SEM) to determine the corrosion-induced fracture mechanisms.

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Keywords: Structure integrity; Multiscale modelling; strain gradient theory, crystal plasticity, continuum damage mechanics models; damage and fracture

* Corresponding author. Tel.: /
E-mail: c.charalampidou@fme.aegean.gr

Tracking hydrogen embrittlement using short fatigue crack behavior of metals

Vishal Singh[a], Rajwinder Singh[a], Amanjot Singh[a], Dhiraj K. Mahajan[a,]*

[a]*Ropar Mechanics of Materials Laboratory, Department of Mechanical Engineering, Indian Institute of Technology Ropar, Rupnagar, Punjab, India, 140001*

Abstract

Understanding hydrogen embrittlement phenomenon that leads to deterioration of mechanical properties of metallic components is vital for applications involving hydrogen environment. Among these, understanding the influence of hydrogen on the fatigue behaviour of metals is of great interest. Total fatigue life of a material can be divided into fatigue crack initiation and fatigue crack growth phase. While fatigue crack initiation can be linked with the propagation of short fatigue cracks, the size of which is of the order of grain size (few tens of microns), that are generally not detectable by conventional crack detection techniques applicable for the long fatigue crack growth behaviour using conventional CT specimens. Extensive literature is available on hydrogen effect on long fatigue crack growth behaviour of metals that leads to the change in crack growth rate and the threshold stress intensity factor range (ΔK_{th}). However, it is the short fatigue crack growth behaviour that provides the fundamental understanding and correlation of the metallic microstructure with hydrogen embrittlement phenomenon. Short fatigue crack growth behaviour is characteristically different from long crack growth behaviour showing high propagation rate at much lower values than threshold stress intensity factor range as well as a strong dependency on the microstructural features such as grain boundaries, phase boundaries, and inclusions. To this end, a novel experimental framework is developed to investigate the short fatigue crack behaviour of hydrogen charged materials involving in-situ observation of propagating short cracks coupled with image processing to obtain their da/dN vs a curves. Various metallic materials ranging from austenitic stainless steel (AISI 316L) to reactor pressure vessel steel (SA508 Grade 3 Class I low alloy steel) and line pipe steels (API 5L X65 & X80) are studied in this work.

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Keywords: Hydrogen embrittlement, short crack, fatigue, 316L, SA 508, X65, X80

* Corresponding author. Tel.: +91-7814252244
E-mail address: dhiraj.mahajan@iitrpr.ac.in

Finite-element analysis of fracture toughness of bovine cortical bone: effect of osteonal micro-morphology

Simin Li[a,*], Mayao Wang[a], Vadim Silberschmidt[b]

[a]*Loughborough University, Loughborough, Leicerstershire, England*
[b]*Vadim Silberschmidt (V.Silberschmidt@lboro.ac.uk), Longborough, Leicerstershire, England*

Abstract

A crack-propagation process in cortical bone is difficult to comprehend using only in-situ experimental studies. A previous work [1] assessed quantitatively the fracture toughening mechanisms of cortical bone using a compact-tension experiment, characterising a linear rising fracture resistance curve, R-curve. Even though a final crack-propagation path could be observed with microscopy, the effect of osteonal morphology and their interaction with a surrounding matrix are still not documented properly. In this paper, a finite-element method employing a zero-thickness cohesive-element scheme was used to analyse the effect of micro-morphology of cortical bone on the crack-propagation process in a bone tissue. Microstructured models of cortical bone, incorporating statistical realisations of main features of the osteonal structure, consisting of osteons, cement lines and an interstitial matrix, were developed. They were based on osteonal morphometric parameters, acquired from experimental samples at posterior cortex of bovine cortical bone and used to simulate the process of crack propagation in the compact-tension experiment. The results of numerical simulations, validated experimentally, demonstrated that the suggested approach is an efficient method for investigation of the crack-growth process and fracture mechanics at micro-level. Observations from the experiments and simulation results indicated that the cement line acted as crack-inhibiting mechanism attracting surrounding cracks, while preserving the osteons. Crack-ligament bridging, another extrinsic toughening mechanism of cortical bone, happens for osteons with relatively large Harversian canals. Still, it is difficult to reduce the damage to osteons during a crack growth. Fracture mechanics, as shown in this paper, is influenced significantly by the micro-morphological parameters of osteons, and studying systematically such interplay between osteonal micro-morphology and crack propagation, one could gain an insight into individual fracture toughening mechanisms of cortical bone and their contribution towards tissue-level fracture resistance.

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Keywords: ESIS TC14 Symposium, finite-element analysis, fracture toughness, cortical bone, micro-morphology

* Corresponding author. Tel.: /
E-mail address: s.li@lboro.ac.uk

Elements of non-destructive damage monitoring by electrostatic potential method

V.M. Kiiko[a], K.A. Khvostunkov[b,*], R.K. Odzhaev[b]

[a]*Institute of Solid State Physics of RAS,, Chernogolovka Moscow distr., 142432 Russia*
[b]*Lomonosov Moscow State University, Moscow, 119992 Russia*

Abstract

We establish a correlation between the magnitude of a propagating crack in current-carrying flat samples and the change in the electric potential field over the surface of the sample when an electric current passes through it. The experimental data correspond to an analytic solution obtained using a conformal map in the two-dimensional formulation. This work can be related to the area of converting mechanical quantities into electrical quantities, which simplifies the process of recording mechanical processes and provides a convenient form for controlling and managing them. This work is aimed at the automatic control of the process of the destruction of conductive materials.

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Keywords: conductive sample, electric potential, equipotential line, crack length, conformal map

* Corresponding author. Tel.: /
E-mail: khvostunkov@gmail.com

Study of the effect of upstream slope on water pressure in concrete gravity dam

Hichem Mazighi[a,*], Mustapha Kamel Mihoubi[a]

[a]*Laboratory Water Resource Mobilization and Enhancement (LMVR), National High School for Hydraulic (ENSH), BP 31 Blida, ALGERIA.*

Abstract

In recent past, some research work has been done to considerate properly the water pressure in concrete gravity dam to take it into account for crack propagation. However, a two-dimensional finite element model is developed to calculate the water pressure under hydrostatic pressure on two geometries cases of Kinta concrete gravity dam.
The results show the upstream slope affects considerably the water pressure at the dam bottom in case one comparing to case two due to vertical hydrostatic pressure, leads to important displacement at the crest of the dam that influence the global behavior of the dam inducing to aperture of cracks.

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Keywords: concrete, dam, water pressure.

* Corresponding author. Tel.: /
E-mail address: h.mazighi@ensh.dz

Inclusion of load sequence effects in the fatigue assessment of offshore wind turbine support structures

Milan Kovarbašić[a,*], Peter Schaumann[b]

[a]Senvion GMBH, 22297 Hamburg, Germany
[b]Leibniz Universitaet Hannover, 30159 Hannover, Germany

Abstract

Offshore wind turbine support structures are exposed to long-term arbitrary loads due to wind and waves. During the design lifetime, commonly 25 to 30 years, a large amount of cyclic excitations causes material fatigue in these structures. Therefore, fatigue is a design driver in the majority of cases. Welded joints are the weakest spots in the support structure. Weld toes are the primary source of fatigue cracking because of stress concentration effects and the presence of residual stresses. Beside this, load sequence effects play an important role due to large overloads which induce significant plastic deformations. The overloads occur periodically during the service life of offshore wind turbine support structures due to highly turbulent wind, abnormal wave or seismic activity. However, fatigue assessment approaches recommended in current standards and guidelines neglect the load sequence effects and assume a linear stress-strain relation regarding material behavior. The present paper considers load history dependent material behavior and show its relevance for fatigue assessment of a welded tubular joint that can be found in offshore wind turbine jacket structures. All investigations are based on the Uniform Material Law and on relevant technical guidelines. An in-house developed tool based on the strain-life approach is used to predict fatigue life to crack formation. Comparisons are made with the results obtained using state-of-practice approach for fatigue assessment. Finally, the relevance of load sequence effects for the current fatigue assessment is estimated.

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Keywords: fatigue, load sequence effects, variable amplitude loading, welded tubular joints, offshore wind energy

* Corresponding author. Tel.: /
E-mail address: milan.kovarbasic@senvion.com

Peculiarities of adhesive zone fracture under combined pulse-vibrational load

Grigoriy Volkov[a,*], Yuri Petrov[a], Roberta Springhetti[b]

[a]*Saint-Petersburg State University, Saint-Petersburg, Russia*
[b]*University of Trento, Trento, Italy*

Abstract

The influence of a weak ultrasonic background field on the strength of adhesive joints is studied. A layer glued on a substrate is modelled either as a string or a beam on elastic foundation and the incubation time criterion is applied to determine fracture initiation. A background harmonic vibration is applied to the layer, together with a loading pulse concentrated at its center, varying with time according to a few different schemes. It is shown that several frequencies of the harmonic vibration allow to dramatically decrease the amplitude of the concentrated load necessary for the detachment. In particular, the behaviour predicted for a string with fixed ends is analogous to the case of a beam with hinged extremities: the additional bending stiffness only entails to shift the range of the eigen-frequencies of the system, whereas maintaining the effect of taking advantage of a background vibration in order to decrease the loading pulse necessary for the detachment.
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Keywords: adhesion strength, incubation time criterion, combined vibrational pulse load, beam approximation

* Corresponding author. Tel.: /
E-mail: g.volkov@spbu.ru

Fracture mechanisms of hard ceramic coatings of different architecture

Aleksandar Miletić[a,*], Peter Panjan[b], Miha Čekada[b], Pal Terek[a], Lazar Kovačević[a], Branko Škorić[a]

[a] *Faculty of Technical Sciences, University of Novi Sad, 21000 Novi Sad, Serbia*
[b] *Jožef Stefan Institute, 1000 Ljubljana, Slovenia*

Abstract

Hard ceramic coatings have been widely used to increase the quality and prolong the lifetime of different components in manufacturing, automotive, and aerospace industry, in medicine and other areas. Although fracture resistance greatly influences integrity and lifetime of ceramic coatings and coated elements, it has been considerably less studied than other properties such as hardness, high-temperature stability, corrosion resistance and oxidation resistance. Fracture resistance and fracture mechanisms depend on chemical bonding, microstructure, crystalline structure, coating architecture, presence of defects, and coating thickness. In this paper, fracture mechanisms of three nitride coatings of different architecture were studied. Monolayer TiAlN, nanocomposite TiSiN and nanolayer TiAlSiN coatings were prepared by magnetron sputtering physical vapor deposition technique. Mechanical properties were evaluated by instrumented indentation tester equipped with a Vickers indenter. Cross sections of formed indents were generated by focused ion beam technique and imaged by scanning electron microscopy to identify fracture mechanisms. It was found that monolayer TiAlN coating, characterized by columnar microstructure, fractures by formation of shear cracks extending between columnar grains straight from the top to the bottom coating surface. On the other hand, in nanocrystalline TiSiN and TiAlSiN coatings, cracks extended only through a portion of a coating and follow a "curved" path around nanocrystalline grains. Indentation load required to initiate fracture is higher for nanocrystalline coatings.

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Keywords: Ceramic coating, fracture mechanisms, magnetron sputtering

* Corresponding author. Tel.: /
E-mail: miletic@uns.ac.rs

Aspects in design of low cycle fatigue in aluminium structures

Mathias Rengstl[a,*]

[a]*Technical University of Munich, Munich, Germany*

Abstract

The investigation of the minimum cycles by sinusodial high loaded structures is always in the context of low cycle fatigue and crack initation. Due to small cracks, which can already result in a failing part, the safe life design is more important in case of structures in civil engineering. Due to effects of local plasticity in redundant system parts the important aspects and relevant rules for the design are given in the paper.
The results of a ongoing projects where the design parameters (stress ratio, yielding stress, stress concentration) and effects of the structure are summarized. The testing results of the aluminium allloys
•EN AW6063 T66
•EN AW5083 O/H111
•ENAW7020 T6
are presented and related to different design codes.
Therefore the focus is on the acting stresses and different viewing points in the design of welded and unwelded parts in the structure and a design concept is presented.

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Keywords: Aluminium structures, low cycle fatigue, welding

* Corresponding author. Tel.: /
E-mail: m.rengstl@tum.de

Case Study: failure analysis of spinal implant and the effect of machining

Štěpán Major[a,*], Vladimir Kocour[b], Michal Hanuš[a], Michal Růžička[a]

[a] *University Hradec Králové,50003 Hradec Králové, Czech Republic*
[b]*Czech Technical University, Faculty of Transportation Sciences, 11000 Praha, Czech Republic*

Abstract

The article analyses failure of implants caused by faulty machining. The implants studied in this work are represented by the assembly of metal plates and screws used for fixation of two parts of broken bones. This analysis was performed on the file of samples which were originally studied within the court settlement. In all causes the failure of implant caused severe pain and other complications in healing process. The sample analysis and other tests served to resolve the case.
The implants failure represents in most cases fracture of the screw. These screws bear relatively great load and they are also subjected to the cyclic loading. These implants are made from titanium alloys. During loading, the fatigue crack nucleate on the stress concentrators. This stress concentrators can be identified by fractography on the fracture surface.
At the initiation site specific groves and uneven surface layer were observed. The groves were caused by machining with flawy tool. Surface treatment caused uneven distribution of oxide particles in the groves surrounding. In this manner many stress concentrators were active at the bottom of the thread, which caused implant failure.
This hypothesis was verified experimentally and using the mathematical model of implant. Some implants were made and one portion of implants was scratched and second portion had smooth surface. Surface analysis shows similar oxide accumulation around the grows. Thus obtained specimens were loaded on testing device to the final fracture of implant. This results were compared with expected number of loading cycles in the case of real patient. Also, the FEM model was used for fracture proces simulation. This model was based on combination of two fatigue crack models characterized by two different crack growth mechanisms. Proposed experimental study apparently corresponds with reality. Also, the mathematical model was is in good agreement with experiments.

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Keywords: fatigue life, implant fracture, failure analysis, fractography, machining effect, surface treatment

* Corresponding author. Tel.: /
E-mail: s.major@seznam.cz

Damage-reliability prediction of strand extracted from steel wire rope

Nadia Mouhib[a,]*, Sara Sandabad[a], Mohammed Lahlou[a], Mohamed Elghorba[a]

[a]*LCCMMS-ENSEM, Casablanca, Morocco*

Abstract

Wire ropes which the constituent material is mainly steel suffer from the continued aggression of the environment (effects of rain, wind, humidity, ...) and changes in loads whose direct consequences are strong modifications in the geometrical and mechanical characteristics of their components (strands, wires). During the service of wire rope, there is an energy stored, an unexpected release of this energy introduces a potential safety issues. Indeed, throughout the life of wire rope, the wires and strands that compose it, are subjected to several degradations indicating a loss of the original energy, which leads to very rapid deterioration leading to sudden and violent rupture. Therefore, predict the behavior of this complex structure is necessary for people's safety.
For this, the present study aims to predict the damage of a strand (7 wires) constituting a steel wire rope (19x7), based upon an experimental tensile test of a strand artificially damaged (2/7 broken wires). Thereafter and with the establishment of the relation Damage-Reliability, three stages of damage are identified and the critical life fraction βc is determined that predicts the moment of critical damage and thus to intervene at the appropriate moment for a predictive maintenance of the system.
Based on the experimental results obtained of strength or by calculating the energy, both methods have shown good agreement and one confirms the other.

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Keywords: Damage, reliability, steel wire rope, strand, tensile tests, energy loss.

* Corresponding author. Tel.: /
E-mail: mouhib.nadia@gmail.com

High energy X-ray diffraction measurements of strain and dislocation density near steel fatigue cracks grown in hydrogen

Matthew Connolly[a,*], Peter Bradley[a], Damian Lauria[a], Andrew Slifka[a], Elizabeth Drexler[a]

[a]*National Institute of Standards and Technology, Gaithersburg, United States*

Abstract

Hydrogen is desirable for energy storage as it is cleaner burning and can store a larger amount of energy than an equal mass of gasoline. However, the existing network of pipeline is constructed of high-strength steels which are susceptible to embrittlement and subsequent increased fatigue crack growth rates (FCGR) during exposure to hydrogen. Proposed mechanisms of hydrogen embrittlement include hydrogen-enhanced decohesion (HEDE) and the hydrogen-enhanced localized plasticity (HELP) mechanisms. In the HEDE mechanism, accumulation of hydrogen at locations of high triaxial stresses lead to the weakening of Fe-Fe bonds once the hydrogen concentration reaches a critical concentration. In the HELP mechanism, the introduction of hydrogen gas creates areas of extended dislocations in the Fe lattice and enhances dislocation mobility in the steel framework.

Quantifying stress and strain fields from fatigue cracking is crucial to the determination of the underlying mechanism behind hydrogen embrittlement and to the study of hydrogen embrittlement and hydrogen-assisted FCGR. We performed high energy x-ray diffraction measurements to characterize the strain fields near cracks that were grown both in air and in hydrogen. Using a novel chamber uniquely compatible with high energy x-ray diffraction, the measured cracks were grown in situ during the scattering measurements. Radiograph images show differences in crack topology between the in-air and in-H2 fatigue cracks. An enhancement in the magnitude strain field near the crack grown in hydrogen compared to near the crack grown in air was observed. Peak broadening analysis indicate significant differences in the dislocation density as a function of distance ahead of the crack tip. We compare the strain fields and dislocation density between the measured in-air and in-H2 crack-tip strain fields, and discuss the differences in the context of the HELP and HEDE mechanisms.

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Keywords: Hydrogen, embrittlement, fatigue, high energy X-ray diffraction, dislocations, strain

* Corresponding author. Tel.: /
E-mail: matthew.connolly@nist.gov

Fracture behaviour of prepreg laminates studied by in-situ SEM mechanical tests

Simon Bard[a], Martin Demleitner[a], Markus Häublein[a], Volker Altstädt[a,*]

[a]*University of Bayreuth, Polymer Engineering, Universitätsstr. 30, 95444 Bayreuth, Germany*

Abstract

By using a miniature testing device placed in a Scanning Electron Microscope (SEM) it was possible to investigate the fracture toughness in mode I of graphite modified prepreg laminates. Different tools have been developed to expand the possibilities of the commercially available tool. In-situ deformation studies can thereby be used to evaluate the crack behavior of carbon fiber reinforced composites (CFRP). The matrix of the CFRP has been optimized for higher thermal and electrical conductivity to be used in electrically driven aircrafts. The crack propagates through the matrix and shows crack deviation at the graphite particles, which could be shown in in-situ SEM mechanical tests. Also the toughening mechanism of thermoplastic interleaved laminates have been investigated in the SEM mechanical tests. A crack transition between different layers was clearly visible in SEM.

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Keywords: SEM; Carbon Fiber; CFRP; fracture toughness, Mode I fracture toughness

* Corresponding author. Tel.: +49 (0) 921 55 7476; fax: +49 (0) 921 55 7473.
E-mail address: simon.bard@uni-bayreuth.de

Analysis of an as-cast high Si slab to elucidate fundamental causes of the fracture mechanism: Clinking

Guy Khosla[a,*], Daniel Balint[a], Didier Farrugia[b], Matthew Hole[a], Catrin M. Davies[a]

[a]*Department of Mechanical Engineering, Imperial College London, South Kensington Campus, London, UK, SW7 2AZ*
[b]*TATA Steel UK, Research & Development, Swinden Technology Centre, Rotherham, S60 3AR*

Abstract

'Clinking' refers to the fast and loud transverse fracture of large slabs of steel during primary processing. Clinking was first observed in reheat furnaces after continuous casting. As slabs are reheated, many catastrophically break apart which causes huge operational disruptions and material loss. As-cast Si slabs were also observed to undergo a similar transverse fracture when left to cool in ambient conditions to below 200°C. The fracture is typically observed to be sub-surface. This paper analyses the as-cast microstructure of the high Si slab. Elements of the microstructure that embrittle the material making it susceptible to the catastrophic fracture, clinking, have been observed. Optical microscopy imaging is completed to understand the grain size, structure and the presence of any inclusions and precipitates. Energy Dispersive X-Ray Spectroscopy (EDX) analysis has been completed to understand the composition of precipitates/inclusions. X-Ray Flourescence (XRF) was completed on samples taken through the thickness to understand the variation of composition. Charpy tests were undertaken to investigate the variation of toughness of the material as a function of the location across the face of the slab. EDX analysis revealed void formation around a MnS particle close to the grain boundary region. Charpy tests showed an improved ductility around 200°C, however a ductile-brittle transition temperature has not been formally defined due to the lack of samples available.

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Keywords: Charpy tests, clinking, as-cast microstructure,

* Corresponding author. Tel.: /
E-mail: gk1010@imperial.ac.uk

Corrosion fatigue crack initiation model of martensitic stainless steels at high cycle fatigue regime

Mohamed El May[a], Nicolas Saintier[a], Thierry Palin-Luc[a,*], Olivier Devos[a,*]

[a] *University of Bayreuth, Polymer Engineering, Universitätsstr. 30, 95444 Bayreuth, Germany*

Abstract

The practical importance of fatigue failure in stainless steel structural materials has directed many experimental research towards assessing the physical reason for material sensitivity to corrosion fatigue and providing damage model for engineers. This paper presents an analytical model of corrosion fatigue crack initiation life in a martensitic stainless steels under high cycle fatigue loading (between 10^5 and 10^7 cycles). Based on the in-situ electrochemical measurements during corrosion fatigue tests in NaCl aqueous solution, the corrosion fatigue crack initiation mechanism was identified. It is devised into two periods: (i) the fracture of the passive film by slip bands and (ii) the free dissolution of the metal developing a critical corrosion defect of fatigue crack initiation. It has been found that the depassivation stress threshold corresponds to the median fatigue limit at 10^7 cycles. For an applied stress range less than this threshold, the depassivation phenomenon was not observed at 10^7 cycles. The proposed model takes into account the slip bands emergence process and the corrosion rate under cyclic loading. The experimental results are compared to which obtained by the proposed model taking into account mechanical, electrochemical and material parameters. The effects of the loading frequencies, the loading ratio and the environment aggressiveness (NaCl concentration) was discussed.

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Keywords: Fatigue, corrosion, crack initiation, depassivation, analytical model

* Corresponding author. Tel.: /
E-mail address: thierry.palin-luc@ensam.eu

Dislocation and twinning behaviors in high manganese steels in respect to hydrogen and aluminum alloying

Xiaofei Guo[a,]*, Stefan Zaefferer[b], Fady Archie[c], Wolfgang Bleck[a]

[a]*Steel Institute, RWTH Aachen University, Intze str. 1, Aachen 52072, Germany*
[b]*Max-Planck-Institut für Eisenforschung GmbH, Max-Planck-Straße 1, Düsseldorf 40237, Germany*
[c]*NLMK Europe, Eutelis-Platz 2, Ratingen 40878, Germany*

Abstract

The dislocation and twinning evolution behaviors in high manganese steels Fe-22Mn-0.6C and Fe-17Mn-1.5Al-0.6C have been investigated under tensile deformation with and without diffusive hydrogen. The notched tensile tests were interrupted once primary cracks were detected using the applied direct current potential drop measurement. In parallel, the strain distribution in the vicinity of the crack was characterized by digital image correlation using GOM optical system. The microstructure surrounding the crack was investigated by electron backscatter diffraction. Electron channeling contrast imaging was applied to reveal the evolution of dislocations, stacking faults and deformation twins with respect to the developed strain gradient and amount of hydrogen. The results show that the diffusive hydrogen at the level of 26 ppm has a conspicuous effect on initiating stacking faults, twin bundles and activating multiple deformation twinning systems in Fe-22Mn-0.6C. Eventually, the interactions between deformation twins and grain boundaries lead to grain boundary decohesion in this material. In comparison, hydrogen does not obviously affect the microstructure evolution, namely, the twinning thickness and the amount of activated twinning systems in Fe-17Mn-1.5Al-0.6C. The Al-alloyed grade reveals a postponed nucleation of deformation twins, delayed onset of the secondary twinning system and develops finer twinning lamellae in comparison to the Al-free material. These observations explain the improved resistance to hydrogen-induced cracking in Al-alloyed TWIP steels.

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Keywords: TWIP steels; hydrogen embrittlement; dislocation and twinning behaviors; fracture initiation

* Corresponding author. Tel.:+49-241-8095809; fax: +49-241-8092253.
E-mail address: xiaofei.guo@iehk.rwth-aachen.de

Modeling of hyper-elastic polymers for automotive lamps under random vibration loading with proportional damping for robust fatigue analysis

C.P. Okeke[a,b,*], A.N. Thite[a], J.F. Durodola[a], N.A. Fellows[a], M.T. Greenrod[b]

[a]*Department of Mechanical Engineering and Mathematical Sciences, Oxford Brookes University, Oxford – OX33 1HX, UK*
[b]*Wipac Ltd, London Road, Buckingham, MK18 1BH, UK*

Abstract

The objective of this paper was to model random vibration response of components of an automotive lamp made of Polycarbonate/Acrylonitrile Butadiene Styrene (PC-ABS), Polymethyl methacrylate (PMMA) and Polypropylene 40% Talc filled (PPT40) materials using a nonlinear hyper-elastic model. Traditionally, the Rayleigh damping matrix used in the dynamic response analysis is constructed considering linear elastic behaviour based on either initial stiffness or secant stiffness. The performance of linear stiffness matrices is compared in this work with that based on the nonlinear hyper-elastic, Mooney-Rivlin model, specifically addressing Rayleigh damping matrix construction. The random vibration responses of 10 samples of each material are measured. The mean square error of acceleration response was used to assess the effectiveness. Considering three materials of study, the hyper-elastic model resulted in the reduction of the least square error at best by 11.8 times and at worst by 2.6 times. The Mooney-Rivlin material model based Raleigh damping matrix was more accurate in modelling the dynamic behaviour of components of nonlinear materials and it also represented the manufacturing variabilities more reliably.

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Keywords: Hyperelastic; Mooney_Rivlin, material models; nonlinear stress-strain; simulation; modelling; proportional damping; rayleigh; transient analysis; random vibration; manufacturing variations

* Corresponding author. Tel.: +44-(0)1865-423011
E-mail address: c.okeke100@gmail.com; 14101309@brookes.ac.uk

A novel test rig for measuring bending fatigue using resonant behaviour

C.P. Okeke[a,b,*], A.N. Thite[a], J.F. Durodola[a], M.T. Greenrod[b]

[a]*Department of Mechanical Engineering and Mathematical Sciences, Oxford Brookes University, Oxford – OX33 1HX, UK*
[b]*Wipac Ltd, London Road, Buckingham, MK18 1BH, UK*

Abstract

A novel test rig for bending fatigue test that based on specimen resonant behaviour has been developed. Determining bending fatigue properties of polymer materials with the standard test systems is challenging, and in some cases results are unattainable. This is particularly true of polymers that exhibit a high level of non-linearity and large deflection. This novel test setup is similar to that of four point bending arrangement resulting in a simple support. The loading is achieved by inertial effect of small masses mounted on the test specimen. A vibration shaker is used to base excite the specimen at the first resonance frequency until it breaks. The proposed test setup reduces the time taken to obtain Stress v/s number of cycles (S/N) curves, typically 1/10th of the universal testing machine based approach. The effect of nonlinearities can be reduced by application of larger loads at higher frequencies using large acceleration and smaller deflection combination. The results based on the proposed approach are in good agreement with tensile fatigue results. It has been successfully used to determine the bending fatigue properties of Polycarbonate (PC) of which determining the tensile fatigue properties were difficult to obtain. The significance of this novel test rig is that it accelerates the fatigue testing and allows the determination of the fatigue properties of some materials that cannot be obtained with existing systems.

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Keywords: Resonant, Polymer, Fatigue, Bending, Tensile, Nonlinearity, Novel, Rig, Deflection

* Corresponding author. Tel.: +44-(0)1865-423011
E-mail address: c.okeke100@gmail.com, 14101309@brookes.ac.uk

Interaction of contact cracks and narrow slits in plate bending

Ivan Shatskyi[a,]*, Taras Dalyak[a]

[a]Ivano-Frankivsk Branch of Pidstryhach-Institute for Applied Problems in Mechanics and Mathematics, NAS of Ukraine, Mykytynetska str., 3, Ivano-Frankivsk, 76002, Ukraine

Abstract

The aim of the proceeding is to study the effect of interaction of rectilinear contact cracks and narrow slits for plate bending and on this basis to demonstrate qualitative differences in the concentration of stresses near defects of different nature. The crack is treated as a mathematical cut, the edges of which contact along the line on the plate outside. The slit is referred to as stress-free surfaces cut, the negative jump of normal displacement can occur on this cut. The problem of uniform bending of infinite plate weakened by through defects: cracks and slits, is considered in the two-dimensional formulation. The crack closure caused by bending deformation was studied based on the classical hypothesis of direct normal and the previously developed model of contact of edges along the line. A new boundary problem for a couple of biharmonic equations of plane stress and plate bending with interconnected boundary conditions on the cuts is formulated. The method of singular integral equations was applied to develop approximate analytical and numerical solutions of the problem. The results for the jumps of displacements and normal rotation angles, for the forces and moments intensity factors near the tips of defects, and for contact reaction on the closed edges of the cracks are obtained. Detailed analysis was carried out for parallel cracks and slits, depending on the parameter of their relative position. The comparison of findings with the known results for dyads: crack-crack and slit-slit is provided. As the results of the research show, the interacting contact crack and free slit are fundamentally different stress concentrators that produce qualitatively different patterns of local perturbations of stresses in the plate.

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Keywords: plate, contact crack, slit, interaction, bending

* Corresponding author. Tel.: +380-99-444-4967; fax: +380-342- 547-139.
E-mail address: ipshatsky@gmail.com

Strength of plate with the filled crack under multiparameter loading

Ivan Shatskyi[a,]*, Iryna Kurtash[a]

[a]*Ivano-Frankivsk Branch of Pidstryhach-Institute for Applied Problems in Mechanics and Mathematics, NAS of Ukraine, Mykytynetska str., 3,Ivano-Frankivsk, 76002, Ukraine*

Abstract

The problem of stressed state of an elastic plate weakened by narrow rectilinear through crack (slit) filled with low-modulus material is considered within framework the classical two-dimensional plate theory. For the inclusion of small width the hypothesis of elastic Winkler's layer is accepted. The boundary problem for the pair of biharmonic equations with complicated boundary conditions on the cut is formulated. The analytical solution of singular integrodifferential equations of the problem is built for a case of elliptical form of slit and uniform multi-parameter load (combined tension, shear, bending and twisting). The jumps of the displacements and the normal rotation angles on the cut, the stress intensity factors for crack tips and the stresses in the filler are obtained. Special attention is paid to the issue of limited equilibrium of composition. The two mechanisms of fracture are considered: cracking of the plate near the peak of a slit and breach of filler integrity. The first of them is described by the criterion of the linear mechanics of fracture and the second one is described by the classical theory of strength. The considered model of the filled slit allows analytically evaluating the results of the renovation of defective lamellar structures. The diagrams of limiting equilibrium of plate with filled slit are built for several options of two-parametric loading. The key parameters that determine the success of injection technology for repair of the cracked plate for a given loading trajectory are the relative stiffness and relative strength of the filler.

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Keywords: plate, filled crack, multiparameter loading, fracture, limiting equilibrium.

* Corresponding author. Tel.:+380-99-444-4967; fax: +380-342- 547-139.
E-mail address: ipshatsky@gmail.com.

Fracture and microstructural study of bovine bone under mixed mode I/II loading

M.R.M. Aliha[a,*], S. Bagherifard[b], Sh. Akhondi[c], S.S. Mousavi[a], A. Mousavi[a], H. Parsania[a]

[a]*Welding and Joining Research Center, Iran University of Science and Technology (IUST), Narmak-16846-13114, Tehran, Iran.*
[b]*Politechnico di Milano, Department of Mechanical Engineering, Via. G. La Masa, 1, 20156 Milano, Italy*
[c]*School of Industrial and Information Engineering, Polytechnic University of Milan, Milano, 20156, Italy*

Abstract

Understanding the fracture behavior and associated crack growth mechanism in bone material is an important issue for biomechanics and biomaterial researches. Fracture of bone often takes place due to complex loading conditions which result in combined tensile-shear (i.e. mixed mode) fracture mechanism. Several parameters such as loading type, applied loading direction relative to the bone axis, loading rate, age and etc., may affect the mixed mode fracture resistance and damage mechanism in such materials. In this research, a number of mixed mode I/II fracture experiments are conducted on bovine femur bone using a sub-sized test configuration called "compact beam bend (CBB)" specimen to investigate the fracture toughness of bone under different mode mixities. The specimen is rectangular beam containing a mid-edge crack that is loaded by a conventional three-point bend fixture. The results showed the dependency of bone fracture toughness on the state of mode mixity. The fracture surfaces of broken CBB specimens under different loading conditions were studied via scanning electron microscopy (SEM) observations. Fracture surface of all investigated cases (i.e. pure mode I, pure mode II and mixed mode I/II) exhibited smooth patterns demonstrating brittle fracture of bovine femur. The higher density of vascular channels and micro-cracks initiated in the weakened area surrounded by secondary osteons were found to be the main cause of the decreased bone resistance against crack growth and brittle fracture.

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Keywords: Bovine femur, Compact beam bend specimen, Mixed mode fracture, SEM analysis

* Corresponding author. Tel.: +98-21-73225031; fax: +98-21-73225098.
E-mail address: mrm_aliha@iust.ac.ir

Evaluation of fatigue properties of S355 J0 steel using ProFatigue and ProPagation software

Stanislav Seitl[a,b], Petr Miarka[a,b,*], Jan Klusák [a], Zdeněk Kala[b], Martin Krejsa[c], Sergio Blasón[d], Alfonso F. Canteli[d]

[a]Institute of Physics of Materials, Academy of Sciences of the Czech Republic, Zizkova 22, 616 62 Brno, Czech Republic
[b]Faculty of Civil Engineering, Brno University of Technology, Veveří 331/95, 602 00Brno, Czech Republic
[c]Faculty of Civil Engineering, VŠB-Technical University of Ostrava, Ludvika Podeste 1875/17,708 33 Ostrava - Poruba Czech Republic
[d]Department of Construction and Manufacturing Engineering, Universidad de Oviedo, 33203 Gijón, Spain

Abstract

The use of S355 high strength steel in civil engineering design of structural elements of cranes, bridges or simple engineering parts allows material and economical savings to be achieved meeting the strict construction requirements. Knowledge of fatigue resistance of the material plays the key role during design and maintenance of the civil engineering structures. With this aim, the fatigue properties (Wöhler field and crack propagation rate curve) of the S355 J0 steel are analyzed according to both traditional and probabilistic models. In the latter case, the ProFatigue and ProPagation software programs are applied in the assessment of experimental fatigue data of S355 J0 for derivation of the probabilistic S–N field and fatigue crack growth rate curve, respectively, where data consist of results for different number of various investigated specimens subject to low cycle and high cycle fatigue with focus on the rolling direction. The results obtained are compared with the customary Basquin formula for the Wöhler-curve and Paris law for the crack growth rate curve, both represented as straight lines in a double-logarithmic scale.

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Keywords: Steel bridge; S355 J0; fatigue; ProFatigue; ProPagation; Wöhler curve; crack growth rate curve

* Corresponding author. Tel.: +420 532 290 361
E-mail address: seitl@ipm.cz

Application of the internal and external Williams functions for stress intensity factors assessment in plane stress problems

Yaroslav Dubyk[a,*], Igor Orynyak[a], Elena Yakovleva[a]

[a]G.S. Pysarenko Institute for Problem of Strength, National Academy of Sciences of Ukraine, 2 Tymiriazevska str, Kyiv, 01014, Ukraine

Abstract

Existing analytical methods for calculating stress intensity factors are the application of the complex variables functions or solutions based on the potential theory. Nowadays, computer programs, most based on the finite element method, are widely used, and allow one to obtain the stress intensity factors of any geometry with any combinations of boundary conditions with an accuracy sufficient for most engineering applications. Thus the further contribution in the analytical methods is questionable. It's preferable to use understandable and easy coding classical methods based on Williams functions, better known as Boundary Collocation Method. However, questions of the application of this method, its educational significance, determination of the real advantages and disadvantages of Williams' functions remain open. The main purpose of this paper is to investigate the possibility of applying internal and external Williams' functions to find the stress intensity factors in plane problems. Also, applying the global equilibrium considerably improves accuracy and convergence of the analysis.

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Keywords: Crack; stress intensity factor; inner and outer Williams function; convergence; Airy functions; static plane body

* Corresponding author. Tel.: +38-050-990-1227.
E-mail address: dubykir@gmail.com

The determining influence of the competition between pore volume change and fluid filtration on the strength of permeable brittle solids

Evgeny V. Shilko[a,b,*], Andrey V. Dimaki[a], Alexey Yu. Smolin[a,b], Sergey G. Psakhie[a]

[a]*Institute of Strength Physics and Materials Science SB RAS, 2/4 pr. Akademicheskii, 634055 Tomsk, Russia*
[b]*Tomsk State University, 36 ave. Lenina, 634050 Tomsk, Russia*

Abstract

The paper is devoted to the numerical study of the dependence of uniaxial compressive strength of permeable fluid-saturated brittle solids on the loading rate. We analyzed the influence of strain rate, sample size, permeability of the material, fluid viscosity and a coefficient of the influence of pore pressure on the stress state of solid skeleton. We have shown that dynamic values of elastic modulus and strength of the sample is a unique nonlinear sigmoid-like function of the dimensionless parameter that characterizes the ratio of applied strain rate to interstitial fluid flow rate. We proposed the unified approximating function, which describes numerically derived dependences with good accuracy. The results of the study are relevant for estimating and forecasting dynamic compressive strength of the samples of different fluid-saturated brittle solids. Moreover, the proposed expression can be applied to determine unknown values of the fluid effect constants on the basis of reducing the experimental data to a unified curve.

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Keywords: brittle solid; strain rate; permeability; poroelasticity; fluid flow; fracture; strength; numerical modeling; discrete element method

* Corresponding author. Tel.: +7-382-228-6971; fax: +7-382-249-2576.
E-mail address: shilko@ispms.tsc.ru

Hydrogen enhanced fatigue crack growth rates in a ferritic Fe-3wt%Si alloy

Antonio Alvaro[a,*], Di Wan[b], Vigdis Olden[a], Afrooz Barnoush[b]

[a]*SINTEF Industry, Dept. of Materials Integrity and Welding, 7456 Trondheim, Norway*
[b]*Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology, 7491 Trondheim, Norway*

Abstract

It is well known that the presence of hydrogen in ferrous materials promotes both static fracture and affect the material fatigue crack growth rates. The latter is often referred to as Hydrogen Enhanced Fatigue Crack Growth Rate (HE-FCGR) which defines the reduction of crack growth resistance of the material under cyclic stresses when hydrogen is present. When it comes to the determination of the life of components exposed to hydrogen it is therefore of paramount importance to establish such hydrogen induced variation in crack speed in the material in order to avoid unexpected catastrophic failures. In this study the fatigue crack growth rate was determined for a Fe-3wt%Si alloy. Compact tension specimens were used to determine the Paris regime of the fatigue crack growth rate curve of the material. Two environmental conditions were investigated: laboratory air and in-situ electrochemically charged hydrogen. Different mechanical conditions, in terms of load ratio (R=0.1 and R=0.5) and test frequency (f=0.1 Hz, 1 Hz and 10 Hz), were used under electrochemically charged hydrogen conditions. The results show that compared to the specimens tested in air, there is a clear detrimental effect of H for the specimens tested in hydrogen, in terms of accelerated crack growth. The strength of the impact of hydrogen in enhancing the fatigue crack growth rates of the Fe-3wt%Si alloy clearly depends on the test conditions. Fractographic investigations were also used to unveil the mechanisms involved in the process leading to accelerate crack growth in presence of hydrogen.

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Keywords: Fatigue Crack Growth, Hydrgen Embrittlement, Steel

* Corresponding author. Tel.: /
E-mail address: antonio.alvaro@sintef.no

Study on stress coupled hydrogen diffusion and fracture of high strength steels using finite element analysis (FEA) based on incremental step load (ISL) testing methodology

Tuhin Das[a,*], E. Legrand[a], S.V. Brahimi[b], J. Song[a], S. Yue[a]

[a] *Department of Mining and Materials Engineering, McGill University, Montreal, QC, Canada*
[b] *IBECA Technologies Corp, Montreal, QCAbstract, Canada*

Abstract

The work is devoted to the experimental and numerical investigation of fracture of the laser-welded specimen under quasi-static tension. In present study, two different steels stainless 316LN and P91 were welded with Laser Welding Process. The experimental study was carried out in Indira Gandhi Centre for Atomic Research (India). The evolution of the temperature field during each test was record by infrared camera CEDIP 420. Experimental results have shown quasi-wave character of the temperature evolution accompanying the specimen fracture process. During the experiments authors shown that accumulation of plastic strain irregular between joined materials, plastic flow in the P91 side overtakes plastic flow in the SS316LN side due to the various strain hardening rates of those materials. Numerical simulation of a tensile test was performed in the finite-element package Comsol Multiphysics under plane stress conditions. Simulation was carried out for two cases: small strain condition and large plastic strains, large plastic strains allow illustrate the necking effect of the specimen in the localization zone. The temperature evolution on the surface of a specimen has quantitative correspondences with the experimental results. Results of numerical simulation provided an explanation of the observed phenomena and let us to propose a model of strain localization.

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Keywords: Hydrogen embrittlement (HE), material susceptibility, incremental step load (ISL) test, finite element analysis (FEA), cohesive zone model (CZM)

* Correpsonding author. Tel.: /
E-mail address: tuhin.das@mail.mcgill.ca

Experimental and numerical investigation of the fracture in steel welded joints

A. Prokhorov[a,*], A. Kostina[a], A. Vedernikova[a], O. Plekhov[a], M. Menaka[b], B. Venkatraman[b]

[a]*ICMM UB RAS, Perm, Russia*
[b]*Indira Gandhi Centre for Atomic Research, Kalpakkam, India*

Abstract

The work is devoted to the experimental and numerical investigation of fracture of the laser-welded specimen under quasi-static tension. In present study, two different steels stainless 316LN and P91 were welded with Laser Welding Process. The experimental study was carried out in Indira Gandhi Centre for Atomic Research (India). The evolution of the temperature field during each test was record by infrared camera CEDIP 420. Experimental results have shown quasi-wave character of the temperature evolution accompanying the specimen fracture process. During the experiments authors shown that accumulation of plastic strain irregular between joined materials, plastic flow in the P91 side overtakes plastic flow in the SS316LN side due to the various strain hardening rates of those materials. Numerical simulation of a tensile test was performed in the finite-element package Comsol Multiphysics under plane stress conditions. Simulation was carried out for two cases: small strain condition and large plastic strains, large plastic strains allow illustrate the necking effect of the specimen in the localization zone. The temperature evolution on the surface of a specimen has quantitative correspondences with the experimental results. Results of numerical simulation provided an explanation of the observed phenomena and let us to propose a model of strain localization.

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Keywords: fracture, quasistatic tension, Infrared termography, steel welded joints, laser-welding

* Correpsonding author. Tel.: /
E-mail address: prokhorov.a@icmm.ru

Hydrogen permeation in 22MnB6 steels: revisiting the role of Nb additions

Valmir Bussola Martin[a], Cláudio Schon[a,]*, Hercilio de Melo[a]

[a]*University of São Paulo, Sao Paulo, Brazil*

Abstract

In a recent work, Zhang et al. [Mater. Sci. Eng. A, vol. 626, 2015, 136 - 143] reported results on hydrogen permeation in samples of 22MnB6 press hardening steel, showing that Nb microalloying produces beneficial effects, delaying hydrogen diffusion through the steel sheets. This, naturally, would have a positive impact, enhancing the resistance to delayed fracture. The present work tests this hypothesis by performing permeation experiments in samples of different origins:
1) Standard 22MnB6 steel of two different distributors, originally in spheroidized state
2) As-pressed sample of one of the standard 22MnB6 steels and
3) A sample of 22MnB6 steel microalloyed with Nb
All samples are tested in the quenched - tempered state.

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Keywords: hydrogen embrittlement, hydrogen permeation, press hardening steel, martensite

* Corresponding author. Tel.: /
E-mail: schoen@usp.br

Microstructure, mechanical and fatigue properties of SiMo- and SiCu- nodular cast irons

Alan Vaško[a,]*, Milan Uhríčik[a], Lenka Kuchariková[a], Eva Tillová[a]

[a]*University of Žilina, Faculty of Mechanical Engineering, Department of Materials Engineering, Univerzitná 8215/1, 010 26 Žilina, Slovakia*

Abstract

Fatigue has been a predominant fracture mode of load-bearing machine members. Therefore, through the years its prevention has become a fundamental design criterion. The objective of this study was to compare the microstructure, mechanical and fatigue properties of two types of the nodular cast irons – ferrite-pearlitic nodular cast iron alloyed by Si and Mo and pearlite-ferritic nodular cast iron alloyed by Si and Cu. Microstructure of the specimens was evaluated according to STN EN ISO 945 and by automatic image analysis. The image analysis system NIS Elements, interfaced with the light microscope, was used for evaluation of the shape factor, count of graphitic nodules and content of ferrite. Fatigue tests were realised at sinusoidal cyclic push-pull loading (stress ratio R = –1) at ambient temperature (T = 20 ± 5 °C). They were carried out in the high cycle fatigue region (from 10^5 to 10^7 cycles) at frequency f ≈ 75 Hz using the fatigue experimental machine Zwick/Roell Amsler 150HFP 5100. The relationships between the amplitude of stress σ_a and number of cycles to failure N_f, as well as the fatigue strength, were determined.

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Keywords: SiMo-nodular cast iron; SiCu-nodular cast iron; microstructure; fatigue

* Corresponding author. Tel.: +421-41-513 2605.
E-mail address: alan.vasko@fstroj.uniza.sk

Investigation of fracture properties by inverse analysis on selected SCC concrete beams with different amount of fibres

Oldřích Sucharda[a], Petr Lehner[b,]*, Petr Konečný[b], Tomasz Ponikiewski[c]

[a]VSB-Technical University of Ostrava, Faculty of Civil Engineering, Department of Building Materials and Diagnostics of Structures, Ludvíka Podéště 1875/17, 708 33 Ostrava-Poruba, Czech Republic

[b]VSB-Technical University of Ostrava, Faculty of Civil Engineering, Department of Structural Mechanics, Ludvíka Podéště 1875/17, 708 33 Ostrava-Poruba, Czech Republic

[c]Silesian University of Technology, Faculty of Civil Engineering, Department of Building Materials and Processes Engineering, Akademicka 5, 44-100 Gliwice, Poland

Abstract

Self-compacting concrete (SCC) and Steel fibre reinforced concrete (SFRC) have higher tensile strength capacity, limited crack width and higher post peak capacity, as well as easier construction handling. Thus SFRC allows for advanced and innovative design of concrete structures. However, the current wider structural applicability of the discussed composite material is limited by lack of knowledge and recommendations for advanced design and analysis considering non-linear calculation as well corrosion related durability. Therefore, it is necessary to have knowledge of several physical and mechanical properties or to be able to identify the properties of interest. The article presents the results of the identification of fracture properties of selected self-compacting concrete that are suitable for nonlinear finite element analyses. Moreover, the ability of selected concrete to the ingress of chlorides is of particular interest as well. Interest in material properties consisted of concrete tensile strength, modulus of elasticity, softening factors and specific fracture energy. The procedure for identifying material properties by inverse analysis was applied. New knowledge of material properties can be used to analyse similar tasks, especially in the case of nonlinear analysis of concrete structures.

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Keywords: Self-compacting concrete; Steel fibres; Flexural tensile strength; Fracture energy; Deflection-CMOD relationship

* Corresponding author. Petr Lehner. Tel.: +420 59 732 1391
E-mail address: petr.lehner@vsb.cz

Stochastic service life prediction of existing steel structure loaded by overhead cranes

Petr Lehner[a], Vít Křivý[b,*], Martin Krejsa[a], Přemysl Pařenica[a], Jaroslav Kozák[c]

[a]*VSB-Technical University of Ostrava, Faculty of Civil Engineering, Department of Structural Mechanics, Ludvíka Poděště 1875/17, 708 33 Ostrava-Poruba, Czech Republic*
[b]*VSB-Technical University of Ostrava, Faculty of Civil Engineering, Department of Building Constructions, Ludvíka Poděště 1875/17, 708 33 Ostrava-Poruba, Czech Republic*
[c]*Vitkovice ENVI a.s., Ruska 1142/30, 703 00 Ostrava-Vitkovice, Czech Republic*

Abstract

The article deals with the fatigue damage analysis of aging steel structures. The structure was built in 1920 and is used to operate an outdoor storage of steel rolled products. The structure serves as a support for overhead cranes with a lifting capacity of 8 tons. Reliability assessment including prediction of the residual service life was requested by the property owner. Corrosion state of structural elements and assessment of fatigue resistance represent the key data for the prediction of the residual service life. The study of the documentation and the inspection of structure was the first steps of the analysis.
Next, the computational numerical model of the steel bar structure was prepared to identify the critical details for the fatigue assessment. The detailed numerical model of the selected structural part was used subsequently to check the fatigue resistance. In this article, special attention is paid to the calculation of load effects resulting from the operation of overhead cranes. A new innovative method based on the Monte-Carlo simulations and FEM model of the structure was used to determine the stress history. The following random variables enter the probabilistic analysis: (a) position of the crane bridge, (b) position of the crab, (c) payload, (d) number of crane travels during the evaluated period. Income information for the probabilistic analysis are taken from the technical documentation, skilled judgement of the operation technologist is used as well.

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Keywords: Fatigue life; load-bearing structure; overhead crane; Monte-Carlo simulations; FEM models.

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* Corresponding author. Tel.:+420 597 321 391.
E-mail address: vit.krivy@vsb.cz

The gigacycle fatigue strength of steels: a review of structural and operating factors

Thierry Palin-Luc[a,*], Dalenda Jeddi[b]

[a]*Arts et Metiers ParisTech, CNRS, I2M Bordeaux, Esplanade des Arts et Metiers, 33405 Talence Cedex, France*
[b] *University of Tunis El Manar, Laboratory of Applied mechanics and Engineering, Campus Universitaire El Manar, BP 37, 1002 Tunis, Tunisia*

Abstract

It is known that usual frequency up to 100 Hz has no influence on the high cycle fatigue (HCF) strength of steels. However, in the very high cycle fatigue (VHCF) regime, the frequency effect is still unclear. Indeed, a high frequency can lead to heating, instability of the microstructure and degradation or improvement of the mechanical properties of the material, which in turn depend on the type of loading and on the operating environment. Based on a large literature review of many experimental data in gigacycle regime, a synthesis is proposed to discuss the effect of the structural and operational factors on the VHCF characteristics of low and high strength steels (Jeddi et al. (2018)). Failure mechanisms in HCF and VHCF (surface or internal crack initiation) are related to S-N curve shape. The effect of the microstructural and mechanical features on the VHCF resistance is debated depending on different parameters: microstructure, inclusion size, inclusion type and depth, hydrogen, environment, maximum tensile strength of the steel and residual stresses. The influence of the loading conditions on the VHCF strength is addressed by taking into account both the loading frequency effect, the highly stressed volume, the loading type and loading ratio. Finally, the influence of the testing techniques (pulse-pause or continuously cyclic loading) is discussed.

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Keywords: Gigacycle fatigue; Steel; Crack initiation; Micromechanism; Influence factors

* Corresponding author. Tel.: +33 556 845 360; fax: +33 556 845 366
E-mail address: thierry.palin-luc@ensam.eu

The fatigue lifetime of AlZn10Si8Mg cast alloy with different percentage of iron

Denisa Závodská[a], Lenka Kucharikováa[a,*], Eva Tillová[a], Mario Guagliano[b], Mária Chalupová[a], Milan Uhríčik[a], Juraj Belan[a]

[a]Department of Materials Engineering, Faculty of Mechanical Engineering, University of Žilina,Univerzitná 1, 01026 Žilina, Slovak Republic
[b]Dipartimento di Meccanica, Politecnico di Milano, Campus Bovisa Sud - via La Masa 1, 20156 Milano, Italy

Abstract

To increase the proportion of Al-cast alloys in a variety of industrial applications, it appears useful to control their fatigue behavior. In general, that behavior is affected by many factors, such as chemical composition, heat treatment, inclusions etc. The problem with utilization of the Al-scrap as a material for casting the Al-Si alloys lies in the fact that the scrap, unfortunately as a rule, is contaminated with iron. The Fe-rich intermetallics, formed during the solidification process, appear in a great variety of shapes and sizes. The most important are platelets or needles Al_5FeSi, because they greatly decrease mechanical and corrosion properties of Al-cast alloys. The effect of the brittle Fe-rich phases on the fatigue properties in the secondary self-hardening AlZn10Si8Mg cast alloys with different percentage of iron (0.150 and 0.559 wt. %) was studied. Microstructure of alloys and the 3D-morphology of phases were analyzed by the optical and SEM microscopy. Rotating bending fatigue tests were realized for a defined number of cycles 3 x 10^6. The results show that with increasing the content of Fe, the area proportion and the average length of Al_5FeSi phases increased a significant influenced on the fatigue life and pores formation.

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Keywords: secondary cast aluminum alloys, iron intermetallic phases, fatigue properties

* Corresponding author. Tel.: +421-41-513 2626; fax: +421-41-565 2940.
E-mail address: lenka.kucharikova@fstroj.uniza.sk

Microstructural and fracture analysis of micro-alloyed steel weld metal

R. Prokić Cvetković[a], O. Popović[a,*], R. Jovičić[b], N. Milošević[a], Z. Burzić[c], I. Cvetković[b]

[a]*University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade, Serbia*
[b]*University of Belgrade, Innovation center Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade, Serbia*
[c]*Military Technical Institute, Ratka Resanovića 1, Belgrade, Serbia*

Abstract

In this paper is presented behavior of microalloyed steel weld metal with niobium during impact testing, as well as microstructural characterization. Impact tests were done on instrumented Charpy pendulum at room temperature, at -400C and - 550C. At room temperature, crack propagation energy is much higher than crack initiation energy, while at -400C and - 550C crack growth energy is lower than crack initiation energy. Fractographic investigation of the fracture surfaces has shown that at room temperature ductile trans-granular fracture is dominant, with a small amount of brittle trans-granular fracture. At lower temperature, the share of brittle fracture is increased, and inter-granular brittle fracture becomes dominant.

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Keywords: weld metal; micro-alloyed steel; microstructures; fracture analysis; toughness

* Corresponding author. Tel.: +381113302-259
E-mail address: opopovic@mas.bg.ac.rs

The peak stress method applied to bi-material corners

Mauro Ricotta[a,*], Michele Zappalorto[b], Mattia Marchiori[a], Alberto Campagnolo[a], Giovanni Meneghetti[a]

[a]*Department of Industrial Engineering, University of Padova, via Venezia, 1, 35131 Padova, Italy*
[b]*Department of Management and Engineering, University of Padova, Stradella San Nicola, 3, 36100 Vicenza, Italy*

Abstract

Bi-material interfaces are unavoidably present in many engineering applications, such as microelectronics, adhesive joints, fiber-reinforced composites and thermal barrier coatings. Under the hypothesis of linear elastic material behaviour, the local stress field at the point located at the free-edge of the bi-material interface has a singular behaviour, of which the intensity can be quantified by a generalized stress intensity factor, H. However, the numerical evaluation of H usually requires very accurate meshes and large computational efforts, hampering the use of H-based criteria in the engineering practice.
The main aim of the present work is to overcome this limitation by extending to isotropic bi-material corners the Peak Stress Method (PSM), first proposed by Meneghetti and co-workers to estimate the stress intensity factor at the tip of a geometrical singular point with relatively coarse mesh patterns.

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Keywords: bi-material corners, generalised stress intensity factor, Peak Stress Method

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* Corresponding author. Tel.: +39 049 827 6762; fax: +39 049 827 6785.
E-mail address: mauro.ricotta@unipd.it

Refinement of defect detection in the contact and non-contact ultrasonic non-destructive testing of wind turbine blade using guided waves

Kumar Anubhav Tiwari[a,*], Renaldas Raisutis[a]

[a]Ultrasound Research Institute, Kaunas University of Technology, K. Barsausko st. 59 - A426, Kaunas LT-51423, Lithuania

Abstract

The guided waves are widely used for the inspection of many composite structures as they can travel up to long distance along the thickness of the structure. Most of the times, the experimental investigations standalone is not able to locate and size the damages or defects due to dispersive, superimposed and scattered guided wave modes. Hence signal refinement of ultrasonic guided wave signals is required for identifying and characterizing the defects. In this work, disbond type defects presented on different locations of the segment of the wind turbine blade are estimated by applying the signal refinement techniques after experimental analysis. The experiment was carried out on a 1005 x 870 mm segment of wind turbine blade manufactured using a composite glass fiber reinforced plastic material. Two defects on the trailing edge (with diameter 15 and 25 mm) and three defects on the main spar (with diameters 25, 51 and 81 mm) of the WTB segment were investigated. The combination of macro fibre composite transducer, contact type and air-coupled transducers were used to transmit and receive the ultrasonic guided waves. The signal processing techniques are applied to the experimental signals for the estimation and characterization of defects.

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Keywords: Guided wave; composite; signal processing; transducer; ultrasound

* Corresponding author. Tel.: +370-64694913; fax: +370-37451489.
E-mail address: k.tiwari@ktu.lt

ECF22 - Loading and Environmental Effects on Structural Integrity

Analysis of dependence of internal damping on temperature of austenitic steels

Milan Uhríčik[a,]*, Monika Oravcová[a], Peter Palček[a], Tatiana Oršulová[a], Lenka Kucharíková[a], Ružica R. Nikolić[b]

[a]*University of Žilina, Faculty of Mechanical Engineering, Department of Materials Engineering, Univerzitná 8215/1, 01026 Žilina, Slovakia*
[b]*University of Žilina, Research Center, Univerzitná 8215/1, 01026 Žilina, Slovakia and Faculty of Engineering, University of Kragujevac, Serbia*

Abstract

The processes of micro-plasticity and energy scattering inside the material are analyzed by measuring the internal damping. The mechanism of micro-plasticity can be evaluated by various dependencies – frequency, time, temperature and amplitude dependencies that characterize the kinetics of accumulation of fatigue damage under long-term load. By measuring the energy scattering in the material, the elastic characteristics, the modulus of elasticity, the degree of stress relaxation in the material can be determined. The ability of a solid to irreversibly disperse energy under mechanical stress is called the internal damping. The time required to achieve the equilibrium deformation value is determined by various processes associated with the reallocation of atoms, magnetic moments and the temperature of the solid subjected to external stresses.
The internal damping mechanisms have been studied by ultrasonic resonant apparatus at a frequency close to 20450 Hz and in a temperature range from 30 °C up to 400 °C. Specimens of an hour glass shape were used for experiments.
Measurement of internal damping dependence on temperature was performed on austenitic steels AISI 316L, AISI 316Ti and AISI 304, in the initial state and after the deformation. Those materials are commercially available stainless steels, which are very often used as biomaterials in medicine.

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Keywords: internal damping; austenitic steel; resonance frequency; temperature.

* Corresponding author. Tel.: +421-41-513-2626.
E-mail address: milan.uhricik@fstroj.uniza.sk

Probabilistic fatigue life prediction of parabolic leaf spring based on Latin hypercube simulation method

Akram Atig[a,*], Rabii Ben Sghaier[a], Raoudha Seddik[a], Raouf Fathallah[a]

[a]UGPM2-ENISo, Tunis, Tunisia

Abstract

Fatigue phenomenon is one of the main causes of parabolic leaf spring failure. Therefore, fatigue life assessment and prediction represent an important aspect during parabolic leaf spring design stage. Nevertheless, the estimation of fatigue life is usually affected by many inherent uncertainties which must be considered in a fatigue design approach. In this work, a stochastic approach based on Latin hypercube simulation method has been performed to predict the fatigue life of parabolic leaf spring. The Morrow fatigue criterion have been used to compute the number of cycles to failure. The proposed approach has been applied on a finite element and a response surface models of parabolic leaf spring. The dispersion of geometrical dimensions, materials properties and cyclic loading parameters have been taken into consideration. The number of cycles to failure distribution has been presented and characterized. The effects of probabilistic variables on the fatigue life results have been studied in order to enhance the fatigue behavior of parabolic leaf spring.

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Keywords: Relability-based fatigue life prediction, parabolic leaf spring, latin hypercube simulation

* Corresponding author. Tel.: /
E-mail address: akram.atig@gmail.com

Probability density evolution method for the evaluation of fatigue reliability of parabolic leaf spring

Akram Atig[a,*], Rabii Ben Sghaier[a], Raoudha Seddik[a], Raouf Fathallah[a]

[a]UGPM2-ENISo, Tunis, Tunisia

Abstract

The aim of this study is to propose a probabilistic methodology for evaluating the fatigue reliability of parabolic leaf spring (PLS) using the probability density evolution method (PDEM). This approach is based on a parametric finite element model of a single asymmetric parabolic leaf spring (SAPLS) to estimate the high value of the applied stress. Furthermore, a fatigue criterion based on Morrow mean stress correction has been taken into account. The effects of shot peening residual stresses, surface roughness and decarburization have been considered. The different implementation steps of this method have been carefully represented. In fact, the PDEM presents a very efficient tool for the assessment of fatigue reliability. In fact, the achievement of the probability density distribution of the limit state function is carried out from a small number of the representative points. In order to validate the implementation of PDEM, a comparison of the obtained results using PDEM with those obtained using the Monte Carlo simulation method has been effectuated and a good consistency has been remarked.

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Keywords: probability density evolution method, parabolic leaf spring, shot peening

* Corresponding author. Tel.: /
E-mail address: akram.atig@gmail.com

Fracture behavior of the secondary A226 cast alloy with 0.9 % Fe

Lenka Kuchariková[a], Magdalena Mazur[b,*], Eva Tillová[a], Mária Chalupová[a], Denisa Závodská[a], Alan Vaško[a]

[a]*Department of Materials Engineering, Faculty of Mechanical Engineering, University of Žilina, Univerzitná 1, 010 26 Žilina, Slovak Republic*

[b]*Department of Management, Czestochowa University of Technology, Al. Armii Krajowej 19B, 42 200 Czestochowa, Poland*

Abstract

The Al-Si-Cu cast alloys are suitable for production of components for automotive and aerospace industries due to an excellent combination of mechanical properties; for such applications, the fracture behaviour of castings is important. A dimple type - trans-crystalline ductile fracture appears on the fracture surface of aluminium alloys, whose overall appearance shows both the matrix (α-phase) violation and the shape and size of the eutectic Si and the secondary - intermetallic phases. Nowadays, an increasing amount of aluminium is coming from the recycled products. The recycled aluminium cast alloys contain various additional elements (especially the higher amount of Fe), which are forming various secondary phases in microstructure. This paper describes dependence of the fracture surface character on the morphology and types of the secondary phases in the recycled A226 cast alloy with 0.9 % of Fe. The used experimental material was heat-treated and the fracture surface properties and morphology of the secondary phases in microstructure were analysed by a combination of different analytical techniques.

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Keywords: fracture behaviour, secondary aluminium alloys, aluminium casting, intermetallic phases, recycling;

* Corresponding author. Tel.: /
E-mail address: magdalena.mazur@wz.pcz.pl

Prediction of ductile fracture initiation in strength mismatched structure by coupled micromechanical model

Nenad Gubeljak[a,*], Marko Rakin[b], Bojan Međo[b], Sameera Naib[c], Stijn Hertele[c], Wim de Waele[c], Primož Stefane[a]

[a] *Faculty of Mechanical Engineering, University of Maribor, 2000 Maribor, Slovenia*
[b] *Faculty of Technology and Metallurgy, University of Belgrade, 11120 Belgrade, Serbia*
[c]*Soete Laboratory, Dept. of EEMMeCS, Ghent University, 9000 Ghent, Belgium*

Abstract

It is known that the differences in mechanical properties between different regions of inhomogeneous structures affect the strain distribution around the crack tip during the fracture test. The welding process produces a dissimilarity of mechanical properties among weld metal, parent metal and heat affected zone. Both, the strength mismatch and geometry of welded joint, contribute to change of constraint in the weld metal.
Micromechanical models seem appropriate for modelling the damage and fracture behaviour of inhomogeneous microstructures, as they correlate local stresses and strains with fracture toughness.
In this paper, the coupled micromechanical model was applied to ductile fracture in a study of constraint effect on crack growth initiation in mismatched welded joints. The single-edged, notched bend specimens (SENB), with average pre-crack length $a_0/W=0.428$- 0.448 in cases of over- and under-matched weld metal, were experimentally and numerically analysed. High-strength low-alloyed (HSLA) steel of S690 QL grade was used as the base metal in a quenched and tempered condition. The flux-cored arc-welding process in shielding gas was used utilized. Two different fillers were selected to obtain over- (OM) and under-matched (UM) weld metal. The micromechanical parameters used in prediction of the crack growth initiation on a pre-cracked specimen were calibrated on a round notched specimen.
The difference in fracture behaviour between over- and under-matched welded metals obtained in experimental results was followed by numerical computations. Using the finite element analysis, the increase of the void volume fraction f was monitored ahead of a crack tip of an SENB specimen. Based on the critical value fc determined on a round smooth specimen, crack tip opening displacement (CTOD) was predicted at a fatigue pre-crack growth initiation in the SENB specimen.
Comparison of the initial CTODi values, corresponding to crack initiation in SENB specimens, showed a very good agreement between experimental and model-predicted results for the UM joints. Moreover, it was also possible to trace very accurately the tendency toward the increase of the CTODi values in the joints following the increase of width of weld metal.

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Keywords: Mismatch, welded joint, , numerical modelling, CTOD

* Corresponding author. Tel.: /
E-mail: nenad.gubeljak@um.si

Low-cycle fatigue hysteresis by thermographic and digital image correlation methodologies: a first approach

Guido La Rosa[a,]*, Carmelo Clienti[a], Adriana Marino Cugno Garrano[a], Fabio Lo Savio[a]

[a]DICAR, University of Catania, Via S. Sofia 64, 95123 Catania, Italy

Abstract

The energetic behaviour of the material under low-cycle fatigue (LCF) can be controlled by the hysteresis cycle in order to define the variation of the mechanical characteristics and to forecast the fatigue and the failure response. The traditional analysis is performed using the force-displacement signals derived by the testing machine that can be coupled with other measuring methodologies. In the present paper, the authors have used the Digital Image Correlation (D.I.C.) to better define the specimen displacement, avoiding many errors of the displacement measurement chain. The thermographic analysis (T.A.), able to follow quickly and with great accuracy the energetic variations, was combined with the stress-strain measurements, allowing to calculate the damping energy. The results pointed out a similar behaviour between the hysteresis areas defined basing on the D.I.C. displacements and those found by the testing machine outputs, but substantial differences in terms of values. The thermal variations and the areas of the hysteresis loops, both linked to the plastic energy, were compared, showing a reliable agreement.

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Keywords: Low-cycle fatigue; Hysteresis; Digital Image Correlation (D.I.C.); Thermography.

* Corresponding author. Tel.: /
E-mail address: glarosa@dii.unict.it

Experimental and numerical investigations of the critical values of J-integral for the steel of steam pipelines

Bojana Aleksić[a,*], Ljubica Milović[b], Aleksandar Grbović[c], Abubkr Hemer[b], Vujadin Aleksić[d], Milorad Zrilić[b]

[a]*Innovation Centre of Faculty of Technology and Metallurgy, Karnegijeva 4, 11120 Belgrade, Serbiab*
[b]*University of Belgrade, Faculty of Technology and Metallurgy, Karnegijeva 4, 11120 Belgrade, Serbia*
[c]*University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11120 Belgrade, Serbia*
[d]*Institute for testing of materials- IMS Institute, Bulevar vojvode Mišića 43, 11000 Belgrade, Serbia*

Abstract

Steel grade 14MoV6-3 is a low-carbon microalloyed steel with addition of chromium and molybdenum. This grade is designed mainly for power industry applications, withstanding operating at elevated temperatures
In this paper, mechanical properties of steel grade 14MoV6-3 and methodology of calculation of critical values of the *J*-integral are presented. The level of damage is determined by analyzing the virgin material of the same grade.
The focus of presented investigation is on the experimental J-integral determination, where critical values of the J-integral (J_{IC}) are compared with the values obtained by using the finite element methods (FEM). FEM model was defined on the basis of experimental conditions and obtained numerical values should confirm our experimental results.

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Keywords: steel for elevated temperature application; mechanical properties; *J*-integral; FEM; crack.

* Corresponding author. Tel.: /
E-mail address: baleksic@tmf.bg.ac.rs

Structural integrity assessment of rigid polyurethane components using energy methods

G. Lesiuk[a,*], K. Junik[a], M. Smolnicki[a], J.A.F.O. Correia[b], A.M.P. De Jesus[b], B. Babiarczuk[a], K. Otczyk[a]

[a]*Department of Mechanics, Materials Science and Engineering, Wrocław University of Science and Technology, Smoluchowskiego 25, 50-370 Wrocław, Poland*

[b]*INEGI/Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal*

Abstract

In the paper, the experimental results of the mechanical investigation have been presented. The main attention was paid to fracture toughness, tearing resistance and fatigue crack growth rate characterization of polyurethane elastomers in terms of two different hardness configurations; 80ShA and 90ShA. The impact of material hardness on the fracture properties (static and cyclic) is reflected in experimental results. For fracture toughness characterization, the EWF (essential work of fracture) method was involved. It has been shown, that the 80ShA and 90ShA materials demonstrate completely different behavior under high stress concentration condition. From the perspective of usefulness of fracture mechanics, the energy approach seems to be crucial in the context of the real operating conditions of the bushing in suspension system of vehicles. For this purpose the fatigue crack growth rate test was performed on planar specimens PS (Pure Shear). Based on the experimental results, it can be concluded that fatigue crack growth rate in 90ShA PUR elastomer was significantly higher in comparison to the 80ShA PUR elastomer.

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Keywords: polyurethane elastomers; static properties; tearing energy; fatigue crack growth rate;

* Corresponding author. Tel.: /
E-mail address: Grzegorz.Lesiuk@pwr.edu.pl

Analysis of strain distribution in overmatching V groove weld using digital image correlation

N. Milošević[a], A. Sedmak[a,*], R. Jovičić[b]

[a]*Faculty of Mechanical Engineering of University of Belgrade*
[b]*Innovation center of Faculty of Mechanical Engineering of University of Belgrade*

Abstract

Welded joints are treated as critical sites when constructing and calculating welded structures due to inhomogeneity and anisotropy of materials at the welded joint site. Because of the change in the geometry of the elements, the welded joint is viewed as the location of the stress concentration and therefore as a place that weakens the overall load capacity of the structure. Due to this approach in the design of welded structures, practice requires that in most cases welded joints are performed with better mechanical properties compared to the base metal. A welded joint that is made so that the mechanical properties of the weld metal exceed the mechanical properties of the base metal is called the overmatching welded joint. This paper presents the measurement of the strain over the 'overmatching' welded V joint using the DIC (Digital Image Correlation) method and the analysis of the strain distribution is provided. The strain distribution obtained is interesting because it shows that in the stress concentration points the strain have almost minimal values.

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Keywords: Strain distribution analysis; Overmatching weld; Digital Image Correlation; Welded joints

* Corresponding auhor.
E-mail address: asedmak@mas.bg.ac.rs

Measurement of strain field in glass ionomer cement

Aleksandra D. Mitrović[a,*], Nenad R. Mitrović[b], Ivan V. Tanasić[c], Miloš S. Milošević[d], Dušan G. Antonović[a]

[a]*University of Belgrade, Faculty of Technology and Metallurgy, Belgrade 11000, Serbia*
[b]*University of Belgrade, Faculty of Mechanical Engineering, Belgrade 11000, Serbia*
[c]*University of Belgrade, Faculty of Dental Medicine, Belgrade 11000, Serbia*
[d]*University of Belgrade, Innovation Center of Faculty of Mechanical Engineering, Belgrade 11000, Serbia*

Abstract

Extensive evolution of glass ionomer cements (GIC) has marked a significant shift in the practice of luting indirect dental restorations limiting the use of zinc-phosphate and zinc-polycarboxylate cements to a few indications. GIC are now one of the materials of choice for cementation of all ceramics, fibre reinforced composite posts and veneers. GICs are determined by unique properties like chemical adhesion to tooth and base metals, low thermal expansion coefficients similar to dentin and minimal microleakage at the tooth-enamel interface due to low shrinkage. Shrinkage strain is identified as the cause and the associated stress as the mechanism for the loss of marginal adaption and cohesive fracture within the material. The aim of this study was to measure strain and displacement field in a conventional (Riva Luting, SDI, Australia) related to different cement diameter, using the 3D Digital Image Correlation Method (DIC). Experiment was done for samples with thickness of 1 mm combined with diameters of 4 mm (Group I) and 3 mm (Group II). Strain field was measured using 3D optical system Aramis 2M (GOM, Braunschweig, Germany). This study provided valuable data about strain behaviour and displacement as a possible failure factor in GIC, Riva Luting. Visible differences between Group I and Group II were observed.

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Keywords: Glass ionomer cement; Riva Luting; strain field; displacement; failure; 3D Digital Image Correlation.

* Corresponding author: Aleksandra D. Mitrović. Tel.: +38166210913.
Email adress: aleksandramitrovic1926@gmail.com

Strain measurement of pressure equipment components using 3D Digital Image Correlation method

Nenad Mitrović[a,*], Aleksandar Petrović[a], Miloš Milošević[b]

[a]*University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11000 Belgrade, Serbia*
[b]*University of Belgrade, Innovation Center of Faculty of Mechanical Engineering, Kraljice Marije 16, 11000 Belgrade, Serbia*

Abstract

Pressure equipment has widespread application in various industrial sectors. Due to this variety, pressure equipment can have complex structure and is subjected to different working loads (static, dynamic, thermal etc.) during the operation life that can cause failure. Strain measurement of complex structure has always been a huge challenge for researchers. Conventional experimental methods (e.g. strain gauges) give only limited data sets regarding measurement on critical areas with high geometrical discontinuities. 3D Digital Image Correlation method is an optical method that enables full-field strain measurement of critical areas on structural components. Sphere/cylinder junction is common geometrical discontinuity on pressure equipment and globe valve housing was chosen as representative example. In this paper, globe valve housing was subjected to external axial loading caused by pipeline dilatations. Highest measured von Mises strain values around 0.15 % were recorded on cylinder/sphere intersection. Determining strain state of critical areas enables better understanding of complex structures and provides an opportunity for further development and improvement for practical industrial application.

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Keywords: Pressure equipment; 3D Digital Image Correlation method; geometrical discontinuity; globe valve housing; axial loading.

* Corresponding author. Tel.: +381 11 3302 200; fax: +381 11 3370 364.
E-mail address: nmitrovic@mas.bg.ac.rs

Chloride permeability of slag concrete in sulphate environment

A. Merida[a,]*, F. Kharchi[a]

[a]University of Algier, Faculty of Civil Eng., 16111, Algier, Algeria

Abstract

Concrete with binary blend of portland cement and finely ground slag was produced to investigate their effects on chloride permeability. Portland cement was partially replaced by 15% finely ground slag (Blaine specific surface: 8000 cm2/g) has a marked influence on the physico-mechanical characteristics of the concrete. The analysis of the experimental results showed that it contributes positively to the improvement of its durability with respect to the chloride permeability. This test was performed using the procedures of ASTM C 1202.The resistance of concrete to penetrating chloride ions was measured by the charge passed through two 50 mm disk specimens maintained under an electric tension of 60V during 6 hours by means of electrodes made of rustproof steel between the two cells of the two compartments. One of the faces of the specimen was in contact with 3% NaCl solution, and the other face was in contact with 0,3N NaOH solution. The test was conducted at 28, 90,180 and 365 days.

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Keywords: concrete, chloride permeability, sulphate

* Corresponding author. Tel.: /
E-mail: merida.hacene@yahoo.fr

The influence of heat input on the toughness and fracture mechanism of surface weld metal

O. Popović[a,*], R. Prokić Cvetković[a], Lj. Radović[b], Z. Burzić[b], D. Arsić[c]

[a]*University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade, Serbia*
[b]*Military technical institute, Ratka Resanovića 1, Belgrade, Serbia*
[c]*University of Kragujevac, Faculty of Engineering, Sestre Janjić 6, Kragujevac, Serbia*

Abstract

Surface welding is a way to extend the exploitation life of damaged parts and constructions and the heat input has a major influence on the weldment properties. In this paper is shown the influence of the heat input on the toughness and the fracture mechanism of the surface welded joint. Surface welding of high carbon steel with self shielded wire was conducted with three different heat inputs (6 kJ/cm, 10 kJ/cm and 16 kJ/cm). Total impact energy, crack initiation and crack propagation energy were estimated at room temperature, -20oC and -40°C. Fracture analysis of fractured surfaces was also conducted and it has been found that increasing of heat input leads to an increase of share of transgranular brittle fracture, what is in complete accordance with the obtained energy values. Based on all obtained results, the optimum value of heat input for welding procedure applied was defined.

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Keywords: Heat input; Fracture mechanism; Toughness; Surface welding

* Corresponding author. Tel.: +381113302-259
E-mail address: opopovic@mas.bg.ac.rs

ECF22 - Loading and Environmental Effects on Structural Integrity

Surface machining condition and fatigue life on Inconel 718

A. Martin-Meizoso[a,*], J.M. Martinez-Esnaola[a], P.J. Arrazola[b], A. Linaza[c]

[a]*Tecnun Ceit-IK4 (University of Navarra), P. Manuel Lardizabal 15, San Sebastian 20018, Spain*
[b]*Faculty of Engineering, Mondragon University, Loramendi 4, Arrasate 20500, Spain*
[c]*ITP Aero, Parque Tecnológico, Edifico 300, Zamudio 48170, Spain*

Abstract

Life assessment of components working in aero-engines at elevated temperatures is critical. Machining has a serious effect on these nickel-based alloys, for example in turbine discs, affecting their life in service. Machining (turning, broaching…) modifies surface roughness, thickness of the affected substrate layer (including the effect of possible broken carbides) and residual stress distribution near the component surface. On top of that, it is possible to shot-peen or not the component, which again modifies its surface integrity. The aim of this work is to discern among the effect of the different parameter: roughness, damage and residual stresses on fatigue performance and optimum machining conditions.

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Keywords: Machining; Surface Condition; Fatigue; High Temperature; Inconel 718

* Corresponding author. Tel.: +34 943212800; fax: +34 943213076.
E-mail address: ameizoso@ceit.es

Assessment of the contribution of internal pressure to the structural damage in a hydrogen-charged Type 316L austenitic stainless steel during slow strain rate tensile test

Jean-Gabriel Sezgin[a,*], Osamu Takakuwa[b], Hisao Matsunaga[b,c,d], Junichiro Yamabe[e]

[a] *National Institute of Advanced Industrial Science and Technology (AIST), Hydrogen Materials Laboratory (HydroMate), Kyushu University, 744 Moto-oka, Nishi-ku, Fukuoka, 819-0395 Japan*
[b] *Department of Mechanical Engineering, Kyushu University, 744 Moto-oka, Nishi-ku, Fukuoka 819-0395, Japan*
[c] *Research Center for Hydrogen Industrial Use and Storage (HYDROGENIUS), Kyushu University, 744 Moto-oka, Nishi-ku, Fukuoka, 819-0395 Japan*
[d] *International Institute for Carbon-Neutral Energy Research (I2CNER), Kyushu University, 744 Motooka, Nishi-ku, Fukuoka, 819-0395, Japan*
[e] *Departement of Mechanical Engineering, Fukuoka University, 8-19-1 Nanakuma, Jonan-ku, Fukuoka, 814-0180, Japan*

Abstract

In Slow Strain Rate Tensile (SSRT) test of H-charged specimens, Type-316 austenitic stainless steel often fails by a cup-and-cone failure mode; however, shows a slight ductility loss and a reduction in void size on the normal stress-fracture region. Since observations of longitudinal cross section reveal that the small-sized dimples are void sheets, which are generally formed on the planes with concentrated shear strains, the hydrogen effect on their SSRT properties has been explained by enhancement of localized slip deformation by hydrogen. However, another mechanism may contribute to the failure. The aim of this study is to provide a quantification of the internal pressure contribution to the SSRT properties of H-charged Type-316L steel tested in air at room temperature. Considering pre-existing penny-shaped voids, the transient pressure build-up has been simulated as well as its impact on the void growth by preforming JIc calculations. Several void distributions (size and spacing) have been considered. Simulations have concluded that there was no impact of the internal pressure on the void growth, regardless the void distribution since the effective pressure was on the order of 1 MPa during the SSRT test. Even if fast hydrogen diffusion related to dislocation pipe-diffusion has been assessed as a conservative case, the impact on void growth was barely imperceptible (or significantly low). The effect of internal pressure has been experimentally verified via the following conditions: (I) non-charged in vacuum; (II) H-charged in vacuum; (III) H-charged in 115-MPa nitrogen gas; (IV) non-charged in 115-MPa nitrogen gas. As a result, the relative reduction in area (RRA) was 0.84 for (II), 0.88 for (III), and 1.01 for (IV), respectively. The difference in void morphology of the H-charged specimens did not depend on the presence of external pressure. These experimental results demonstrate that the internal pressure had no effect on the tensile ductility and void morphology of the H-charged specimen.

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Keywords: void growth, slow strain rate tensile test, hydrogen gas, hydrogen embrittlement, hydrogen diffusion, austenitic stainless steel

* Corresponding author. Tel.: +81-942-81-3597; Fax: +81-92-805-5281.
E-mail address: sezgin.jean-gabriel@aist.go.jp

Fatigue strength of hybrid FSW and adhesive bonded joints for longitudinal fuselage joints

Daniel Braga[a,*], Luciano Bergmann[b], Virginia Infante[c], Lucas Da Silva[d], Jorge Dos Santos[b], Pedro M.G.P. Moreira[a]

[a]*INEGI/FEUP, Porto, Portugal*
[b]*Helmholtz-Zentrum Geesthacht, Geesthacht, Germany*
[c]*Instituto Superior Tecnico, Lisboa, Portugal*
[d]*FEUP , Porto, Portugal*

Abstract

The continuous push for lighter and more efficient vehicle structures, along with the development of newer joining methods, has led designers to pursue the adoption of innovative joining methods in metallic structures. Friction Stir Welding (FSW), is one technology that has been proposed for fuselage joints as the excellent mechanical properties it generates along with the potential weight savings it creates especially in butt joint configuration are significant. However, manufacturing concerns and tolerance management difficulties has hinder its application. In this work a combination of overlap FSW and adhesive bonding is proposed for longitudinal fuselage joints. The joints are submitted to cyclic loading, and the resulting S-N curve is compared with FSW and riveted joints from the literature. Comparable performance to SoA riveted joints was found with improvements in joint weight reduction.

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Keywords: Friction Stir Welding, fuselage joints, S-N curve

* Corresponding author. Tel.: /
E-mail address: dbraga@inegi.up.pt

Analysis of fatigue life of the steel cord used in tires in unidirectional and bidirectional bending

Robert Kruzel[a,*], Małgorzata Ulewicz[a]

[a]*Czestochowa University of Technology, Faculty of Civil Engineering*

Abstract

The results of fatigue life tests of steel cord used in construction machinery tyres are presented in this paper. Steel wire used in tyres, called the steel cord, is largely responsible for transferring large loads, but unfortunately it quickly undergoes fatigue. The fatigue life of this steel cord is influenced by many factors related to its construction, workmanship quality, as well as the method of bending during each working cycle. In laboratory tests, the fatigue life of steel cords was compared in the conditions of unidirectional and bidirectional bending, on a specially built, innovative fatigue testing machine for steel cords. In fatigue life tests, a fundamental difference is visible in the number of cycles leading to breaking. For a one-way bending process, the number of cycles is significantly greater than for the bidirectional bending. Instead of the wire fracture process, a steel cord elongation process takes place that increases the number of fatigue cycles, which is reflected directly in the number of failures in the tyres of construction machines.

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Keywords: fatigue strength, steel cord, crack propagation

* Corresponding author. Tel.: /
E-mail address: robert.ulewicz@wz.pcz.pl

Cause analysis of the train drawhook fatigue failure

Robert Ulewicz[a,]* Frantisek Novy[b], Pavol Novak[b], Peter Palcek[b]

[a]*Czestochowa University of Technology, 42-201 Czestochowa, Poland*
[b]*University of Zilina, Department of Material Engineering, 01001 Zilina, Slovakia*

Abstract

The driving dynamics and braking effects in the railroad transport are constantly increasing, so it is necessary to take into account the fatigue resistance of the drawhooks. This article deals with the cause of the fatigue fracture of the drawhook of the coach. The broken drawhook had a pre-existing fatigue crack in the most critical part. In this case, the several factors contribute to the fatigue fracture of drawhook. The simulations performed using the FEM model showed that fatigue fracture occurred mainly due to non-compliance with the prescribed transition radius. The inadequate transient radius caused a high local stress concentration resulting in a premature initiation of the fatigue fracture. In addition, the results of other analyzes, i.e., chemical analysis, mechanical tests, metallographic and fractographic analysis, showed that fatigue fracture was significantly accelerated by the additional bending loading and the low toughness of the steel from which the hook was made.

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Keywords: fatigue fracture, fatigue resistance, FEM model

* Corresponding author. Tel.: /
E-mail: robert.ulewicz@wz.pcz.pl

Development of FEM model for residual stress calculations based on displacement field measurements near drilled hole

Barbara Romelczyk-Baishya[a,*], Tomasz Brynk[a]

[a]*Warsaw University of Technology, Warsaw, Poland*

Abstract

Residual stresses are very important from the point of view of research in the field of fracture mechanics, might be determined using inverse method calculations based on displacement fields measurements near drilled holes. Displacement fields are determined by means of noncontact optical methods such as Digital Image Correlation (DIC) or Electronic Speckle Pattern Interferometry (ESPI). Analytical model linking residual stress components with displacement fields, convenient for use in the inverse method calculations, is available only for the through hole case. However, some corrections may be introduced to analytical equations allowing their use also for blind hole cases which are more practical, especially when residual stresses have to be estimated in large constructions. Small blind hole drilling in large elements is considered as a nondestructive technique. In the paper Finite Element Method (FEM) model is described which was used for determination of correction terms for different hole geometry and for locations placed in different distances from the hole center for uniaxially loaded plates of different thickness. Elements' death technique has been applied for simulating material removal in holes locations. Obtained results were discussed and compared with available literature data. Finally, the general procedure of correction terms utilization in residual stress measurements was described.

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Keywords: FEM, residual stress, DIC, inverse method

* Corresponding author. Tel.: /
E-mail: barbara.romelczyk@inmat.pw.edu.pl

Analysis of causes of brittle fractures of locomotive drawhooks

František Nový[a], Michal Jambor[a,*], Trško Libor[a], Peter Palček[a], Otakar Bokůvka[a]

[a]University of Zilina, Department of Material Engineering, 01001 Zilina, Slovakia

Abstract

The traction force of the locomotives is constantly increasing due to the pulling of heavier trains, while the material of the drawhooks remained the same as 50 years ago. The use of the current UIC standards and the relevant national standards defining the methodology for testing the mechanical properties of the hooks is very problematic. Despite the fact that all material properties of the drawhooks tested according to UIC 825 and other related standards fully comply with the minimum values set by the standards, in operation, the unexpected failure occurs frequently. This article deals with causes of brittle fractures of locomotive drawhooks operated by Slovak Railways. An exemplary study uses a drawhook of a locomotive that broke when a freight train accelerated after stop at signal between two stations in the winter period at ambient air temperature of -2 ° C. The performed analysis showed that the brittle fracture of the drawhook was caused by the usage of the brittle steel with the coarsened microstructure. All experimentally measured material properties of a broken hook meet the limit specified in UIC 825 as the material testing at temperatures below +20 ° C is not required in that standard. This study shows that the only technical solution to the long-term persistent problem of brittle fractures of locomotive drawhooks, is to redefine their acceptance conditions and change the prescription for testing of the impact strength of the steels, from which the drawhooks are made of.

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Keywords: brittle fracture, locomotive drawhook, material testing

* Corresponding author. Tel.: /
E-mail michal.jambor@fstroj.uniza.sk

Molecular-dynamic investigation of the initial failure of the crystal structure at the external cyclic uniaxial extension

Igor Golovnev[a], Elena Golovneva[a,]*, Andrey Utkin[a]

[a]Kristianovich Institute of Theoretical and Applied Mechanics SB RAS, Novosibirsk 630090, Russia

Abstract

The paper deals with the molecular-dynamic simulation of the cyclic uniaxial tension of a nano-sized rod. The external action is described as follows: $V_X = V_0 \sin(\omega t)$. The criterion of the damage beginning (beginning of the crystal structure failure) has been found: there is the critical value of the atomic plane dispersion; as it is exceeded, irreversible changes occur in the nano-sized rod crystal structure.

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Keywords: nano-sized rod, cyclic loading, failure of crystal structure, damage accumulation, fracture, atomic plane dispersion, molecular dynamics simulation;

* Corresponding author. Tel.: +7-913-938-33-76; fax: +7-383-330-72-68.
E-mail address: elena@itam.nsc.ru

Analysis of the energy dissipation in multiaxial fatigue tests of AISI 304L stainless steel bars

Daniele Rigon[a], Vittoria Formilan[a], Giovanni Meneghetti[a,]*

[a]*University of Padova, Department of Industrial Engineering, via Venezia 1 – 35131 Padova, Italy*

Abstract

In the recent past, the specific heat loss per cycle (Q parameter) was used to synthesise in a single scatter band approximately 140 uniaxial fatigue test results obtained from constant amplitude, push-pull or torsional, stress- or strain-controlled fatigue tests on plain and notched AISI 304 L stainless steel specimens. It was also demonstrated that the Q parameter can be evaluated during a fatigue test by measuring the cooling gradient after a test stop at the hot spot region of the specimen surface. In the present contribution, the specific heat loss Q has been adopted for the first time to correlate the fatigue strength of AISI 304L specimens subjected to low-cycle multiaxial fatigue loadings. Completely reversed (R = -1) pure bending, pure torsion and combined bending and torsion tests were carried out on hourglass-plain specimens by using two servo hydraulic actuators. In-phase (ϕ = 0°) as well as out-phase (ϕ = 90°) multiaxial fatigue tests were performed by adopting two different biaxiality ratios. In addition, thin-walled tubular specimens were tested under completely reversed tension and torsion fatigue loadings for comparative purposes. Afterwards, all fatigue test results were expressed in term of specific heat loss and compared with the scatter band previously evaluated for plain and notched stainless-steel specimens subjected to uniaxial loading. In the LCF regime the scatter band relevant to uniaxial data correlated well the multiaxial fatigue data.

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Keywords: Multiaxial fatigue; Energy-based method; Thermal energy, AISI 304L

* Corresponding author. Tel.: +39 049 827 6751.
E-mail address: giovanni.meneghetti@unipd.it

Behavior determining of bucket wheel drive depending on the wear impact of the cutting elements

Filip Miletić[a], Predrag Jovančić[a,*], Svetan Djenadić[a]

[a]*Faculty of Mining and Geology, University of Belgrade, 11120 Belgrade, Serbia*

Abstract

The capacity of the rotor excavator depends largely on the operation of the subsystem for digging. There is a great contribution to the correct and sharp teeth when the capacity is the highest. In the function of time, the teeth become clogged due to abrasive wear, or changes in their geometric shape. Due to the toothed teeth, the resistance to digging also increases, and in this connection there is an increased load on the gear unit, and the whole construction of the subsystem of digging. Finally, this results in a change in the mode of operation of the excavator, there is a reduction in its capacity, which negatively affects the economic effects of production.

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Keywords: rotor excavator, bucket wheel drive, cutting elements

* Corresponding author. Tel.:
E-mail address: predrag.jovancic@rgf.bg.ac.rs

Chemical method of fatigue and corrosion fatigue crack growth arrest in steels by metal treatment with the special technological environment

Ya. Khaburskyi[a,*], H. Nykyforchyn[a]

[a]*Karpenko Physico-Mechanical Institute of the National Academy of Sciences of Ukraine, Lviv, 79060, Ukraine*

Abstract

Novel method of fatigue crack growth arrest in structural steels based on artificial creation of crack closure effect is proposed. Special technological environment is used which, falling into a crack cavity, forms solid products there. These products practically totally fill up a crack cavity and serve as a wedge which prevents crack closure during a period of unloading and, respectively, cyclic deformation in a crack tip.

Fatigue crack growth curves are built for low alloyed steel without and with crack treatment which demonstrate crack arrest in a wide range of stress intensity factor (SIF) ΔK, from the threshold level up to almost fatigue fracture toughness Kfc. i.e for the whole actual range of ΔK.

The peculiarity of artificial crack closure is accentuated: a decrease of effective ΔK is accompanied by an increase of a middle level of SIF therefore a risk of stress corrosion cracking and corrosion fatigue rises. This factor is especially important for long-term operated steels which lost their initial brittle fracture resistance.

The interaction of active components of the technological environment with a metal at the crack surface which provides formation of solid products in a crack cavity is analyzed. Some technological aspects for practical application of the proposed method are considered.

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Keywords: fetigue, corrosion fetigue, crack closure, crack growth arrest

* Corresponding author. Tel.: /
E-mail address: khabursky.yaroslav@gmail.com

Peculiarities of bond strength degradation in reinforced concrete induced by accelerated electrochemical methods

Myroslava Hredil[a,]*

[a]Karpenko Physico-Mechanical Institute of the National Academy of Sciences of Ukraine. 5 Naukova str., Lviv 79020, Ukraine

Abstract

Reinforced concrete (RC) structures are long-term operated objects with service life of 50–100 years. During their operation they subject to continuous ambient effects (cyclic temperature changes, acid rains, de-icing salts) and service loads (e.g. traffic) which effect on structural integrity of the composite and lead to worsening of structures serviceability. One of the reasons for strength loss of RC members is bond degradation between rebar and concrete. It could be caused by two different factors: overprotection of RC and reinforcement corrosion. These effects were simulated in the laboratory conditions by the electrochemical methods, applying of impressed cathodic current and accelerated corrosion tests respectively. It was shown that applied anode polarization causes not only concrete cracking due to internal pressure of corrosion products at the interface, but also due to their expansion far from rebar, for a distance comparative with a specimen thickness, evidently into preliminary formed cracks. Since intensive corrosion of steel reinforcement decreases its diameter and corrosion products can migrate from the rebar surface into a depth of concrete these factors could weaken bond in RC installations up to a total loss of cohesion between rebar and concrete. The influence of cathodic polarization of steel embedded in concrete is commonly seemed to consist in its possible hydrogen embrittlement and ions redistribution in concrete matrix. In this paper the effect of hydrogen recombined at the rebar–concrete interface on bond weakening and concrete cracking is considered.

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Keywords: reinforced concrete, accelerated corrosion, impressed current, hydrogen charging, bond strength.

* Corresponding author. Tel.: +380991939062; fax: +380322649427.
E-mail address: mysya@ipm.lviv.ua

Comparison between fatigue lives of AA5052 H-32 butt joints produced by FSW, GMAW and CW-GMAW

R.A. Ribeiroa[a], P.D.C. Assunção[a], V. Infante[b], A. Vilaça[c], G.P. Ciprinano[c], P.M.G.P. Moreira[d,*], D. Braga[d], E.M. Braga[a]

[a]*Laboratory of Characterization of Metallic Materials (LCAM), Federal University of Pará, Pará, Brazil*
[b]*LAETA, IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa*
[c]*Department of Mechanical Engineering, School of Engineering, Aalto University, Aalto, Finland*
[d]*INEGI, Campus da FEUP, Rua Dr. Roberto Frias, 400, 4200-465 Porto*

Abstract

The Friction Stir Welding (FSW) process enables good weldability of several materials sensible to fusion welding, which could induce porosity, cracking and dealloying, particularly, in some aluminum alloys. The Cold Wire Gas Metal Arc Welding (CW-GMAW) process was proposed in order to achieve welding with high deposition rate (kg/h), low heat input (kJ/mm) and avoiding undesirable effects, such as, distortion. This process is mainly characterized by the feeding of an extra cold (non-energized) wire into the weld pool. One important application of welding is the transport industry where nowadays the main challenge is to combine mechanical strength with lightness, allowing good energy efficiency and structural safety. Often, such structures are submitted to dynamic loads, which lead to fatigue related failures. The main target of this study is to compare the fatigue performance of 5 mm thickness aluminum alloy AA5052 H32 butt joints fabricated by FSW, GMAW and CW-GMAW processes based on similar heat input condition. The fatigue tests were carried out with constant amplitude loading and with a stress ratio (R) of 0.1. Metallurgical characterization was performed to assess the different zones resulting from each welding process, their size and influence on fatigue life. Moreover, Vickers microhardness measurements were carried out to correlate the fatigue performance with the microstructural features. The fatigue life and strength of the FSW specimens were significantly higher than the ones obtained from the electric arc welded specimens. Beside the fatigue S-N curves, a correlation was established between the cold wire fraction fed into the welding pool and the joints fatigue performance.

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Keywords: AA5052-H32, fatigue life tests, FSW, GMAW, CW-GMAW, microstructures, microhardness, fractography

* Corresponding author. Tel.: /
E-mail: pmoreira@inegi.up.pt

Evaluation of mechanical properties of polyethylene for pipes by energy approach during tensile and fatigue tests

G. Risitano[a,*], E. Guglielmino[a], D. Santonocito[a]

[a]*University of Messina, Department of Engineering, Contrada di Dio, 98166 Messina, Italy*

Abstract

Since its introduction in pipe applications more than 40 years ago, polyethylene (PE) has been taking a growing place in gas and water distribution due to its low cost, lightness and good corrosion resistance. Besides, long-term properties have been steadily rising due to the development of novel PE-based materials. The present highest standard is the PE100 class.
Several laboratory tests are used to extract design data for long-term failure-type prediction based on stress and time to failure relationship. It remains difficult to assess the relation between creep and fatigue loadings on the one side. On the other side, the manufacturing process of the test specimens influences considerably the obtained performance for viscoelastic materials subjected to working conditions.
In present paper, the mechanical properties of high-density polyethylene (HDPE), PE 100 class, for pipes were investigated using experimental techniques. Thermographic technique was used during the static tests in order to identify the maximum stress zone and also during the fatigue tests to study the temperature evolution of the specimen. The aim of this study is the application of the Thermographic Method for the fatigue assessment of PE100.

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Keywords: polyethylene; fatigue assessment; Thermographic Method.

* Corresponding author. Tel.: /
E-mail: grisitano@unime.it

Structural reliability analysis of corroded pipeline made in X60 steel based on M5 model tree algorithm and Monte Carlo simulation

Mohamed El Amine Ben Seghier[a,*], José A.F.O. Correia[b], Abílio De Jesus[b], Behrooz Keshtegar[c], Grzegorz Lesiuk[d]

[a] *Laboratory of Petroleum Equipment's Reliability and Materials, University M'hamed Bougara of Boumerdes Boumerdes, Algeria*
[b] *INEGI, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal*
[c] *Department of Civil Engineering, University of Zabol, P.B., Zabol, Iran*
[d] *Wroclaw University of Technology, Faculty of Mechanical Engineering, Wroclaw, Poland*

Abstract

Accurate determination of the failure probability of oil and gas pipeline is very important in integrity assessment and work conditions of such structure. The inspection results of an operational pipeline carrying gas for sevrel kilomiters made in X60 steel has reveal of multiple external corrosion defects. The Monte Carlo simulation have been extensively used to deal with this kind of problems. However, this method suffers from the expensive computational cost, especially for the small probability of failure. In this paper, the time-dependent reliability of a the pressurized gas pipeline containing external active corrosion defects has been evaluated using a new methodology which combining the M5 model tree algorithm and Monte Carlo simulation method. The burst failure mode is considered in this work, where the failure pressure in the limit state function is characterized using a probabilistic model.

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Keywords: Time-dependent reliability, corroded pipeline, M5 model, tree algorithm, X60 steel, external corrosion

* Corresponding author. Tel.: /
E-mail address: benseghier.ma@univ-boumerdes.dz

ECF22 - Loading and Environmental Effects on Structural Integrity

Fracture analysis of semi-circular bend (SCB) specimen: A numerical study based on meshless method

Farid Mehri Sofiani[a,]* Behzad V. Farahani[a], J. Belinha[b]

[a] FEUP, Faculty of Engineering, University of Porto, Dr. Roberto Frias Street, 4200-465, Porto
[b]INEGI, Institute of Science and Innovation in Mechanical and Industrial Engineering, Dr. Roberto Frias Street, Porto

Abstract

A variety of numerical analysis has been carried out by Finite Element Method (FEM), and Extended FEM (XFEM) on Semi-circular Bend (SCB) specimens to evaluate its material behavior, in particular fracture characterization. This work concentrates on calculating stress intensity factor (SIF) and strain energy release rate (G) on this specimen, assuming an elastic brittle behavior. In order to obtain the required variable fields, two advanced discretization techniques are addressed: the Radial Point Interpolation Method (RPIM) and the RPIM Natural Neighbor version (NNRPIM). In this work, peak load (Pmax) is assessed with both RPIM and NNRPIM and the corresponding results are compared with those obtained by XFEM. Furthermore, force-displacement curves of the SCB specimen are numerically implemented and the process from initiation to propagation is investigated, leading to produce a high accurate solution in comparison to the literature. Besides, the internal fields are monitored adjacent to the cracked area.

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Keywords: Fracture characterisation, LEFM, RPIM, NNRPIM, FEM, SIF

* Corresponding author. Tel.: /
E-mail address: up201600432@fe.up.pt

Development of numerical-experimental model of connecting lugs and application on the lugs calculation of container terminals

Đorđe Đurđević[a], Nina Anđelić[b,*], Taško Maneski[b], Vesna Milošević-Mitić[b], Ana Petrović[b], Andrijana Đurđević[a]

[a]*College of Applied Engineering Studies, 11000 Belgrade, Serbia*
[b]*Faculty of Mechanical Engineering, 11000 Belgrade, Serbia*

Abstract

The present paper describes numerical and experimental methodology and development of the model for stress and deformation state analysis of the connecting lug of container terminals. Numerical analysis was conducted by applying the finite element method in a "KOMIPS“ software package. Experiments were performed at the Laboratory for stress and deformation measurements, Faculty of Mechanical Engineering, Belgrade University, using "GOM“ equipment and "ARAMIS" software application. This paper demonstrates how it is possible to anticipate the results by applying FEM. This paper will present how experimental results can be predicted using the finite element method. The paper presents an overview of the existing research and review of previous results achieved in this field. Container terminal used to supply electrical energy and management system of conveyor belts that are used in the exploitation of the mining basins. Stress and deformation state analysis of the connecting lugs is carried out at the loading of the container.

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Keywords: connecting lug; FEM; experiment; stress; deformation

* Corresponding author. Tel.: /
E-mail address: nandjelic@mas.bg.ac.rs

Effects of welding technology on the occurrence of fracture in welded joints

Radomir Jovičić[a], Simon Sedmak[a,*], Radica Prokić Cvetković[b], Olivera Popović[b], Katarina Jovičić Bubalo[c], Nenad Milošević[b]

[a]*Innovation Centre of Faculty of Mechanical Engineering, 11120 Belgrade, Serbia*
[b]*Faculty of Mechanical Engineering, 11120 Belgrade, Serbia*
[c]*GOŠA Institute, 11000 Belgrade, Serbia*

Abstract

Welded joints represent locations where failure is most likely to occur in welded structures. Welded joint failure depends on their vulnerability to crack initiation and growth. These factors are significantly influenced by the welding technology. The effect of welding technology on the frequency of welded joint failure is complex, and has been thoroughly researched in literature. However, there are still numerous factors whose influence is not sufficiently explained. In this paper, the ratio of strength and plasticity of parent materials and weld metals on deformation properties of welded joint zones were analysed, along with the effects of groove edge temperature on cooling time in the heat affected zone and the effect of multiple defects on local stress increase.

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*Keywords:*welding technology, strength and plasticity, cooling time, welded joint defects

* Corresponding author. Tel.: +38162295496; fax: +0-000-000-0000 .
E-mail address:simon.sedmak@yahoo.com

An experimental study on failure of welded aerospace components

Ho-Sung Lee[a,*], Jung-Hoon Yoon[a], Joon-Tae Yoo[a]

[a]*Korea Aerospace Research Institute, Daejon, South Korea*

Abstract

There are many methods to weld sheets of materials to manufacture various aerospace components. In friction welding, high temperature can be obtained from the frictional heat induced from mechanical sliding or rotating motion between two materials. In diffusion welding, enough time is required to allow atomic diffusion at elevated temperature. Welding is obtained by applying heat, below the melting temperature of the materials and a microscopic force or pressure. Since these welding technologies are formed without liquid phases, the interface is homogeneous and hence mechanical properties and microstructure at the welded region show better properties than fusion welding.
In this study, an experimental investigation of the failure of aerospace components welded with various welding methods is presented. Welding methods include friction stir welding, laser beam welding, diffusion welding and electron beam welding. The comparison of failure behavior is presented for aluminum, titanium, superalloy and stainless steel for different welding methods. It is shown that solid state welding is an attractive method to weld materials without melting where mechanical properties and microstructurally homogeneous joining are important. Examples of failure of welded structure in aerospace components are also included.

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Keywords: Fracture, welding, aerospace, Friction Stir Welding, diffusion welding, microstructure

* Corresponding author. Tel.: /
E-mail address: hslee@kari.re.kr

Change of magnetic properties in austenitic stainless steels due to plastic deformation

Tatiana Oršulová[a,*], Peter Palček[a], Marek Roszak[b], Milan Uhríčik[a], Milan Smetana[a], Jozef Kúdelčík[a]

[a]*Faculty of Mechanical Engineering & Faculty of Electrical Engineering, University of Žilina, Univerzitná 8215/1, 010 26 Žilina, Slovak Republic*
[b]*Institute of Engineering Materials and Biomaterials, Silesian University of Technology, Konarskiego 18a St, 44-100 Gliwice, Poland*

Abstract

The austenitic stainless steels, investigated in this research, are widely used in different fields of industry. Investigated materials belong into a group of the so-called high-alloy TRIP (Transformation Induced Plasticity) steels. The nondestructive evaluation (NDE) methods were used for determination of plastic deformation influence in investigated materials. The NDE methods permit products to be inspected throughout their service life, to determine when to repair or replace a particular part. The main goal of this study was to measure and thus separate different levels of applied plastic deformation of selected conductive biomaterials. Two different devices were used to evaluate the effect of plastic deformation. The first device was commercially available magnetic field sensor GF708. The second device was Magnet Physik, on which is possible to determine magnetic quantities (remanence, coercivity), make measurements with surrounding coils to determine the magnetic mean values and measure at temperatures up to 200 °C. Both of those devices are suitable for measuring the magnetic properties. Effect of plastic deformation was observed by the light microscope, as well.

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Keywords: nondestructive evaluation; magnetic properties; plastic deformation; austenitic stainless steels

* Corresponding author. Tel.: +421-41-513-2632.
E-mail address: tatiana.orsulova@fstroj.uniza.sk

Theoretical prediction of fracture of initially crack-free brittle materials

Fuzuli Ağrı Akçay[a,*]

[a]*İstanbul Teknik Üniversitesi Gemi İnşaatı ve Deniz Bilimleri Fakültesi, Maslak, İstanbul 34469, Turkey*

Abstract

Accurate determination of failure is crucial for designing engineering structures as their failure may cause not only economic loss but also loss of human life. Brittle fracture is a type of material failure, and literature on brittle fracture mainly focuses on fracture of bodies with pre-existing crack. In this study, however, a new brittle fracture criterion (of tensile mode) that is applicable at quasi-static loading conditions is proposed for initially crack-free bodies. The fracture criterion is based on the continuum modeling of energy release rates and it is developed using Karr-Akçay energy balance concept. The criterion can be implemented to determine (Mode I) fracture toughness of a material as well as (fracture) strength of a material if its characteristic length is known, whereas the characteristic length of a material can be obtained (using the proposed criterion) if its (fracture) strength is known. Tensile strength of a gray cast iron is determined using the proposed criterion and compared to the results in the literature. Theoretical result is in good agreement with the experimental result published in the open literature.

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Keywords: Brittle fracture; Strength; Characteristic length; Energy release rates

* Corresponding author.
E-mail address: akcayfu@umich.edu

Determining material's equivalent stress-strain curve with axisymmetric notched tensile specimen

Shengwen Tu[a], Xiaobo Ren[b], Jianying He[a], Zhiliang Zhang[a,]*

[a]*Norwegian University of Science and Technology, Trondheim, Norway*
[b]*SINTEF Materials and Chemistry, Trondheim, Norway*

Abstract

Large deformation analyses of problems such as plastic forming, ductile fracture with finite element method need a full range of material's equivalent stress-strain curve or flow stress-strain curve. The equivalent stress-strain curve determined from the smooth round bar specimen should be corrected after diffuse necking, since tri-axial stress state occurs in the neck. The well-known Bridgman correction method is a candidate, however, it is not accurate with the increase of the strain. Furthermore, it is impossible to measure the equivalent stress-strain curve of each individual material zone in a weldment with cross weld tensile tests, due to the inhomogeneous and mismatch of weldment. To cope with these challenges, a correction function and an associated test procedure are proposed in this study. With the proposed procedure, the true stress-strain curve from any axisymmetric notched tensile specimens can be converted to the material's equivalent stress-strain curve accurately and no Bridgman correction is needed. The proposed procedure can be applied to both perfectly plastic and strain hardening materials. The equivalent stress-strain curve of each individual material zone in a weldment can also be measured with the proposed procedure.

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Keywords: Equivalent stress-strain curve, notched tensile specimen, weldment, bridgman correction

* Correspinding author. Tel.: /
E-mail: zhiliang.zhang@ntnu.no

Advanced model of chloride penetration considering concrete heterogeneity

Tuan Duc Le[a,b], Petr Lehner[b], Petr Konečný[b,]*

[a] *Saigon Technology University, Faculty of Civil Engineering, 180 Cao Lo Str., Ward 4, Dist. 8, HCMC 700000, Vietnam*
[b] *VSB-Technical University of Ostrava, Faculty of Civil Engineering, Department of Structural Mechanics, Ludvíka Podéště 1875/17, 708 33 Ostrava-Poruba, Czech Republic*

Abstract

This paper is aimed at 2D chloride ingress modelling of reinforced concrete structures with respect to concrete heterogeneity. The spatial variation of concrete ability to resist the ingress of chloride along the studied area may allow for a more realistic description of concrete aggregate and matrix effect. Time dependent chloride concentration at reinforcement level in both homogeneous and heterogeneous models was comparatively considered. Combination of random fields and 2nd Ficks Law based diffusion model through finite element method seems to be a promising approach and this mergence was preliminarily evaluated.

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Keywords: Chloride penetration; concrete heterogeneity; random fields; 2D diffusion model; correlation length; spatial variation.

* Corresponding author.Tel.; /
E-mail address: petr.konecny@vsb.cz

Numerical simulation of fatigue crack growth in straight lugs equipped with efficient structural health monitoring

Marc Moonens[a,*], Eric Wyart[b], Michael Hinderdael[a], Dieter De Baere[a], Patrick Guillaume[a]

[a]*Mechanical Engineering Department, Vrije Universiteit Brussel, Pleinlaan 2, 1050 Brussels, Belgium*
[b]*Cenaero ASBL, Rue des fr`eres Wright 29, 6041 Gosselies, Belgium*

Abstract

This paper addresses the influence of the efficient Structural Health Monitoring system (eSHM) on the fatigue life of straight lug components. The eSHM system is a mechanical fatigue crack detection system developed at the Vrije Universiteit Brussel (VUB). It consists in integrating pressurized capillaries into the to-be-monitored component, so that when a fatigue crack breaches the capillary network, a leak flow is created, and the pressure equilibration between the capillary and the open atmosphere is detected by a pressure sensor. The system is therefore aimed for additively manufactured structures. In this paper, one considered the example of straight lugs, quite common in aeronautical structures and well documented in the literature, to assess whether fitting the lug with the eSHM would significantly influence the fatigue crack growth behavior. Therefore, comparisons are made between lugs not equipped with the eSHM and lugs with integrated capillaries, both with identical initial defect. The aim is to determine whether the capillaries have a significant influence on the number of cycles to failure. The evaluation of this influence will be done by numerical computations using the eXtended Finite Elements Method (XFEM). In particular, the computations will be done on the Morfeo software developed by Cenaero. Conclusions from this research will serve as basis for sound implementation of the crack detection system on industrial components. Indeed, the system has to offer a quick detection of the propagating fatigue crack (by being placed as close as possible to the most probable initiation region) while not affecting the component's life (the capillary should not initiate a defect nor reduce the crack growth life of the lug)

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Keywords: efficient structural health monitoring(eSHM); fatigue crack growth; XFEM; straight lug

* Corresponding author. Tel.: +32 2 629 23 24
E-mail address: marc.moonens@vub.be

An improved K_I expression for a semi-elliptical surface crack in a finite plate subjected to uniform tension

Yinghao Dong[a], Xiaofan He[a,*], Yuhai Li[a]

[a]*School of Aeronautic Science and Engineering, Beihang University, Beijing 100191, China*

Abstract

Newman-Raju solution for a surface cracked plate under uniform tension has been widely used in surface crack-related problems. However, comparisons of Newman-Raju solution with numerical stress intensity factor (K_I) solutions indicated the accuracy of Newman-Raju solution at the depth point inferior to that at the surface point. Therefore, we feel there is a need to improve the accuracy of Newman-Raju solution. With the domain integral method provided by ABAQUS, numerical K_I solutions with high accuracy were obtained for a large number of surface crack configurations. By fitting assumed functions to the numerical results, a K_I expression was developed for a surface cracked finite plate subjected to uniform tension. The proposed expression can be used to determine K_I at an arbitrary point on the crack front. A detailed analysis was conducted on the accuracy of the K_I expression, with two application ranges respectively allowing for accuracy better than 3% and 5% provided. The K_I expression yields better accuracy than Newman-Raju solution within the application ranges that cover most surface crack configurations occurring in practice, and the accuracy of Newman-Raju solution at the crack depth point has been substantially improved.

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Keywords: surface crack, stress intensity factor, uniform tension, finite element method, curve fitting method

* Corresponding author. Tel.: +86(10) 82315738.
E-mail address: buaa_he@hotmail.com (X. He)

Understanding the tensile strength of ceramics in the presence of small critical flaws

Eric Martin[a,*], Dominique Leguillon[b], Olda Sevecek[c], Raul Bermejo[d]

[a] *Laboratoire des Composites Thermo-Structuraux, Université de Bordeaux, Bordeaux, France*
[b] *Institut Jean Le Rond d'Alembert, Sorbonne Université, Paris, France*
[c] *Institute of Solid Mechanics, Faculty of Mechanical Engineering, Brno University of Technology, Brno, Czech Republic*
[d] *Institut fuer Struktur- und Funktionskeramik, Montanuniversitaet Leoben, Leoben, Austria*

Abstract

The strength of ceramics is sensitive to the presence of flaws which act as crack initiators. Common flaws are spherical pores generated during the elaboration phase and sharp defects introduced by surface machining. Influence of such flaws on the ceramic strength is usually assessed by estimating an equivalent crack length to apply the Griffith criterion. For a blunt defect like a pore, the presence of a small crack with a given length is postulated in the vicinity of the defect.
The objective of this paper is to analyze the effect of a small flaw on the strength of polycrystalline ceramic materials. For this purpose, a coupled criterion is used to describe the initiation of a crack near a stress concentrator. The advantage of this finite fracture mechanics approach is that the critical stress can be easily determined without requiring any assumption concerning the crack length at the initiation. We focus on surface flaws which are considered to be the critical ones. Both a blunt and a sharp geometry are studied. The initiation criterion combines a stress and an energy condition. The required input fracture-mechanics parameters are the tensile strength and the fracture toughness. Based upon these data, the coupled criterion introduces a characteristic length L. Numerical predictions reveal the expected strength decrease with the increasing defect size. It is not possible to distinguish strength values predicted on a sharp geometry and on a blunt one for a defect size smaller than 0.5L. Furthermore, if the defect size is less than 0.1L, the defect can be ignored and the strength reaches a plateau corresponding to the intrinsic strength. Those results are in a good agreement with strength values measured experimentally on ceramic materials with controlled flaws. It is also shown that combining two fracture tests after introducing flaws with controlled sizes allows to identify the fracture parameters.

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Keywords: Crack nucleation, coupled criterion, brittle fracture, ceramics

* Corresponding author. Tel.: /
E-mail address: martin@lcts.u-bordeaux.fr

Functional and structural fatigue of pseudoelastic NiTi shape memory

Petro Yasniy[a], Volodymyr Iasnii[a,*], Yura Lapusta[b], Oleksandr Kononchuk[a]

[a]*Ternopil National Ivan Puluj Technical University, 46001 Ternopil, Ukraine*
[b]*SIGMA Clermont, 63178 Aubiere, France*

Abstract

Some shape memory alloys like Nitinol present high damping property. Two key factors for successfully using these materials as dampers for structures are superelasticity and energy dissipation through hysteretic behaviour.
The influence of stress ratio on functional and structural fatigue of pseudoelastic NiTi shape memory alloys at uniform loading was studied. Main attention was paid to the effects of cyclic load on the stress-strain hysteresis. The material used in this study was a wire with a diameter of 1.5 mm of NiTi alloy with 55.8 % Ni. The material was received from Wuxi Xinxinglai Steel Trade Co., Ltd. The experiments were performed for wire using loading - unloading uniform cycle at frequencies 0.5 Hz and room temperature, which is higher than the temperature of the transformation Af. The transformation temperature was obtained by differential scanning calorimetry measurements. The characteristic features of fatigue failure were studied using scanning electron microscopy.
The damping properties of NiTi wires is studied by considering energy dissipation and loss factor. With increasing number of load cycles, the damping capacity at difference stress ratio is reduced. The main regularities of load cycles influence on Young's modulus of the austenite and the martensite are shown. To describe the structural fatigue of the SMA stress, strain and energy approaches are used. The obtained results allow the better understanding of structural and functional fatigue in damping applications.

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Keywords: shape memory alloys, damping capacity, functional fatigue, structural fatigue, stress-strain hysteresis

* Corresponding author. Tel.: /
E-mail address: petroyasniy@gmail.com

Experimental study of mechanical properties of steel 40Cr in the necking area of specimen during the postcritical deformation

M.P. Tretyakov[a,*], M.P. Tretyakov[a], V.E. Wildemann[a]

[a]*Center of Experimental Mechanics, Perm National Research Polytechnic University, 29 Komsomolskiy Ave., Perm, 614990, Russia*

Abstract

The work is devoted to the experimental study of the evolution of mechanical properties of the structural steel 40Cr during postcritical deformation of solid cylindrical specimens in conditions of strain localization formation in the form of neck at tension. The methodical issues of providing tests by 'specimen from specimen' scheme are observed. Different levels of preliminary postcritical deformation of initial samples are realized, and the results of testing specimens cut from the initial samples with a neck are obtained. To measure the displacement and strain fields in the gauge length of specimens with the neck the noncontact 3D video system Vic 3D, based on the digital images correlation technique, was used. On the base of test results, the stiffness and strength of steel 40Cr were evaluated in a necked specimen at various stages of postcritical deformation. The hardness distribution on the specimen after necking was analyzed too. It is shown that the material in the peripheral areas of the gauge length of the sample is in a strengthened state, which does not depend on the degree of previously achieved postcritical deformation, and the strength of the material in the neck-forming zone on the initial specimens is thereby increased.

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Keywords: Experimental mechanics, postcritical deformation stage, tension, strain localization, necking effect, hardness, digital image correlation.

* Corresponding author. Tel.: +7-342-239-1111; fax: +7-342-239-1224.
E-mail address: cem_tretyakov@mail.ru

Analytical limit load predictions in heterogeneous welded Single Edge notched Tension (SE(T)) specimens

Sameera Naib[a,*], Wim De Waele[a], Primož Štefane[b], Nenad Gubeljak[b], Stijn Hertelé[a]

[a]*Soete Laboratory, Dept. of EEMMeCS, Ghent University, Belgium*
[b]*Faculty of Mechanical Engineering, University of Maribor, Slovenia*

Abstract

The integrity assessment of defected welds is dependent on accurate estimations of their load carrying capacity. As welds consist of variable microstructures, a large degree of heterogeneity is to be expected. The variation of constitutive properties within the weld influences the deformation patterns around the crack and, as a consequence, the load bearing capacity of the joint. Constitutive heterogeneity is simplified in standardized assessments in order to facilitate the analysis and reduce the complexity of its required input. However, these weld simplifications may lead to inaccurate assessments with unknown errors. This motivates the work of the authors, which aims to include the effects of weld heterogeneity into integrity assessment procedures. The presented paper focuses on the prediction of limit load, which allows to calculate the structure's proximity to plastic collapse. Simplified theorems have been developed to identify lower and upper bound values of limit load. This work explores the predictive accuracy of various methods to estimate the limit load of heterogeneous welds, including lower and upper bound theorems. A parametric study involves 2D plane strain simulations of single-edge notched tension (SE(T)) specimens. Welds consisting of two regions of different material properties (at the root and at the cap) are introduced. The obtained estimations of limit load are then compared against the simulated limit loads.

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Keywords: Weld heterogeneity; SE(T); Limit loads; upper and lower bound; slip lines

* Corresponding author. Tel.: /.
E-mail address: sameera.naib@ugent.be

Comparison of tensile behaviour of polypropylene, aramid and carbon fibre reinforced cementitious composite at high strain rate loading

Martina Drdlová[a,*], René Čechmánek[a]

[a]*Research Institute for Building Materials, Hnevkovskeho 65, Brno, 61700, Czech Republic*

Abstract

This paper presents an experimental study on uniaxial mechanical properties of polypropylene, aramid and carbon micro-fibre reinforced high performance cementitious composite subjected to both static and high strain rate tensile loading. This cementitious composite is intended to be used as a matrix for slurry infiltrated fibre concrete, which is being developed to be used for elements and structures for blast, ballistic and other impact protection. Cylindrical specimens of 30 mm diameter and 15 mm thickness were subjected to the indirect tensile (Brazilian) test at loading rate about 5.10-5 $GPa.s^{-1}$ (quasi-static load regime) and 2.103 $GPa.s^{-1}$ (high strain rate load regime). Specimens were tested using servo hydraulic press machine and 15 mm diameter Split Hopkinson pressure bar. Dynamic strength increase factor and fibre reinforcement factor have been studied versus both strain-rate and fibre type. Indirect tensile strength and post peak behaviour vary for specimens with different micro-fibre reinforcement, which allows to find the optimal reinforcement for high strain rate impacted concrete structures.

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Keywords: Cementitious composite; fibre; concrete; SHPB; Split Hopkinson Pressure Bar; Brazilian test; indirect tensile strength, high strain rate

* Corresponding author. Tel.: +420-608-620-953; fax: +420-543-216-029
E-mail address: drdlova@vustah.cz

Influence of additional vibration impact on kinetics of strain bands due to the Chernov-Lüders deformation and Portevin-Le Chatelier effect in metals

Tatyana Tretyakova[a,*], Ekaterina Zubova[a]

[a]*Centre of Experimental Mechanics, Perm National Research Polytechnic University, 29 Komsomolsky AVE, Perm 614990, Russia*

Abstract

The aim of the work is to investigate the influence of additional vibration impact on spatial-time inhomogeneity of plastic flow due to the Chernov-Lüders deformation and Portevin-Le Chatelier effect in metals (carbon steel and Al-Mg alloy) during uniaxial tension tests. Experimental data were obtained (diagrams, evolution of strain fields and local deformation rates, temperature fields, AE parameters) characterizing the kinetics of the strain bands initiation and propagation. The evolution of inhomogeneous strain and temperature fields were analyzed by using the digital image correlation technique and the infrared thermography accordingly. The mechanical behavior and the regularities of the jerky flow were studied using analysis of stress serrations and the accompanying acoustic emission.

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Keywords: jerky flow; strain band; digital image correlation; thermography; acoustic emission; additional vibration impact.

* Corresponding author. Tel.: +7-912-499-59-60; fax: +7-342-219-8732.
E-mail address: cem.tretyakova@gmail.com

Decreasing bridge member´s resistance due to reinforcement corrosion

Miroslav Strieška[a,*], Peter Koteš[a], Aleksandar Sedmak[b]

[a]*University of Žilina, Department of Structures and Bridges, Univerzitná 8215/1, 01026 Žilina, Slovakia*
[b]*University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11,000 Belgrade, Serbia*

Abstract

The traffic infrastructure is very important for the economy, people and progress of the country. The infrastructure consists of numerous structures and their structural members like bridges, abutments, piers, rails, guard-rails etc. This constructions are very loaded by surrounding environment. Aggressiveness of this environment is different in various areas in Slovak republic due to morphology of terrain, which causes the different corrosion depth in those areas. This corrosion depth can be calculated by standard ISO 9223, describing the calculation of the corrosion rate r_{corr} for the first-year and the standard ISO 9224 describe the estimation of the corrosion rate D for the following years. The input parameters for these calculation are sulphur dioxide SO_2, chloride ions Cl^-, temperature T and relative humidity Rh measured by Slovak Hydrometeorological Institute (SHMÚ). The article is focused on the determining load-carrying capacity of reinforced concrete (RC) bridges changing in time due to corrosion of the reinforcement diameter. This information can be very useful not only for the design of the new bridge construction, but also for the estimation of the remaining lifetime of the existing structure.

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Keywords: Traffic infrastructure, bridge, environment, corrosion rate, reinforcement, concrete

* Corresponding author. Tel.: +421-41-513-5663; fax: +421-41-513-5690.
E-mail address: miroslav.strieska@fstav.uniza.sk

3D Stress fields versus void distributions ahead of a notch tip for semi-crystalline polymers

L. Laiarinandrasana[a,*], N. Selles[a], Y. Cheng[b] , L. Helfen[b,c], T.F. Morgeneyer[a]

[a]*PSL-Research University, MINES ParisTech, MAT-Centre des Mat´eriaux, CNRS UMR7633, BP 87, F-91003 Evry Cedex, France*
[b]*European Synchrotron Radiation Facility (ESRF), BP 220, F-38043 Grenoble Cedex, France*
[c]*Institute for Photon Science and Synchrotron Radiation (IPS), Karlsruhe Institute of Technology (KIT), D-76344 Eggenstein-Leopoldshafen, Germany*

Abstract

The creep durability of engineering structures relies on the theory of Fracture Mechanics for Creeping Solids (FMCS). The studied material is a semi-crystalline polymer. The lifespan of plastic pipes being generally specified in terms of years of service, its prediction requires reliable constitutive models accounting for time dependent deformation under multiaxial stress states and failure criteria based on the mechanisms of damage and failure. Here, an experimental approach was developed so as to analyze the mechanisms of deformation and cavitation at the microstructural scale by using 3D imaging (tomography/laminography). Three stress triaxiality ratios were addressed using various notched specimen geometries. The void characteristic dimensions (volume fraction, height and diameter) were then measured by defining a volume of interest. The spatial distributions of these characteristics at a prescribed creep time were observed to be dependent on the stress triaxiality ratio. A finite element constitutive model using the porosity as an internal variable, was selected. Comparison of the multiscale experimental database with those simulated at the macroscopic scale as well as at the microstructure level was satisfactory. In the light of the finite element results, the principal stress singularities were in good agreement with the void characteristic lengths.

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Keywords: Semi-cristalline polymers, Fracture Mechanics for Creeping Solids, Notch tip, stress triaxiality

* Corresponding author. Tel.: +33-1-60-76-30-64; fax: +33-1-60-76-31-50.
E-mail address: lucien.laiarinandrasana@mines-paristech.fr

Environmentally assisted fatigue cracking from corrosion pits in oil and gas pipelines

Farnoosh Farhad[a,b,c,*], Xiang Zhang[a], David Smyth-Boyle[b]

[a]Coventry University, Coventry, United Kingdom
[b]TWI Ltd., Cambridge, United Kingdom
[c]NSIRC Ltd., Cambridge, United Kingdom

Abstract

Due to the enormous demand for energy worldwide, the network of oil and gas pipelines is growing and this emphasises the need for research into the structural integrity of pipelines. Corrosion pits are a form of localized corrosion that can jeopardize the service life of pipelines. Pipes are typically subjected to cyclic loading and the internal surfaces are often exposed to sour corrosive environments. Fatigue cracking initiated from corrosion pits has been identified as one of the predominant failure mechanisms in pipeline steels in a sour environment, which causes rupture of the entire oil and gas transmission pipe, with potentially serious environmental and commercial consequences and risk to life. The purpose of this work is to assess the effect of corrosion pit sizes on the fatigue cracking mechanism of X65 steel pipelines exposed to 3.5% NaCl solution saturated with a gas mixture of 12.5% H2S in balance CO2 at ambient pressure and room temperature. Understanding this mechanism helps to improve the available corrosion fatigue life prediction models and eventually optimising the inspection and repair schedule in oil and gas pipelines. All the corrosion fatigue tests were undertaken using a bespoke environmental vessel. Prior to the start of the corrosion fatigue tests, the samples were pre-pitted using an electrochemical method creating a corrosion pit of desired dimensions. Examination of fracture surfaces by Scanning Electron Microscopy (SEM) was carried out and the location of crack initiation in the pre-pitted samples was assessed. Also, the effect of stress level on the fatigue fracture characteristics was studied.

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Keywords: corrosion fatigue, environmental effect, corrosion pitting, toxic sour environment, pit-to-crack

* Corresponding author. Tel.: /
E-mail address: farhadf@uni.coventry.ac.uk

Analysis of the statistical size effect model with a critical volume in the range of high-cycle fatigue

Tomasz Tomaszewski[a,*]

[a]*Institute of Mechanical Engineering, University of Science and Technology, 85-789 Bydgoszcz, Poland*

Abstract

The size effect defined as a relationship between strength properties of the material and specimen cross-section. The study analyses the statistical size effect model with a critical volume. The method is commonly used for objects with different size, including notched specimens and in the bending load tests. The purpose of the study was to verify the size effect model allowing for the loads with gradient and statistically distributed material defects. The analysis model relates the fatigue properties to the material volume. This volume depends on the geometrical dimensions and the specimen volume. For fatigue tests, stress at the specimen surface can be considered a deterministic value defined by the distribution of random variable of failure probability. Fatigue strength is determined for the critical volume at assumed probability. The analyses were carried out for material susceptible to the size effect (acid-resistance steel 1.4301). The tested specimens included a reference specimen and a minispecimen. The selected statistical model was implemented for the experimental data obtained in a high-cycle fatigue range. The method allows to estimate the σ_a-N characteristic other than determined experimentally. The model was implemented for a minispecimen. σ_a-N characteristic for the reference specimen was estimated based on the model.

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Keywords: minispecimen; stainless steel; analitical model; size effect

* Corresponding author. Tel.. /
E-mail address: tomaszewski@utp.edu.pl

Fatigue behaviour of additively manufactured Inconel 718 produced by selective laser melting

K. Solberg[a,]*, J. Torgersen[a], F. Berto[a]

[a]Norwegian University of Science and Technology, Richard Birkelandsvei 2b, 7034 Trondheim, Norway

Abstract

Selective Laser Melted (SLM) Inconel 718 has promising use in various applications, where complex design and excellent strength is required. Yet fatigue properties of respective components in critical load bearing applications are yet poorly understood. Here, we investigate the fatigue behaviour of different notch geometries of as-build specimens at room temperature. The fatigue strength of semi-circular and v-shaped notch geometries are evaluated and the results compared with those of smooth specimens. The stress fields of the different geometries are analysed by use of analytical models and numerically by use of finite element. The fatigue data shows a smaller scatter in the geometries with printed overhangs than the ones without. High values of notch sensitivity is obtained for both notch geometries. Fatigue properties of AM Inconel 718 are so far underexplored, this research therefore adds to the applicability of this material and manufacturing method for load bearing applications.

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Keywords: Fatigue, Additive Manufacturing, Inconel 718, Notch, Elastic Stress Fields

* Corresponding author. Tel.: +47 975 00 723.
E-mail address: klas.solberg@ntnu.no

Implications of substrate geometry and coating thickness on the cracking resistance of polymer-based protective coatings

L.A. Wray[a,*], D. Ayre[a], P.E. Irving[a], P.A. Jackson[b], P.R. Jones[c], F. Zhao[c]

[a]*School of Aerospace, Transport and Manufacturing, Cranfield University, UK*
[b]*AkzoNobel Paints and Coatings, Felling, UK;*
[c] *AkzoNobel Marine, Protective and Yacht Coatings, Felling, UK*

Abstract

Welded steel T-sections of different weld fillet geometries coated with water ballast tank protective coatings were subjected to thermal cycling with a temperature range from 60°C to -10°C. Cracks developed in the coatings at the weld line, propagating longitudinally along it. The number of cycles required to create 1 mm cracks was strongly dependent on the weld geometry and the coating Dry Film Thickness (DFT). Finite Element Modelling (FEM) was employed to calculate thermally induced strain fields in the coatings subjected to the same temperature range.
FEM predicted that the greatest strain concentrations are present at the coating surface within the weld fillet region. Increased DFT and decreased fillet radius leads to increased maximum principal strains. Numerical analysis predicts that greatest strain ranges promoting the earliest cracking/failure are found in thicker coatings applied to smaller weld radii. Experimental observations confirm this.

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Keywords: Coatings; Thermal Strains; Fatigue; FEM Analysis; Cracking Failure; Coating Life

* Corresponding author. Tel.: /
E-mail: lesley-anne.wray@cranfield.ac.uk

Calculation of size independent fracture energy of concrete

Deepak Sutar[a,*], Sonalisa Ray[a]

[a]*IIT Roorkee, Roorkee, Uttarakhand, India*

Abstract

Calculation of fracture energy of concrete plays an important role in understanding the fracture behavior. Past researches have found out that the existence of size effect in fracture energy in concrete is due to the presence of a non-linear micro-cracks zone, called Fracture process zone. Development of Fracture process zone (FPZ) and Fracture Crack Zone (FCZ) are two regions where most of the energy gets dissipated. FCZ is the zone of interconnected micro-cracks which finally meet to form a real crack. Thus, calculation of size independent fracture energy of concrete demands for accurate and clear understanding of FPZ and FCZ produced. In this research work, geometrically similar beams of three different sizes with a fixed notch/depth ratio have been prepared and tested under crack mouth opening displacement control manner. Digital images have been captured and stored in digital form during the entire test and Digital Image Correlation (DIC) technique has been used to calculate the strain data of the beam. Using strain data; length, width and various parameters of FPZ and FCZ have been calculated at varying loads. From the dimensions of FPZ and FCZ, fracture energy has been calculated using calculated fracture volume incorporating proper distribution of energy in the FPZ and FCZ zones and a new parameter for crack length and meandering area. Of the total energy dissipated in cracked zone, 70% of the energy has been assumed to be dissipated in FCZ and 25% in FPZ. Calculated Fracture energy has been compared with Size independent fracture energy from Bazant's size effect law and RILEM method.

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Keywords: Fracture energy, size effect, fracture process zone, fracture crack zone, DIC

* Corresponding author. Tel.: /
E-mail: deepaksuthariitr97@gmail.com

Stable crack growth in Al-Cu-Mg alloy under various stiffness of loading system in bodies with concentrators

Tatyana Tretyakova[a,]*, Mikhail Tretyakov[a], Valery Wildemann[a]

[a]*Centre of Experimental Mechanics, Perm National Research Polytechnic University, 29 Komsomolsky AVE, Perm 614990, Russia*

Abstract

In the present work, the influence of the stiffness of the loading system on regularities of inelastic behavior and on processes of the equilibrium crack growth during uniaxial tension in bodies with stress concentrators was studied. Flat specimens (Al-Cu-Mg alloy) with a center notch and initial fatigue crack were extended with a biaxial servo-hydraulic testing system Instron 8850 at room temperature. The mechanical tests were complemented by a digital image correlation (DIC) and an infrared thermography. By using the 3D DIC-measurement system Vic-3D and the software module 'virtual extensometer', it was possible to evaluate the crack opening value, to analyze the evolution of heterogeneous strain fields during the initiation and propagation of cracks. It was revealed that with increasing stiffness of the loading system (by decreasing the gauge length of specimens), the realization of the stable postcritical deformation stage is increasing as well as the inhomogeneity of plastic flow and temperature in the crack tip.

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Keywords: digital image correlation; ifrared analysis; stress concentrator; crack; stiffness of loading system; failure.

* Corresponding author. Tel.: +7-912-499-59-60; fax: +7-342-219-8732.
E-mail address: cem.tretyakova@gmail.com

Methods for characterization of fresh and hardened state of fibre concrete

René Čechmánek[a,*], Vladan Prachař[a], Martina Drdlová[a], Martin Boháč[a]

[a]Research Institute for Building Materials, Hněvkovského 30/65, Brno 61700, Czech Republic

Abstract

Design, preparation and testing of fibre-cement composites are a task of wide range of research workplaces and universities in our country and abroad. However, a question on homogeneity of all cement matrix components and mainly optimal dispersion of fibre reinforcement in a mixture has not been yet solved sufficiently. A research team from the Research Institute for Building Materials has designed new experimental devices for the Discovery Hybrid Rheometer to measure rheological properties of fresh cement-based mixtures. The aim of research works was to find suitable homogenization techniques, design of mixing process and optimal dosing of individual components. By means of these actions it is possible to achieve the best dispersion of selected fibre types in fine-grained cementitious matrixes, which is subsequently verified in hardened composites at first by non-destructive and then by destructive methods. At the first stage non-destructive testing by means of ultrasound waves was carried out at first on a compact test slab with dimensions 500 × 500 × 40 mm and subsequently on individual test specimens with dimensions 250 × 40 × 40 mm, cut from the test slab according to a designed pattern. At the second stage destructive testing of test specimens was performed, mainly evaluation of flexural strength with 4-point bending and subsequently preparation of thin sections from the failure area for observation by means of polarizing microscopy to assess their structural integrity. The aim of research works was to find a method for monitoring homogeneity of cement composites reinforced with both metal and non-metal fibres before being subjected to mechanical loading.

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Keywords: fibre concrete; homogeneity; rheology; polarizing microscopy; destructive and non-destructive methods

* Corresponding author. Tel.: +420-602-445-343; fax: +420-543-216-029.
E-mail address: cechmanek@vustah.cz

Modelling approach for predicting crack initiation at forging defects

Ali Aydin[a,]*, Igor Varfolomeev[a], Crhistian Amann[a]

[a]*Fraunhofer IWM, 79018 Freiburg*

Abstract

Depending on the type of manufacturing defects, the risk of fracture initiation can be considerably overestimated if the defects are treated as sharp initial cracks. In particular, a substantial increase of the design lifetime of forged components can be achieved by both experimental and numerical analyses provided that the phase of crack initiation from a defect field is taken into account. While the respective tests are much cost and time consuming, numerical modelling is regarded as an efficient way facilitating the design and fitness-for-service assessment of components with manufacturing defects. In this paper, several aspects are considered which are judged to have significant impact on the performance and accuracy of computational predicting of damage accumulation at defects. These are, in particular, the meshing strategy for a material region containing a defect field, the description of individual defects and their interaction with the matrix material, the effects due to stress-strain singularities arising at sharp corners and those due to cyclic plasticity modelling on the damage evolution within a defect field. Both numerical and experimental results are discussed in view of their potential application to component's design.

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Keywords: crack initiation, forging defects, finite element method, meshing strategy, damage modelling, cyclic plasticity modelling

* Corresponding author. Tel.: +420-602-445-343; fax: +420-543-216-029.
E-mail address: ali.aydin@iwm.fraunhofer.de

Fatigue life of a railway wheel under uniaxial and multiaxial loadings

H. Soares[a], V. Anes[b], M. Freitas[a], L. Reis[a,*]

[a]IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais,1, 1049-001, Lisbon, Portugal
[b]Instituto Superior de Engenharia de Lisboa, Instituto Politécnico de Lisboa, Rua Conselheiro Emídio Navarro, 1, 1959-007, Lisbon, Portugal

Abstract

In this paper, a railway wheel material is under evaluation using multiaxial fatigue testing. The experiments were conducted using a servo-hydraulic machine with standardized specimens. All samples were machined from a single worn-out railway wheel. The damage scale between normal and shear stresses was evaluated in the normal stress space for proportional and non-promotional loadings. Moreover, the uniaxial SN curves were obtained. A critical plane analysis was performed using theoretical criteria and experimental results. Results show a strong influence of heat treatments on the material fatigue behavior.

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Keywords: Stress Scale Factor (SSF); multiaxial fatigue; critical plane criteria, heat treatment, experiments

* Corresponding author. Tel.: +351-966-415-585; fax: +351-218-417-459.
E-mail address: luis.g.reis@tecnico.ulisboa.pt

Quasi-DC potential drop measurements for materials testing

Joseph Corcoran[a,*], Catrin Davies[a], Peter Nagy[b]

[a]*Imperial College London, London, United Kingdom*
[b]*University of Cincinnati, Cincinnati, Unites States of America*

Abstract

Potential drop measurements are well established for use in materials testing and are commonly used for crack growth and strain monitoring. Traditionally, the experimenter has a choice between employing direct current (DC) or alternating current (AC), both of which have strengths and limitations. DC measurements are afflicted by competing spurious DC signals and therefore require large measurement currents (10's or 100's of amps) to improve the signal to noise ratio, which in turn leads to significant resistive Joule heating. AC measurements have superior noise performance due to utilisation of phase-sensitive detection and a lower spectral noise density, but are subject to the skin effect and therefore not well-suited to ferritic materials. A quasi DC monitoring system is presented which uses very low frequency (0.3-30 Hz) which combines the positive attributes of both DC and AC while mitigating the negatives. Bespoke equipment has been developed that is capable of low-noise measurements in the demanding quasi-DC regime; an overview of the system is described. The combination of the quasi DC methodology and the specially designed electronics yields exceptionally low-noise measurements using typically 100-400 mA; at 400mA the quasi-DC system is shown to achieve a 13-fold improvement in signal to noise ratio compared to a 20A DC system. The reduction in measurement current from 400mA to 20A represents a ~3900 fold reduction in measurement power, effectively eliminating resistive heating and enabling much simpler experimental arrangements. Several example experiments are presented to illustrate the utilisation of the technique for materials testing.

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Keywords: Potential drop, DCPD, ACPD, NDE

[*] Corresponding author. Tel.: /
E-mail address: jc207@ic.ac.uk

Stable and unstable growth of crack tip precipitates

Wureguli Reheman[a], Per Ståhle[b,*], Ram N. Singh[c], Martin Fisk[d]

[a]*Mechanical Engineering Dept., Blekinge Institute of Technology, Karlskrona, Sweden*
[b]*Solid Mechanics, LTH, Lund University, SE22100 Lund, Sweden*
[c]*Bhabha Atomic Research Centre, Mumbai-400085, Mumbai, India*
[d]*Materials science and applied mathematics, Malm¨o University, SE20506 Malm¨o, Sweden*

Abstract

A model is established that describes stress driven diffusion, resulting in formation and growth of an expanded precipitate at the tip of a crack. The new phase is transversely isotropic. A finite element method is used and the results are compared with a simplified analytical theory. A stress criterium for formation of the precipitate is derived by direct integration of the Einstein-Smoluchowski law for stress driven diffusion. Thus, the conventional critical concentration criterium for precipitate growth can be replaced with a critical hydrostatic stress. The problem has only one length scale and as a consequence the precipitate grows under self-similar conditions. The length scale is given by the stress intensity factor, the diffusion coecient and critical stress versus remote ambient concentrations. The free parameters involved are the expansion strain, the degree of anisotropy and Poisson's ratio. Solutions are obtained for a variation of the first two. The key result is that there is a critical phase expansion strain below which the growth of the new phase is stable and controlled by the stress intensity factor. For supercritical expansion strains, the precipitate grows even without remote load. The anisotropy of the expansion strongly affects the shape of the precipitate, but does not have a large effect on the crack tip shielding.

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Keywords: Crack tip precipitation; unstable precipitate growth; crack tip shielding; delayed hydride crack growth; stress driven discussion.

* Corresponding author. Tel.: /
E-mail address: per.stahle@solid.lth.se

Influence of the Interfacial Transition Zone on crack behavior in a matrix/aggregate system

Lucie Malíková[a,b,*], Jan Klusák[a]

[a]*Institute of Physics of Materials, Czech Academy of Sciences, Žižkova 22, 616 62 Brno, Czech Republic*
[b]*Brno University of Technology, Faculty of Civil Engineering, Institute of Structural Mechanics, Veveří 331/95, 602 00 Brno, Czech Republic*

Abstract

Fracture behavior of a crack in a matrix/aggregate (MTX/AGG) system is studied. Influence of the Interfacial Transition Zone (ITZ) between the individual phases on the fracture response is investigated. It is discussed how the crack propagation process depends on properties of matrix and aggregate but especially the influence of the ITZ (that arises between the individual layers) is investigated. Various combinations of materials of matrix, aggregate and ITZ affect the fracture behavior of the whole system. Numerical simulations of a crack terminating at the MTX/ITZ interface based on the finite element method are presented to analyze the critical loading and discuss the effects of several parameters (ITZ thickness, AGG radius, MTX/ITZ elastic mismatch) on the crack propagation near a bi-material interface.

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Keywords: Matrix/aggregate system; interfacial transition zone; finite element method; three-point bending test; generalized fracture mechanics; bi-material interface

* Corresponding author. Tel.: +420541147381.
E-mail address: malikova.l@fce.vutbr.cz

Through process modeling of the fracture toughness test of multipass welds incorporating residual stress distribution

Yoshiki Mikami[a,]*, Houichi Kitano[b], Tomoya Kawabata[c]

[a]*Joining and Welding Research Institute, Osaka University, 11-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan*
[a]*National Institute for Materials Science, 11-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan*
[c]*Graduate School of Engineering, The University of Tokyo, Hongo 7-3-1, Bunkyo, Tokyo 113-8656, Japan*

Abstract

Weld residual stress inevitably occurs in multipass welds of thick steel plates, and it affects the fracture toughness testing procedure and test results; therefore, it is important to clarify the effect of residual stress on fracture toughness evaluation. However, it is almost impossible to measure the entire residual stress distribution in welded joints and to consider the detailed distribution in fracture toughness testing. Therefore, in this study, a numerical simulation method to model the fracture toughness test considering the weld residual stress is developed. The weld residual stress incorporated into the simulation was validated through experimental measurement. The transition of the residual stress throughout the processes of multipass welding, specimen machining, residual stress modification, precracking, and fracture toughness testing were evaluated using the proposed method. Three-point bend fracture toughness test simulations were performed for the following three cases: (1) base metal, (2) as-welded joint, and (3) residual stress modified (reverse bent) specimen by reverse bending. It was shown that the residual stress distribution in multipass welded joint was effectively modified by reverse bending. Finally, it was demonstrated that residual stress has a considerable influence on the crack-tip opening profile.

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Keywords: fracture toughness test; crack-tip opening displacement; multipass welds; residual stress modification

* Corresponding author. Tel.: +81-6-6879-4371.
E-mail address: mikami@jwri.osaka-u.ac.jp

Dynamic deformation and fracture toughness of pipe steel

A.M. Bragov[a,]*, A.Yu. Konstantinov[a], A.K. Lomunov[a], Yu.V. Petrov[b], A.V. Basalin[a]

[a]*Research Institute of Mechanics, National Research Lobachevsky State University, 23/6 Gagarin Ave., Nizhny Novgorod 603950, Russia*
[b]*Institute of Problems of Mechanical Engineering RAS, V.O., Bolshoj pr., 61, St.Petersburg 199178, Russia*

Abstract

Results of dynamic tests of pipe steel of strength category of 650 MPa on dynamic strength, fluidity and fracture toughness are presented. The stress-strain curves for shock tension and the dependence of the ultimate destruction characteristics of materials on the strain rate and temperature are constructed. To obtain the parameters of dynamic fracture toughness, modifications of the Kolsky method were used on tension a solid cylindrical specimen weakened by an annular V-notch. The work and fracture toughness are determined. To describe the velocity dependences of the utmost characteristics of the fracture toughness, a well-known Morozov-Petrov incubation time criterion was used.

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Keywords: pipe steel; Kolsky method; strength; fracture toughness; Morozov-Petrov's incubation time criterion; fractographic analysis

* Corresponding author. Tel.: +7-831-465-1622; fax: +7-831-465-6025.
E-mail address: bragov@mech.unn.ru

Development of simplified evaluation method of brittle crack arrest toughness on small-scale bending test in steels

Yuki Nishizono[a,*], Tomoya Kawabata[a], Shuji Aihara[a]

[a]*Graduate School of Engineering, The University of Tokyo, Bunkyo, Tokyo, Japan*

Abstract

The priority items in the safety evaluation of steel structural components generally include an ability to arrest crack propagation, which is necessary to prevent a catastrophic failure even if a brittle fracture occurs. The 'double integrity' concept of brittle crack initiation control and arrest has been considered to be an effective and rational methodology for several decades. The wide plate tensile test such as ESSO test is one of the major methods for evaluating brittle crack arrest toughness of steel plates. Although ESSO test makes it possible to accurately evaluate arrest toughness which indicates the Arrhenius type temperature dependence, it is not suitable for quality assurance test at mass production of steel plates due to its high economical cost and long lead-time. Thus, a number of studies has attempted to establish simplified evaluation method of brittle crack arrest toughness for many years. Generally, bending test is certainly one of the most hopeful methods since it does not require a relatively high test load. However, the phenomenon that brittle crack propagates at extremely high speed in bending condition becomes highly complicated. When brittle crack propagates at almost the same speed as stress wave in bending condition, stress distribution is the middle of the initial state and fully reallocated state by the static equilibrium. It is not easy to make out the detail only by theoretical consideration. In this study, by performing the dynamic elasto-plastic FEA in various test designs based on SEN(B) test, the authors calculated the stress distribution at the crack tip and developed a new test design suitable for evaluating arrest toughness. Moreover, the authors investigated the correlation between the result of ESSO tests and that of the developed tests and presented its applicability.

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Keywords: Brittle crack propagation; Dynamic 3D FEA; Dynamic stress intensity factor; Arrest toughness; Tapered press-notched bend test;

* Yuki Nishizono. Tel.: +81-3-5841-6517;
E-mail address: nishizono@fract.t.u-tokyo.ac.jp

Fracture analysis of axially flawed ring-shaped bending specimen

Walid Musrati[a], Bojan Medjo[a,*], Nenad Gubeljak[b], Primož Štefane[b], Darko Veljić[c], Aleksandar Sedmak[d], Marko Rakin[a,*]

[a] *University of Belgrade, Faculty of Technology and Metallurgy, Karnegijeva 4, Belgrade 11000, Serbia*
[b] *University of Maribor, Faculty of Mechanical Engineering, Smetanova 17, Maribor 2000, Slovenia*
[c] *IHIS Techno Experts Research & Development Center, Batajnički drum 23, Belgrade 11000, Serbia*
[d] *University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade 11000, Serbia*
** bmedjo@tmf.bg.ac.rs, **marko@tmf.bg.ac.rs*

Abstract

Application of pipelines is common in process industry and energetic facilities, as parts of storage and transport systems. Structural integrity and fracture resistance of the pipeline elements is typically assessed by testing fracture mechanics specimens, like compact tensile CT or single-edge notched bending, SENB. However, fabrication of these geometries is often not possible for thin-walled pressurized elements, commonly used in structures of process and energetic facilities. Therefore, some proposals for non-standard specimens have been given in the literature, differing by the position of the initial defects, in circumferential or axial direction, and by the degree of complexity of procedures for fabrication and testing. Recently proposed ring-shaped specimen (PRNB - Pipe Ring Notched Bend) is used here to assess the fracture resistance of pressurized cylinders with defects in axial direction, critical for the internal pressure loading. The specimens are simple to fabricate and have the same material history as the actual structure, such as thermo-mechanical treatment, assembly or exploitation conditions. In this work, the ring specimens are cut from the thin-walled non-alloy steel pipes for pressure purposes. Experimental-numerical procedure is applied for prediction of fracture behavior. The methods include material characterization, fracture testing and micromechanical analysis of specimen failure. The results obtained so far lead to conclusion that PRNB specimen is a good option for testing of fracture resistance of pipelines and small-scale vessels.

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Keywords: Ductile fracture; Steel pipes; Stress concentrator; Micromechanical analysis.

* Corresponding author.
E-mail address: bmedjo@tmf.bg.ac.rs

The corrosion resistance in artificial saliva of titanium and Ti-13Nb-13Zr alloy processed by high pressure torsion

Dragana R. Barjaktarević[a,*], Jelena B. Bajat[a], Ivana Lj. Cvijović-Alagić[b], Ivana D. Dimić[a], Anton Hohenwarterc, Veljko R. Đokić[a], Marko P. Rakin[a]

[a]*Faculty of Technology and Metallurgy, University of Belgrade, Belgrade, Serbia*
[b]*Institute of Nuclear Sciences ''Vinča'', University of Belgrade, Belgrade, Serbia*
[c]*Department of Materials Physics, Montanuniversität Leoben, Leoben, Austria*

Abstract

In order to optimize and enhance the implant material properties, metallic materials may be modified by severe plastic deformation (SPD) procedures. One of the most attracting SPD methods is high-pressure torsion (HPT), which is method where deformation is obtained mainly by simple shear. In the present study ultrafine-grained titanium (UFG cpTi) and ultrafine-grained Ti-13Nb-13Zr (UFG TNZ) alloy were obtained by high pressure torsion (HPT) under a pressure of 4.1 GPa with a rotational speed of 0.2 rpm up to 5 rotations at room temperature. In order to analyse microstructure of materials before and after HPT process, scanning electron microscope (SEM) was used. The aim of this study was to determine the corrosion resistance of titanium and its alloy after HPT process. Electrochemical measurements were performed in artificial saliva with a pH value of 5.5 at 37°C, in order to simulate the oral environment. The materials were analysed by electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization. All examined materials showed good corrosion resistance, but results indicate that HPT process can improves corrosion resistance.

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Keywords: corrosion resistance, biomaterials, high pressure torsion, titanium alloy

* Dragana R. Barjaktarević. Tel.: +381-63-546-596.
E-mail address:dbarjaktarevic@tmf.bg.ac.rs.

Effect of socket depth on failure type of fasteners

Barış Tanrıkulu[a,b,]*, M. Burak Toparli[a], Emrah Kılınçdemir[a], Sezgin Yurtdaş[a], Umut İnce[a]

[a]*Norm Cıvata San. ve Tic. A.Ş., A.O.S.B., Izmir, Turkey*
[b]*Dokuz Eylül University Mechanical Engineering Department, Izmir, Turkey*

Abstract

In this study, the effect of socket depth on failure types of fasteners were investigated in detail. Socket depth plays a vital role in structural integrity of fasteners particularly in weight reduction studies. Therefore, experimental studies were carried out by cold forged bolts having various socket depths. Fatigue and torque-tension tests were conducted to examine the critical socket depths under different loading types. Finite element analysis were also performed using SIMUFACT FORMING software. According to experimental and numerical investigations, it was shown that the socket depth has significant influence on failure mechanism of fasteners. Depending on the depth of sockets, the locations of the failures were shifted from the threads to the head of fasteners. The main reason for this type of shift was associated with the higher stress levels due to decrease in cross-sectional area of fastener heads. Consequently, it was shown that the critical socket depth is very important parameter in terms of structural integrity of fasteners and it has to be taken into account in the design stage of the every fasteners.

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Keywords: Fastener; socket depth; failure; weight reduction

* Corresponding author. Tel.: +90 505 633 5627
E-mail address: baris.tanrikulu@norm-fasteners.com.tr

Clarification of micro-mechanism on brittle fracture initiation condition of TMCP steel with MA as the trigger point

Atsuhisa Kitade[a,*] , Tomoya Kawabata[a] , Shintaro Kimura[b], Hideaki Takatani[c], Kiyoshi Kagehira[c], Tatsuki Mitsuzumi[c]

[a]*The University of Tokyo, 7-3-1 Bunkyo, Tokyo, 113-8656, Japan*
[b]*Mitsubishi Heavy Industries, 2-1-1 Shimahama, Arai-machi, Takasago, Hyogo, 676-8686, Japan*
[c]*Primetals Technologies Japan, 4-6-22 Kanonshinmachi, Hiroshima, 733-8553,Japan*

Abstract

Brittle fracture of carbon steel has a serious effect on the safety of steel structures. In case of bainitic microstructure it is well known that MA works as a triggering point of brittle fracture. However, the brittle fracture prediction procedure has not been fixed yet because of its complexity of the microstructure.
The target of this series of research is to clarify the selection rule of the MA which causes brittle fracture from a number of MAs in the bainitic steel manufactured by TMCP process. Double-notch tests was carried out to identify the true trigger point of brittle fracture comparing with a simple whole cleavage fracture surface observation. Then, with respect to the nucleus of fracture occurrence, orientation information data of crystals acquired by EBSD was investigated after surface processing using FIB polishing. As a result, it was revealed that brittle crack occurred from the MA located in the much more coarse crystal grain than the surrounding grains. Furthermore, according to the GROD (Grain Reference Orientation Deviation) map, a large amount of piled-up dislocations is observed around MA which worked as the trigger of brittle crack initiation. This observation will help an establishment of quantitative model which can explain the behavior of brittle fracture in TMCP steel. Authors also established numerical simulation model of DWTT test used in quality assurance in line pipe field.

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Keywords: Brittle fracture TMCP bainitic steel FIB and flush polishing EBSD

* Corresponding author. Tel : +81-80-6709-0167 ; fax : +81-42-576-6530 .
E-mail address: kitade@fract.t.u-tokyo.ac.jp

The synergistic interplay of the localized plasticity (HELP) and decohesion (HEDE) mechanisms of hydrogen embrittlement in steels: effects on macromechanical properties

Miloš Đukić[a,*], Gordana Bakić[a], Bratislav Rajičić[a], Vera Šijački-Žeravčić[a], Aleksandar Sedmak[a], Radivoje Mitrović[a], Žarko Mišković[a]

[a]*University of Belgrade, Faculty of Mechanical Engineering, 11120 Belgrade, Serbia*

Abstract

Hydrogen damage includes a wide range of environmental types of failure, hydrogen assisted mechanical degradation processes - hydrogen embrittlement (HE), and hydrogen-material interactions, including material microstructural changes, caused by the presence of hydrogen in metals. The connection between microstructure-based behaviors of materials and the effects of hydrogen on its macroscopic measurable properties is of the utmost importance in order to provide a unified model for HE in metallic materials, including steels.
The simultaneous activity and synergistic interplay of the hydrogen-enhanced localized plasticity (HELP) and hydrogen-enhanced decohesion (HEDE) mechanisms of HE (HELP+HEDE) was recently detected and confirmed trough simulations (modeling), and also experimentally, in the case of different materials, such as low carbon steels, dual-phase steels, ultra high strength steels, advanced high-strength steels, martensitic steels, martensitic stainless steels, nickel, and nickel-based alloys. This complex interaction dependence between the simultaneously active micro-mechanisms of HE, degree of mechanical properties degradation, hydrogen concentration/distribution, and temperature is particularly pronounced in the case of industrial components that are exposed to hydrogen during operation at different temperatures and from different sources.
This paper presents an overview about the simultaneous activity and synergistic interplay of HELP+HEDE mechanisms in metallic materials and an in-depth study of the model based on the correlation of mechanical properties to scanning electron microscopy fractography analysis of fracture surfaces in the presence of simultaneously active hydrogen embrittlement micro-mechanisms (HELP+HEDE) in a low carbon steel.

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Keywords: hydrogen embrittlement, hydrogen trapping, HELP, HEDE, SEM, mechanical properties

* Corresponding author. Tel.: /
E-mail address: mdjukic@mas.bg.ac.rs

Fatigue life extension of airframe structures by combining geometrical modifications and laser heating

Nikolai Kashaev[a,*], Jin Lu[a], Norbert Huber[a]

[a]Helmholtz-Zentrum Geesthacht, Institute of Materials Research, Materials Mechanics, Geesthacht, Germany

Abstract

Fatigue issue is the most critical concern for the safety of the aircraft. Therefore, various local engineering techniques, such as crenellation and laser heating, were proposed to further improve the fatigue performance of airframe structures. Previously those fatigue life extension approaches were only investigated separately. However, in real applications it is possible to apply them in a combined way, which can exploit the collaborative effects between different techniques and achieve a much more pronounced fatigue life extension. In this study, a new approach of improving the fatigue performance of airframe structures was investigated, which hybridizes two promising fatigue crack retardation techniques: crenellation and laser heating. In this approach, additional fatigue life gain is achieved by applying jointly a systematic modulation of panel thickness together with a superimposed beneficial residual stress field introduced by laser heating. To obtain the optimum configuration, a FEM-genetic algorithm coupled method was used, where the crenellation geometry and the position of the heating lines need to be encoded in a binary string, which will be improved in a generation-by-generation evolution. The fatigue performance of different configurations is automatically evaluated by FEM simulations, where the corresponding residual stress fields are introduced into FEM models by an inherent strain approach. It was found that the optimized configuration shows a significant fatigue life extension, which is larger than the linear superimposition of the fatigue life improvements achieved by each individual technique. The applied optimization method was found to be able to fully exploit the cooperative interactions and to avoid negative interactions between the two different techniques.

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Keywords: airframe structures, beneficial residual stresses, fatigue life improvement, genetic algorithm, geometric optimization

* Corresponding author. Tel.: /
E-mail address: nikolai.kashaev@hzg.de

Evaluation of bending fatigue strength in automotive gear steel subjected to shot peening techniques

R.D. Lambert[a,]*, C.J. Aylott[a], B.A. Shaw[a]

[a]*Design Unit, School of Engineering, Newcastle University, Newcastle upon Tyne, NE1 7RU, UK*

Abstract

The effect of residual stress is known to have a large influence on the integrity of engineered components including gears. Shot peening is a popular process used to introduce compressive residual stresses into a material which are beneficial to their fatigue life. Bending fatigue failure of gears is one of a number of failure modes a gear designer must account for and which can cause catastrophic failure of a gearbox.
This paper presents results from the Innovate UK funded ULTRAN project to demonstrate the effects of a number of different shot peening processes upon the bending fatigue strength of an automotive gear steel. Results to be presented include residual stress measurements, bending fatigue results from pulsator tested gears and a study of the fatigue crack growth in the material.
Four different shot peening techniques are presented along with baseline data. Whilst there was a large change in bending fatigue strength between the as-carburised and shot peened samples, the changes in residual stress caused by the optimised and the duplex shot peening methods did not correspond to a similarly dramatic increase in fatigue strength.

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Keywords: Gears; bending fatigue; residual stress; shot peening; fracture.

* Corresponding author. Tel.: +44 191 208 6280;
E-mail address: robert.lambert@ncl.ac.uk

Change of residual stress due surface conditions of Al7075-T6

Marijana Milković[a,]*, Denis Đonlagić[b], Nenad Gubeljak[a]

[a]*Faculty of Mechanical Engineering, University of Maribor, Smetanova cesta 17, Maribor 2000, Slovenia*
[b]*Faculty of Electrical Engineering and Computer Science, University of Maribor, Koroška cesta 46, Maribor 2000, Slovenia*

Abstract

Important goal of Structural Health Monitoring is detection of disintegration process in material in early stage of operation. One possibility is by monitoring the influence of surface degradation process on change of residual stresses during fatigue loading. Results of this investigation are important in analysis of condition and possibility for a Fiber Bragg Grating sensor installation for continuous strain measurements on the surface. The initial condition of the material surface is a consequence of sheet Al7075-T6 plate manufacturing procedure, but during the high cycling fatigue loading, the surface degradation with micro-grain separation occurred. Quantitative measurement of this process consist SEM surface analysis and residual stress measurement in some stage of fatigue loading. It was found the material surface is affected by fatigue loading level and loading ratio. Electropolished and no-electropolished surface have been observed and analyzed. Results show that the range of residual stress change is the similar after same number of fatigue cycles.

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Keywords: fatigue, roughness, residual stress, surface condition, Al7075-T6

* Corresponding author. Tel.: +386 (2)220 7664; fax: +0-000-000-0000 .
E-mail address: marijana.milkovic@um.si

In-situ quasi-static and dynamic experimental studies on the compression behavior and failure process of a porous SiC

Yanpei Wang[a,*], Yulong Li[a]

[a]Northwestern Polytechnical University, Xian, China

Abstract

SiC exhibits excellent shock resistance property as a traditional material. Hot-pressed porous SiC is manufactured to inherit these advantages but have less density. Few literatures investigated the failure process of porous SiC, especially under dynamic loading. In this research, In-situ quasi-static and dynamic experiments of a porous SiC was performed. High resolution images were captured to reveal the specimens' failure process with Digital image correlation method (DIC).
The specimens were cut from the as-received plate and the loading surfaces were polished to ensure the parallelism. The dimensions of the specimen were 5×6×3 mm^3. The quasi-static experiments were performed on an electronic universal testing machine at the strain rate of 5×10^{-3} s^{-1}. The dynamic compression tests employed a modified split Hopkinson pressure bar which engaged with a copper pulse shaper and two platens between bars and the specimen at a strain rate of 200 s^{-1}. Real-time images of the specimens under dynamic loading were captured by a high-speed camera at a frame rate of 1,000,000 with a resolution of 440×380 pixels.
Three kinds of methods (DIC, strain gauge on the specimen and Hopkinson bar) were used to calculate the strain. Fig.1(a) shown that DIC and strain gauge correspond, while the strains calculated by Hopkinson bar were much larger. Fig.1(b) shown that, under dynamic loading, the strength was almost two times compared to quasi-static loading. But they share nearly the same strain. Fig.2 shown the images that indicated the failure process along with the stress-time curve. The crack initiated from the edge contact with the transmitted bar, and then expand to whole specimen. Two main cracks were found in the surface after the peak stress. DIC were calculated in Fig.2, and them supported the failure process analysis.
The porous SiC shown positive strain rate effects. The crack initiated from the transmitted edge and then expand. Main cracks occurred after the peak stress. DIC results verified the failure process.

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Keywords: Porous SiC ceramic, in-situ dynamic observation, strain rate effect, DIC

* Corresponding author. Tel.: /
E-mail address: wangyanpei@mail.nwpu.edu.cn

Impact of machine stiffness and heat treatments on crack propagation instabilities in an Al-Mg-Si alloy

Tom Petit[a,b], Claire Ritter[b], Jacques Besson[a], Thilo Morgeneyer[a,*]

[a]*Mines ParisTech, Paris, France*
[b]*CEA Saclay, Paris, France*

Abstract

This study investigates rapid but limited crack propagation associated with a sudden decrease in load some-times observed during fracture toughness tests. This phenomenon is often referred to as “pop-in”.
Tensile and compact tension specimens made of 6061 Al-alloy were machined from blocks which had been subjected to different isothermal ageing (4 or 8 or 12 or 16 h at 175 °C) heat treatments to obtain different mechanical properties and keep the same microstructure except the nanometric hardening precipitates. Tensile and fracture toughness tests have been performed. The observed mechanical behavior was correlated to metallurgical characterizations in two dimensions (scanning electron microscopy, EBSD, profilometer) and three dimensions (tomography, synchrotron laminography, atom-probe tomography).
An influence of ageing time on both tensile and fracture toughness properties was revealed. Increasing the ageing time reinforced the yield and tensile strengths. For 4 and 8 hours of ageing time the material investigated did not show pop-in occurrence whereas pop-in is observed on 50% of specimens after 12 hours and on 100% after 16 hours.
3D scans were made via synchrotron laminography (ESRF, France) on flat specimens extracted from a CT specimen, containing a stopped crack. Reconstructions show very rough crack surface and the heterogene-ous presence of large clusters of porosity at the crack tip. However, no difference between the differently heat treated materials and associated tearing moduli was found in terms of fracture mechanism.
An innovative assembly has been designed in order to vary machine compliance during a toughness test. It is shown that the appearance of pop-in is related to the competition between crack growth toughness, i.e. tearing modulus and the double system stiffness (contributions of machine and specimen). An instability criterion has been investigated accounting for machine and sample stiffness and displacement considerations. It showed an excellent agreement with the experimentally found pop-ins.

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Keywords: pop-in, fracture toughness, instability, aluminium, machine stiffness

* Corresponding authors. Tel.: /
E-mail address: thilo.morgeneyer@ensmp.fr

ECF22 - Loading and Environmental Effects on Structural Integrity

Mark tracking technique for experimental determination of fracture parameters

Liviu Marşavina[a,*], Octavian Pop[b], Raluca Pepelan[a]

[a] *University Politehnica Timisoara,Department Mechanics and Strength of Materials, Timisoara 300222 Romania*
[b] *Universite de Limoges, GC2D, EA 3178, Egletons F-19300, France*

Abstract

The Mark Tracking method represents a modern and simple optical method to determine the displacement and strain fields. The principle of the marks tracking method is based on the comparison between two images acquired before and after sample deformation. The algorithm of method track the local displacement of the marks in two directions. Having measured displacements in certain points around the crack it is relative simple to estimate the Stress Intensity Factor (SIF) by displacement correlation methods. The students can compare different data processing algorithms for extracting the SIF's. Basically, a simple geometry like Single Edge Notch Bend specimen loaded in Three Point Bending was tested, for which the exact solution of SIF is well known. The reliability of experimental technique is assessed by comparing the results with the exact solution.

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Keywords: mark tracking, displacement correlation, stress intensity factor

* Corresponding author. Tel.: /
E-mail: liviu.marsavina@upt.ro

Creep-fatigue life prediction of 316H stainless steel by utilizing non-unified constitutive model

Takehiro Shimada[a,*], Kenji Tokuda[a], Kimiaki Yoshida[a], Nobutada Ohno[b], Tatsuya Sasaki[c]

[a]*IHI Corporation, Yokohama, Japan*
[b]*Nagoya industrial Science Research Institute, Nagoya, Japan*
[c]*Department of Computational Science and Engineering, Nagoya University, Nagoya, Japan*

Abstract

True stress and strain are necessary to estimate the rupture life under creep-fatigue conditions. Finite element analysis (FEA) is one of the most reliable method to calculate true stress and strain, but the accuracy of the obtained result is often greatly dependent on the constitutive model used. Non-unified constitutive model has been proposed, where inelastic strain is decomposed into creep strain and visco-plastic strain. In this paper, a cyclic hardening effect and a plastic strain range dependency were introduced into the non-unified constitutive model to predict the creep-fatigue damage of 316H stainless steel. This model was implemented in a finite element program and FEA were conducted to develop a life assessment method and calculate the creep-fatigue damage by modified ductile exhaustion method. As a consequence, it was revealed that the predicted creep-fatigue lives showed high correspondence with the experimental results by the modified ductile exhaustion method utilizing the non-unified constitutive model.

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Keywords: 316H steel; Creep fatigue; Constitutive model;

* Corresponding author. Tel.: /
E-mail address: takehiro_shimada@ihi.co.jp

Mode II fracture parameter determination for notched polyurethane materials

Radu Marcel Negru[a], Dan Andrei Serban[a], Filippo Berto[b], Liviu Marsavina[a,*]

[a]*University Politehnica Timisoara,Department Mechanics and Strength of Materials, Timisoara 300222 Romania*
[b]*Norwegian University of Science and Technology, 7010 Trondheim, Norway*

Abstract

The notch effect in a low-density polyurethane rigid (PUR) material is analyzed using a ring shaped specimen containing a single radially U-notch of different tip radii. If the specimen is subjected to a diametral compression load, various mixed mode I-II conditions are acquired depending on the notch orientation angle. The obtained experimental results are compared with the theoretical predictions based on theory of critical distances (TCD) and local strain energy density (SED) approaches. Both criteria provide reasonable estimates for the critical fracture load. A discussion on determination of mode II and predominantly mode II fracture parameters for the two engineering approaches will be presented.

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Keywords: brittle fracture, theory of critical distances, local strain energy density, ring shaped specimen

* Corresponding author. Tel.: /
E-mail: liviu.marsavina@upt.ro

Validity limits of the one-parameter elastic-plastic fracture mechanics (*J*-integral) considering SE(B), C(T) and clamped SE(T) specimens

Gustavo Henrique Bolognesi Donato[a, *], Felipe Cavalheiro Moreira[a]

[a]*Centro Universitário FEI, Humberto de A. Castelo Branco Av., 3972, São Bernardo do Campo, 09850-901, Brazil*

Abstract

The increasing severity of current structural applications (stresses, strains, displacements and aggressive environments), combined to the use of high toughness materials and low constraint geometries, strongly affects the validity of fracture mechanics methods to predict the mechanical behavior and final fracture of such structures using data obtained from laboratory tests, motivating further research in the field. However, the most important aspect of the one-parameter fracture mechanics framework is to ensure that the stress-fields in a reduced laboratory specimen are comparable to those found in real structures to whose design the properties taken from the specimen will be employed. This is the similitude concept, in which a single-parameter can describe the stress-fields ahead of a specimen's or structure's crack tip. To establish objective criteria for assessing similitude, this work compared the stress-fields obtained from high-constraint reference models (MBL) with those obtained from laboratory scale fracture mechanics specimens. The extensive analysis matrix, considering computational simulations under plane-strain, complemented by 3-D analyses, allowed the determination of the deformation limits *M* for C(T), SE(B) and clamped SE(T) geometries considering a wide range of geometrical features and material properties characteristic of structural steels applicable to pressure vessels and pipelines. The results confirmed the low constraint response for short-cracked SE(B) and SE(T) specimens and clarified the effects of crack depth and thickness on *M* values. In addition, some unexpected behaviors were evidenced and explained, as the case in which (for some particular crack depths and loading modes) thin specimens seem to be more constrained than thick ones. Thus, this work provides insights and quantitative results that enable the development of an objective basis to guarantee similitude in structural integrity assessments based on elastic-plastic fracture mechanics supported by the *J*-integral either with its critical values (*Jc*) or *J-R* curves.

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Keywords: Elastic-plastic fracture mechanics; J-integral; Deformation limit (M); C(T) specimens; SE(B) specimens; SE(T) specimens.

* Corresponding author. Tel.: +55-11-43532900.
E-mail address: gdonato@fei.edu.br

Crack growth analysis and residual life estimation of structural elements under mixed modes

Mirko Maksimović[a,*], Ivana Vasović[b], Katarina Maksimović[c], Stevan Maksimović[d], Dragi Stamenković[e]

[a]*Belgrade Waterworks and Severage, Belgrade, Serbia*
[b]*Lola Institute, Kneza Višeslava 70a, Belgrade, Serbi*
[c]*Secretariat for Utilities and Housing Services Water Management, Kraljice Marije 1, 11120 Belgrade, Serbia,*
[d]*Military Technical Institute, Ratka Resanovica 1, Belgrade, Serbia*
[e]*IDS GmbH Oberhausen, Germany,*

Abstract

Attention in this work is focused to crack growth analysis and residual life estimation of metal structural components under mixed modes I/II. Primary attention of this investigation is numerical simuation crack growth trajectory. For this purpose FEM is used together with the maximum tangential stress (MTS) criterion. To determine crack growth trajectoties of cracked structural components under mixed modes convencional singular finite elements are used. In this investigation specimen with two holes and crack between its is considered. The crack between two holes is defined to achieve mixed mode I/II crack growth trajectory.The main objective of this work is to develop a computational analysis methodology to simulate realistic crack growth and to predict remaining life and residual strength of complex aircraft and another flight structures. Modern aircraft structures are designed using damage tolerance philosophy. This design philosophy envisions sufficient strength and structural integrity of the aircraft to sustain major damage and to avoid catastrophic failure. An special attention in this work is focused to study the effects of initial angle of crack between two holes on crack growth trajectories. Computation crack growth trajectories are compared with own experimental results. There are good agreements in determining the path of the crack growth and life estimation. Good agreement between computation and experimental crack growth trajectory is obtained.

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Keywords: Fatigue, crack growth, trajectory, residual life, mixed modes, finite elements

* Corresponding author. Tel.: /
E-mail address: maksimovic.mirko@gmail.com

Analytical prediction of damage in a multilayer composite tubular structure under a cyclic loading

Abdelhamid Ghouaoula[a,*], Mohammed Hadj Meliani[a], Abdelkader Hocine[a]

[a]*University of Chlef Algeria, Chlef, Algeria*

Abstract

The model proposed allows simulating the mechanical response of the structure to a cyclic loading. The model is based on a meso macro approach and takes into account the damage behavior of the composite .The results obtained are compared with experimental data. Finally, the effect of stacking sequence of filament layers on the damage level in the composite is investigated.

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Keywords: Tubular structure, multilayer composite, viscoelastic, damage, pressure loading

* Corresponding author. Tel.: /
E-mail address: a.ghouaoula@univ-chlef.dz

Low and high cycle fatigue assessment of mismatched load-carrying cruciform joints

Wei Song[a,b], Xuesong Liu[a,*], Filippo Berto[b]

[a]State Key Laboratory of Advanced Welding and Joining, Harbin Institute of Technology, Harbin 150001, China
[b]Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology (NTNU), 7491 Trondheim, Norway

Abstract

Fatigue behaviors of load-carrying cruciform joints considering geometry variations and strength heterogeneity between base metal and weldments were studied. Low and high cycle fatigue tests were performed on specimens under displacement controlled and force controlled conditions. Observation of the specimens revealed that crack propagation paths differ by different loading conditions and that failure life was dominated by crack propagation. Besides, it was found that the effect of the strength under matching on the fatigue strength becomes large in low cycle fatigue region by significantly reducing fatigue life of the specimen. The test data were also assessed by nominal strain and proposed design guidance based on effective notch strain.

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Keywords: Low cycle fatgiue; load-carrying cruciform joints; material mismatch; effective notch strain.

[*] Corresponding author. Tel.: +86-451-86418433.
E-mail address: liuxuesong@hit.edu.cn.

Influence of selected laser cutting parameters to the formation of intergranular corrosion on austenitic stainless steel X10CrNi18-8

Rastislav Nigrović[a,*], Jozef Mesko[a], Ružica Nikolić[b]

[a]*University of Zilina, Faculty of Mechanical Engineering, Department of Technological Engineering, Zilina, Slovakia*
[b]*University of Kragujevac, Faculty of Engineering, Kragujevac, Serbia*

Abstract

The presented research paper is dealing with principles and technology of the laser cutting. The properties of the CO_2 laser beam, input parameters of the laser cutting, assist gasses, interaction with the cut material and the cutting process stability are described. In the scientific paper, the influence of heat from the laser beam on intergranular corrosion in heat affected zone is investigated. As an experimental material was used stainless austenitic steel X10CrNi18-8 with a thickness t = 2mm. The optimization of laser cutting of stainless austenitic steel was performed by changing the most important parameters - cutting speed, gas pressure and laser beam focus point. Corrosion in the heat affected zone was investigated with a submerged corrosion test and evaluated visually.

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Keywords: Laser cutting, intergranular corrosion, stainless steel, HAZ

* Corresponding author. Tel.: /
E-mail address: rastonig@gmail.com

A multiscale approach to model cleavage fracture in ferritic steels

Guian Qian[a,]*, Weisheng Lei[b]

[a]Paul Scherrer Institute, 5232 Villigen, Switzerland
[b]Applied materials,58039 Santa Clara, California, United States

Abstract

In the integrity analysis of a reactor pressure vessel (RPV) in a nuclear power plant shown in Fig. 1, the stress intensity factors (SIFs) KI of postulated cracks are compared with fracture toughness KIc. This is the global approach for the fracture mechanics analysis.
The prediction of RPV fracture behavior can also be attained by the local approach (LA) models. This work proposes and validates a new LA in ferritic steels. A self-consistent cumulative failure probability model for cleavage fracture is formulated. A cleavage fracture toughness model was derived. Instead of being an intrinsic constitutive material constant, the threshold value of cleavage fracture toughness varies with temperature and geometrical constraint.

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Keywords: Ferritic steels, local approach to fracture, cleavage fracture, statistical mode

* Corresponding author. Tel.: /
E-mail address: guian.qian@psi.ch

Effect of crack length on fracture toughness of welded joints with pronounced strength heterogeneity

Primož Štefane[a,*], Sameera Naib[b], Stijn Hertelé[b], Wim De Waele[b], Nenad Gubeljak[a]

[a]*Faculty of Mechanical Engineering, Smetanova 17, Maribor 2000, Slovenia*
[b]*Soete Laboratory, Dept. of EEMMeCS, Ghent University, Technologiepark Zwijnaarde 903, Ghent 9052, Belgium*

Abstract

The integrity assessment of repaired welds is dependent on accurate characterization of their fracture behavior and limit load estimation. The final weld consists of multiple microstructures due to different weld consumables used for repair welding. As a result, a large degree of heterogeneity is to be expected. The variation of mechanical and fracture properties within the weld influences the fracture behavior and limit load capacity of repaired weld. This motivated the authors of this work to adapt existing testing methods in order to characterize the fracture behavior of repair welds and to develop limit load solutions which include the effects of weld heterogeneity. This work focuses on the idea of implementing T-stress in characterization of fracture toughness at the onset of crack tip blunting. By normalizing J-integral by stress biaxiality coefficient β, obtained from T-stress solution, a new fracture toughness parameter is derived which tends to be dependent only on the distance from crack tip to interface between two mismatched weld materials.

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Keywords: Repair weld; bi-material interface; T-stress; Crack driving force

* Corresponding author. Tel.: +386-2-220-7704; fax: +0-000-000-0000 .
E-mail address: primoz.stefane2@um.si

The Mala Rijeka Bridge - specificity of maintenance

Vera Vujović[a,*]

[*]*DIVK, Belgrade, 11000, Serbia*

Abstract

The Mala Rijeka Bridge was designed in a unique way by the most prominent experts of the Yugoslav Railways Union ZJŽ in the 1970s. Built in 1973 by GP Mostogradnja with complex construction technologies in the steep Mala Rijeka Canyon with a built-in monitoring system, whose role is to provide continuous and stationary control of the behavior of the high pillars of the bridge over a longer period of time during the exploitation of the bridge. During the development of the main design, Energoprojekt made a seismic calculation in 1969 on a computer. Due to the dominant influence of the wind after the completion of the bridge, tests were carried out on the model in the aerodynamic tunnel in cooperation with the Faculty of Mechanical Engineering in Belgrade and the Military Technical Institute, and for the purpose of safe railway traffic a strong steel protection fence was designed. Due to its enormous dimensions, difficult environment conditions and age, maintenance and monitoring requirements are very high. The bridge is included in the list of public procurement of investments of Railway Infrastructure of Montenegro JSC-Podgorica (RIoM) within the project of rehabilitation of 15 steel bridges on the Vrbnica-Bar line, and after the special inspection and assessment of the condition, the main rehabilitation design with anticorrosion protection was made.

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Keywords: steel bridge; maintenance; monitoring; environmental conditions; anticorrosion protection

* Corresponding author. Tel.: +381 654 726 776; fax:.
E-mail address: veravujovic10@gmail.com

Regularities of multiparticle interactions in random structures, damage and failure of unidirectional glass-epoxy plastics

Alexey Zaitsev[a], Vitaliy Koksharov[a,]*, Yuriy Sokolkin[a]

[a]Perm National Research Polytechnic University, Perm, Russia

Abstract

The structural stochasticity of unidirectional composites is caused by randomness of the shape, relative arrangement and orientation of fibres and the scatter of their diameters. The principles of constructing algorithms for the computer generation of random-structure glass-epoxi plastics were formulated, the maximal void fractions of fibres were defined and the effects of self-organization and self-regu–larization were detected and explained. Analytical expressions for the conditional and unconditional multipoint correlation functions (i.e. CF) of different orders for random-structure random stress and strain fields are obtained. A detailed convergence analysis of the series obtained allows one to investigate localization and presence of periodic terms in the random fields. Analytical expressions for derivatives of the conditional and unconditional CF of second and third order at the points corresponding to zero values of arguments are obtained. Applying a correlation analysis to the unidirectional fibre-reinforced random-structure composites created new criteria for determining the characteristic size of the representative volume element with account of the multi-particle interaction in the system of reinforcement aggregates. A nonlinear two-level structurally phenomenological model of damaged glass-epoxi plastics was presented. The model allowed us to describe the inclination and coarsening of defects in the matrix as a multistage process and determine the instant of macrofailure as a result of the loss of stability of damage evolution. An iteration procedure is presented for an automatic selection of a quasi-static loading step for a composite with elastic-brittle structural elements in numerically solving boundary-value problems by using FEM. The procedure suggests that a minimum possible number of matrix domains change their deformation properties owing to the partial loss or recovery of the bearing strength if the type of stress-strain state changes on the structural level. Computational experiments in transverse shear and tension, uniform tension in the reinforcement direction, and anti-plane shear showed that the effective elastic moduli of the composites did not depend on the symmetry and asymmetry of the distribution laws. But the asymmetry significantly affected the fractional structure of the materials and the character of multi-particle interaction at distances from half to two averaged fibre diameters. These length scales predetermined the character of strain and stress heterogeneity in undamaged composites and significantly affected the damage evolution scenario at the initial stage of quasistatic loading. For various schemes of combined triaxial proportional macrodeformation and anti-plain shear of composites, the main regularities in the evolution of damaged matrix domains were determined. The phenomenon of ‘quantum’ character of damage evolution under hydrostatic compression, which did not depend on the type of statistical distribution law of fibre diameters was detected and investigated. A qualitative correlation between the macrofailure in computational experiments and the results of mechanical tests in the anti-pain shear of glass-epoxi plastics was shown to exist.

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Keywords: random-structure glass-epoxi plastics, triaxial quasi-static macrodeformation, step-by-step iteration procedure, collective multi-particle interaction in a defect ensemble, scale levels of multistage damage evolution

* Corresponding author. Tel.: /
E-mail address: koksharovvs@gmail.com

ECF22 - Loading and Environmental Effects on Structural Integrity

Effects of crack tunneling and plasticity on the elastic unloading compliance technique for SE(B) – current limitations and proposals

Leonardo Giangiulio Ferreira de Andrade[a], Gustavo Henrique Bolognesi Donato[a,*]

[a]*Centro Universitário FEI, Humberto de A. Castelo Branco Av., 3972, São Bernardo do Campo, 09850-901, Brazil*

Abstract

Understanding how cracks behave in high toughness structural materials is critical for high responsibility applications. Design and fitness-for-service activities in this scenario are highly dependent on accurate resistance curves (*J-R* curves) and fatigue crack growth data (*da/dN-ΔK*). Such mechanical properties correlate crack driving forces with instantaneous crack size *a*, determined using real time techniques such as the Elastic Unloading Compliance (*EUC*). In this method, load *P* and displacement *V* (*CMOD*) allow real-time compliance (*V/P*) computation, whose increase can be used to predict increasing crack size *a*. Despite usually accurate, *EUC* predictions sometimes deviate from post-mortem analyses (errors above *10%* were found by the research group) or present spurious effects such as apparent negative crack growth. Several phenomena may affect *EUC* accuracy, including: stress triaxiality, side-grooves, specimen rotation, closure, crack tip plasticity and crack tip tunneling. This paper investigates the effects of tunneling and plasticity on the *EUC* technique applied to *SE(B)* specimens of varying thicknesses and geometrical features. Very refined numerical simulations were conducted considering varying thicknesses, levels of crack depths and five levels of crack curvatures. Regarding tunneling, results show that for the same equivalent *ASTM-E1820* straight crack, elastic compliance decreases with the increase of crack front curvature, leading to a predicted crack smaller than *ASTM* equivalent. No significant deviations were detected within *ASTM* limits, however, when such limits are violated, significant deviations occur. As a step to improve size predictions for tunneled cracks, a new proposal for determining the equivalent straight crack was developed and expands the applicability of current methods. In terms of plasticity, results revealed that near-tip plasticity causes a decrease followed by an increase in specimen's compliance, whose deviation varies depending on its geometry and material properties. The effects of varying plasticity levels on crack size estimation could be identified and discussed.

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Keywords: Fracture testing; Fatigue crack growth testing; Elastic unloading compliance; SE(B); Effects of crack tunneling; Effects of plasticity.

* Corresponding author. Tel.: +55-11-43532900.
E-mail address: gdonato@fei.edu.br

Effects of manufacturing plastic pre-strains found on calendared and UOE pipes and pressure vessels on structural integrity assessments regarding fatigue crack growth and LBB

Rodrygo Figueiredo Moço[a], Fábio Gonçalves Cavalcante[a], Gustavo Henrique Bolognesi Donato[a,*]

[a]*Centro Universitário FEI, Humberto de A. Castelo Branco Av., 3972, São Bernardo do Campo, 09850-901, Brazil*

Abstract

High responsibility components operating under cyclic loading can have their resistance against initiation and growth of fatigue cracks highly influenced by previous thermomechanical processing. Within the interest of the present work, different manufacturing processes (such as the fabrication of pipes using UOE) or installation procedures (such as pipe reeling) can lead to non-uniform plastic pre-strain fields thus affecting lifetime and safety. Previous studies conducted by the authors revealed that pre-straining up to 14% considerably reduced fatigue crack growth rates (da/dN-ΔK) for a hot-rolled (1/2") ASTM-A36 steel as a result of strain hardening and its effects on plastic zone sizes. In addition, results also revealed two interesting trends: i) the larger is the imposed pre-strain, the greater is the growth rate reduction in a nonlinear asymptotic relationship; ii) the larger is imposed ΔK, the more pronounced is the effect of pre-straining. Within this scenario, this work explores the effects of those results on more realistic lifetime predictions applicable to pipelines and pressure vessels. First, a nonlinear model based on the experimental results was developed to predict crack growth rates (da/dN) as a function of ΔK and varying plastic pre-strain levels. Second, refined nonlinear FE models were developed to quantify plastic pre-strain fields caused by manufacturing sequence of the studied pressure vessels and pipes. Such fields proved to be remarkably non-uniform, in accordance to the literature. Finally, considering an idealized cyclic internal pressure and the obtained fields, a MatLab algorithm was implemented to predict fatigue crack growth rates until LBB (Leak Before Break) condition takes place. Best practices for implementing such evaluations are presented and results revealed that effects of plastic pre-strains are not negligible and should be taken into account on recommended practices and structural integrity assessments to avoid excessive conservatism or lack of safety in applications.

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Keywords: Structural steels, Fatigue crack growth, Effects of plastic pre-strain, Pressure vessels, Pipelines.

* Corresponding author. Tel.: +55-11-43532900.
E-mail address: gdonato@fei.edu.br

Inelastic deformation, strain-softening and localized failure in sandstone media under triaxial quasistatic loading

Yuri Kovalenko[a,*], Ivan Panteleev[b], Alexey Zaitsev[b], Vladimir Karev[a], Yuriy Sokolkin[b], Yuriy Sidorin[a], Konstantin Ustinov[a]

[a]*Institute for Problems in Mechanics RAS, Moscow, Russia*
[b]*Institute for Continues Media Mechanics of the Ural Branch RAS, Perm*

Abstract

The two-level-phenomenological structural model for brittle sandstone was developed with the aim to study the character of collective multi-particle interaction in the defect ensemble, the general laws and the change in failure mechanisms and scale levels of damage evolution under combined triaxial quasistatic loading. A partial or complete loss of load-carrying capacity by structure elements is connected with violation of strength conditions and, as consequence, with jump-like changes of deformational characteristics. The model allowed us to describe the inelastic deformation accompanied by inclination and coarsening of defects as a multistage process of damage accumulation and to determine the instant of rocks media macrofailure as a result of loss of stability of this process. In the course of computational simulations, we found and analyzed such regularities of mechanical behaviour of brittle sandstone as the strains corresponding to the instant of macrofailure and the character of damage evolution in relation to the stiffness of the loading system, the effect of lateral pressure on strain-softening, the dilatation under uniaxial compression, the unequal resistance of heterogeneous bodies, and the self-supported accumulation of defects. If the macrofailure is considered to be the critical state, where structural transition under loading results in a loss of continuity in the damaged solids or in reaching of connectivity in the defect ensemble, we can determine parameters widely used in the physics of critical phenomena which characterize collective multi-particle interactions and the mutual arrangement of failed grains. A nonlocal critical dimensional lengths constant for damaged solids is found to exist, which does not depend on the type of stress-strain state and quasistatic proportional and nonproportional loading modes. The constant determines the instant of transition from the stage of accumulation of disperse damage to a localized failure and to the strain-softening. The new nonlocal criterion allow one to determine a unique quantitative relation between the connection of damaged domains and the regularities in the behaviour of isotropic and anisotropic brittle rocks.

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Keywords: random-structure brittle rocks, triaxial quasistatic loading, collective multi-particle interaction in a defect ensemble, scale levels of multistage damage evolution, nonlocal conditions for transition to a localized failure

* Corresponding author. Tel.: /
E-mail address: perfolinkgeo@yandex.ru

Experiments and modeling of ductile fracture behaviour and fracture toughness of low-alloy C-Mn steel

Luděk Stratil[a,*], Ivo Dlouhý[a], Yazid Madi[b], Jacques Besson[b]

[a]*Institute of Physics of Material, Academy of Sciences of the Czech Republic, Brno, Czech Republic*
[b]*Centre des matériaux, CNRS UMR 7633, Mines ParisTech, PSL Research University, France*

Abstract

The contribution deals with experiments and modelling of ductile fracture behaviour and size effect on fracture toughness of low–alloy C–Mn pipeline steel. Fracture behaviour of the steel was studied at room temperature. Smooth and notched tensile bars were tested in order to describe plasticity and damage at different stress levels. A size effect on J–R curve using three sizes of compact tension specimens was evaluated. The results of tensile tests were analysed by finite element method. Consequently the constitutive equations of the plasticity and the parameters of GTN damage model of ductile fracture were determined. The GTN model is then used to describe fracture behaviour of tested compact tension specimens.

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Keywords: fracture toughness, size effect, GTN, C-Mn steel

* Corresponding author. Tel.: /
E-mail address: stratil@ipm.cz

A finite fracture mechanics approach to debonding accounting for residual friction

Pietro Cornetti[a,*], María Del Mar Muñoz-Reja Moreno[b], Vladislav Mantić[b], Alberto Sapora[b]

[a] *Politecnico di Torino, Torino, Italy*
[b] *University of Seville, Seville, Spain*

Abstract

Aim of the present paper is to provide an easy analytical tool to determine the load causing debonding along an interface under prevailing mode II conditions. The task is achieved by resorting to the Finite Fracture Mechanics approach. Applications are focused on (but not limited to) FRP-to-substrate joints. A 1-D model is used. With respect to other models already available in the literature, the novelty is here represented by the allowance of a residual stress, caused by friction between the debonding crack surfaces. Applicability of the formulation can range from the debonding of externally-bonded FRP-plates to the pull-out of a reinforcement from a brittle substrate. Model predictions are compared with recent analytical findings obtained by implementing a bi-linear cohesive law with residual stress. Agreement between Finite Fracture and Cohesive Crack Model turns to be excellent, thus justifying the use of the simpler Finite Fracture mechanics approach for preliminary sizing. Moreover, both the approaches provide a different solution for short and long bonded lengths, the latter ones being characterized by a stable crack growth before peak load is achieved. The last part of the presentation is the application of the present model to the sliding of a soil or snow layer along a slope, a classical geotechnical problem here revised in the Finite Fracture Mechanics framework. Also in this case the agreement between Finite Fracture Mechanics and Cohesive Crack Model is excellent. An approximate formula giving the critical nominal stress is finally provided, highlighting the size effect for the problem at hand.

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Keywords: Finite Fracture Mechanics, Cohesive Crack Model, FRP retrofit

* Corresponding author. Tel.: /
E-mail address: pietro.cornetti@polito.it

Analytical investigations to the specimen size effect on the shear resistance of the perfobond shear connector in the push-out test

Mohammed A. Al-Shuwaili[a,*]

[a]*School of Architecture, Civil and Building Engineering, Loughborough University,Loughborough, LE11 3TU, UK*

Abstract

Perfobond shear connectors (PSCs) are widely used in steel-concrete composite structures as an available alternative to the shear studs which have a limited shear resistance, and are prone to fatigue problems. The evaluation of the structural performance of PSC ribs is mainly obtained through a destructive test known as the push-out test (POT). However, the size of the specimen in the POT is varied significantly.
The main objectives of this study are (i) to examine the effect of the POT specimen size on the predicted shear resistance of the PSCs by conducting numerous numerical analyses to the design parameters that affect the shear resistance obtained from POT test. The numerical investigations were conducted utilising several empirical shear resistance equations which are originally derived from the regression analysis of the POT results. These investigations were performed on Eurocode-4 (EC-4) and British Standard-5 (BS-5) POT specimens as the size of these specimens is varied significantly. Furthermore, (ii) to quantify the scale of the influence of the design parameters in the POT on the resulting shear resistance by conducting several sensitivity numerical analyses as the design parameters have variable effects on PSCs shear resistance
The results of this study suggest that the size of the POT specimen has a minor effect on the predicted shear resistance which might have the same effect on the actual shear resistance from the push-out test. In addition, the results of the sensitivity numerical analyses have shown that both the diameter of the holes and the rebars are the most influential factors on the shear resistance of the PSC, and the thickness of the connector has the least influence among the other design parameters, and the effect of the design parameters on the PSC shear resistance is varied according to the geometry of the connector.
Further, a more efficient design for PSCs is presented by selecting large holes in a small number instead of small holes in a large number for the same cross-sectional area of the connector. This efficient design has the potential to increase the PSC shear resistance which directly affects the bending resistance and deflection of the composite beams that employ the perfobonds as a shear connector.

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Keywords: push-out test; perfobond; shear resistance; numerical investigation; sensitivity analysis

* Corresponding author. Tel.: /
E-mail address: m.a.al-shuwaili@lboro.ac.uk

Determination of combined hardening parameters to simulate deformation behavior of C(T) specimen under cyclic loading

Ho-Wan Ryu[a], Hune-Tae Kim[a], Yun-Jae Kim[a,]*, Jin-Weon Kim[b]

[a]*Department of Mechanical Engineering, Korea University, Anam-Dong 5-Ga, Seongbuk-Gu, Seoul 136-701, Republic of Korea*
[b]*Department of Nuclear Engineering, Chosun University, Seosuk-Dong, Dong-Gu, Gwangju 501-759, Republic of Korea*

Abstract

Cyclic hardening rule is important to simulate deformation behaviors in low cycle fatigue analysis. Due to a complexity of cyclic hardening, it is hard to predict deformation of components accurately. Also, in the case of a cracked problem, severe deformation occurs in the region of crack front. To perform low cycle fatigue analysis and predict deformation behaviors, the type of cyclic hardening rule should be determined. In this study, the determination procedures of combined hardening parameters (Chaboche model) are described briefly and the effects of two parameters on deformation behavior are analyzed. Combined hardening parameters are determined from each hysteresis loop with different strain amplitudes. The experiment data from two different materials (SA312 TP316 stainless steel and CF8A cast austenite stainless steel) and two different load ratios (R=-0.5 and -0.1) are used for simulations. In addition, hysteresis loops from three strain amplitudes are used to explain how the parameters from different strain amplitudes can influence on deformations of cyclic C(T) simulation.

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Keywords: Low cycle fatigue, C(T) specimen, Deformation, Combined hardening rule, Cyclic loading, Strain amplitude

* Corresponding author. Tel.: +82-2-3290-3372; fax: +82-2-929-1718.
E-mail address: kimy0308@korea.ac.kr

Effect of different cold working plastic hardening on mechanical properties of 316L austenitic stainless steel

Shuai Wang[a], He Xue[a,*], Yinghao Cui[a], Wei Tang[a], Xiaoyan Gong[a]

School of Mechanical Engineering, Xi'an University of Science and Technology, Xi'an 710054, China

Abstract

It is the important foundation data that the material mechanics properties parameters in the important structure integrity evaluation and safety analysis. Since cold working will change the mechanical parameters of the local region material, and these local regions often play an important role in structural integrity analysis. To obtain the preliminary data of the mechanical parameters with different cold deformation, the relation of the cold deformation and mechanical parameters of 316L austenitic stainless steel is analyzed by combining the theoretical analysis, numerical simulation and uniaxial tensile testing in this paper. The investigated results indicate that the cold working will increase the yield stress of the material to some extent, but has little effect on the reduction factor. The approach proposed in this paper could be used to preliminary estimate the mechanical properties parameters of materials subjected to cold working in the important engineering structures.

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Keywords: Material mechanics properties; Elastic-plastic FEM simulation; Cold working; 316L austenitic stainless steel; Mechanical experiment

* Corresponding author. Tel.: /
E-mail address: xue_he@hotmail.com

Numerical investigation into crack-tip constraint of SEN(T) and full-scale pipe with a surface crack

Ik-Joong Kim[a], Youn-Young Jang[b], Nam-Su Huh[b,]*, Cheol-Man Kim[a], Young-Pyo Kim[a]

[a]KOGAS Research institute, 41062 Daegu, South Korea
[b]Department of Nuclear Engineering, Chosun University, Seosuk-Dong, Dong-Gu, Gwangju 501-759, Republic of Korea

Abstract

The elastic-plastic fracture parameters, such as J-integral and crack-tip opening displacement (CTOD), have been used as crack driving force or crack resistance curve of structures with a flaw and fracture specimens. In the ASTM standard for measurements of fracture toughness, it is required to satisfy deep crack length and thick-thickness of fracture specimen to produce conservative fracture toughness since J-integral and CTOD are varied with geometric size due to constraint effect. It has been well-known that there could be a large difference of fracture toughness between standard specimens and actual pipelines. The main reason is that thickness and crack length of pipeline are usually smaller than those of standard specimens. For this reason, single edge notched tension (SENT) specimen has been suggested as one of the suitable fracture specimens for pipelines with a shallow-crack, and the DNV-RP-108 and BS 8571 standards adopted SENT as a lower-constraint specimen. However, there are some differences between the geometric size of SENT required from DNV-RP-108 and BS 8571 standard, respectively. To improve the clarity and assure the transferability, a constraint effect should be intimately investigated.

In the present study, crack-tip constraint levels of SENT and full-scale pipe with an internal surface flaw were investigated by using the finite element (FE) analyses. The crack-tip constraint levels were quantified by using the Q-stress parameter. The effects of geometric parameters on crack-tip constraint levels such as flaw length, thickness and width were considered to determine relevant geometric size of specimen representing comparable fracture toughness of pipeline by comparing the Q-stress of specimens with that of pipeline. Furthermore, the crack-tip constraint levels of SENT required from DNV-RP-108 and BS 8571 standard were also examined to assure transferability for full-scale pipe.

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Keywords: Low cycle fatigue, C(T) specimen, deformation, combined hardening rule, cyclic loading, strain amplitude

* Corresponding author. Tel.: /
E-mail address: nam-su.huh@seoultech.ac.kr

Prediction of the Hertzian contact damage in ceramic materials using Finite Fracture Mechanics

Oldřich Ševeček[a,*], Zdeněk Machů[a], Dominique Leguillon[b], Eric Martin[c], Raul Bermejo[d]

[a]*Brno University of Technology, Faculty of Mechanical Engineering, Brno, Czech Republic*
[b]*Institut Jean Le Rond ∂'Alembert, Sorbonne Université, Centre National de la Recherche Scientifique, Paris, France*
[c]*Laboratoire des Composites Thermo-Structuraux, CNRS UMR 5801, Université de Bordeaux, Bordeaux, France*
[d]*Institut fuer Struktur- und Funktionskeramik, Montanuniversitaet Leoben, Leoben, Austria*

Abstract

The contribution deals with a prediction of the Hertzian contact damage in ceramic materials. Namely, a contact of a spherical indenter with a ceramic plate is investigated and a critical applied load, leading to an initiation of the ring crack nearby the contact area is predicted using the coupled stress-energy criterion (based on the Finite Fracture Mechanics theory). The only necessary fracture-mechanics characteristics coming into these calculations are the tensile strength of the ceramic plate and its fracture toughness. The 2D FE calculations (with prescribed rotational symmetry) are used to calculate necessary stress and energy quantities at the location of the potential ring crack onset. Based upon the coupled criterion, in each step of the iterative FE simulation, it is decided if the condition for the crack onset is fulfilled. If not, the applied load is increased and the simulations repeated up to the simultaneous satisfaction of both the energy and stress condition for crack initiation. Based upon the performed parametrical studies a typical location of the crack onset with respect to the contact area is determined and dependence of the critical force on the indenter radius and its stiffness is analysed. The predictions of the critical failure load are at the end of the work compared with available experimental observations.

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Keywords: Hertzian contact, coupled criterion, ceramic, FE model,ring crack

* Corresponding author. Tel.: /
E-mail address: sevecek@fme.vutbr.cz

ECF22 - Loading and Environmental Effects on Structural Integrity

Experimental measurement of structural steel corrosion

Jaroslav Odrobiňák[a], Jozef Gocál[a,]*

[a]*University of Žilina, Faculty of Civil Engineering, Univerzitná 1, 01026 Žilina, Slovensko*

Abstract

Corrosion is recognized as the most significant degradation effect of the structural steel. This degradation process is affecting the cross-sectional and structural element resistance and deformation parameters of structure. To estimate the speed of corrosion loss in the case of steel plates, rapid test in corrosion chamber were done. Such measurements have their significance, however for their evaluation and confrontation with the results measured in situ much more data from corrosion processes observed in actual environment are still needed. Therefore, the paper also presents the results of first round of experimental measurement of corrosion losses carried out on specimens of structural steel placed on several bridge structures built in different places. Effects of local microclimate factors on corrosion process resulting from the type of bridge structures or their individual elements is pointed. To underline justification of experimental program, the influence of corrosion on flexural load-carrying capacity of three chosen structural elements from bridges in service is presented, as well.

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Keywords: Corrosion; structural steel; experimental measurement; corrosion losses; rapid test.

* Corresponding author. Tel.: +421-41-513-5664; fax: +421-41-513-5690.
E-mail address: jaroslav.odrobinak@fstav.uniza.sk

Load tests of precast segmental bridge in Slovakia

Petra Bujňáková[a,]*

[a]*University of Žilina, Faculty of Civil Engineering, Univerzitná 1, 01026 Zilina, Slovakia*

Abstract

The new bridge composed of two separate precast prestressed structure is located near the city of Žilina, approximately aligned in the south and north direction of European highway corridor. The superstructure has been built with a length up to 1042 m between expansion joints. After consideration of the technical and architectural aspects in the urban area, it was decided that each bridge structural system would consist of a total of eighteen continuous spans with lengths 46.10 +15 x 60.50 + 49.80 + 32.80 m. The same twin parallel precast box girders were used with main spans of 60.5m with same constant cross section for the bridge. The 60-ton segments were precast in an existing yard and delivered by trailers. They were lifted into place by a self-launching gantry deck. The shorter end spans minimize the length of the bridge adjacent to the abutment, which had to be built by employing falsework.
In this paper, the general information on the behaviour of this bridges under static and dynamic loading have been analysed.

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Keywords: segmental bridge, load test, precast girder

* Corresponding author. Tel.: /
E-mail: petra.bujnakova@fstav.uniza.sk

Study of various conical projectiles penetration into Inconel-718 target

Israr ul Haq[a,*], Guo Weiguo[a], Mariyam Arif[b], Muhammad Zakir Sheikh[a]

[a]*Dept. of Aeronautical Structural Engineering, School of Aeronautics, Northwestern Polytechnical University, Xi'an, Shaanxi 710072, China*
[b]*School of Electrical Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi 710049, China*

Abstract

Impact behavior of a spherical and four different apex angles (40°, 60°, 80° & 100°) of rigid conical projectiles into the Inconel-718 target plates are studied numerically, by using ABAQUS/Explicit. Johnson Cook constitutive model is used to define plasticity and failure properties of Inconel-718 target, whereas projectile is considered as a rigid material. Firstly, experimental results of spherical projectile impact on 2mm thick Inconel-718 target at the ballistic limit i.e., 133m/s is compared with that one of the simulations. According to which, numerical results predicted the deformation behavior in the target plate and size & mass of the plug, precisely. Afterwards, numerical simulations for ballistic performances were done for conical nose shaped projectile's impact on subject target, and it has been concluded that projectile with minimum apex angle has the minimum ballistic limit. It has also been found that the variation in apex angle on ballistic limit has an increasing trend from 40° - 80° and subsequently it drops at 100°. Also, deformation modes by various conical projectiles near ballistic limit has been considered. To conclude the research, it has been observed that change in apex angle has significant effect on number of petals, crack length, curling of petals and bending of the target plate.

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Keywords: Ballistic Impact; Nickel Based Alloy; Perforation; Conical Projectile, Apex Angle

* Corresponding author. Tel.: +86-155-0297-0718
E-mail address: israrrind@hotmail.com

Numerical investigation of various caliber-radius-head (CRH) ogive projectiles impact on Inconel-718 target

Israr ul Haq[a,]*, Guo Weiguo[a]

[a]Dept. of Aeronautical Structural Engineering, School of Aeronautics, Northwestern Polytechnical University, Xi'an, Shaanxi 710072, China

Abstract

This article is based on numerical investigation of ogive projectiles on Inconel-718 target. Inconel-718 is an important material generally used in turbine blades of Turbofan engines. Impact of ogive projectile on represents situation when some sharp foreign object hits turbine blades. Therefore, purpose of impact of ogive projectiles on Inconel target is to find out ballistic impact resistance when subjected to various impacting objects. Numerical simulation is performed in ABAQUS/Explicit. 2D axisymmetric model is considered for both projectile and target. During numerical simulation in ABAQUS/Explicit, projectile is considered as discrete rigid. CRH for ogive shaped projectile are varied from 0.5 to 3.0. Impact experiments are performed with spherical projectile on Inconel-718 targets. Johnson Cook plasticity constitutive model is used to represent material model in ABAQUS/Explicit. Various sets of Johnson Cook parameter available in literature are studied to find out the best set of parameters representing experimental results achieved from spherical projectile impact. Similarly Johnson Cook damage parameters are also selected in a similar way to find out damage parameters that provide results closest to experimental data. Mesh independence study is performed by increasing mesh density in impact zone. Effect of variation in CRH is studied for various impact velocities. Numerical results from explicit dynamic analysis are compared with analytical results to validate the results from simulation. Various kinds of deformation modes are discussed for various CRH values. Target deflection is also studied with various CRH and impact velocities. Energy absorbed during impact is also studied and also work done during deformation process is compared for various projectile CRH. Effect of variation of friction coefficient between projectile and target surface is also studied. Effect of variation of target thickness-to-projectile diameter is also studied for conical projectiles. Finally, results are summarized and discussed in detail to conclude the ballistic perforation of Inconel-718 for various apex angles conical shaped projectiles.

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Keywords: Ballistic impact, Inconel-718, nickel based alloy, perforation, penetration, Ogive projectile

* Corresponding author. Tel.: +86-155-0297-0718
E-mail address: israrrind@hotmail.com

The effect of transient material behaviour on predicted residual stress fields and the cyclic J-integral

Darko Panić[a,*]

[a]Technische Universität Darmstadt, Materials Mechanics Group, Franziska-Braun-Straße 3, D-64287 Darmstadt, Germany

Abstract

An accurate description of residual stresses and its redistribution depends on the quality of the parameter identification. Therefore, the formulation of plausible assumptions for constitutive equations for metallic structures incur porating the combined hardening rule (isotropic and kinematic hardening) are necessary. The examination of the non-contradiction of the assumptions with the material-independent statements of thermodynamics and the experimental identification of constitutive parameters is arranged by a novel parameter identification program based on a hybrid non-linear optimization algorithm. An important part of the work is the discussion of the path independence of the cyclic integral due to the plasticity effects.
Finally the presented fracture mechanical results accomplished by the node release algorithm and the effective range of the crack tip parameter ΔJ_{eff} underline the effect of the transient material behavior on the cyclic J-Integral and thus on the durability of the component.

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Keywords: Cyclic effective J-Integral, incremental theory of plasticity, thermodynamically consistent

* Corresponding author. Tel.: /
E-mail address: panic@wm.tu-darmstadt.de

Correlation among energy based fatigue curves and fatigue design approaches

Bruno Atzori[a,]*, Mauro Ricotta[a], Giovanni Meneghetti[a]

[a]University of Padova, Padova, Italy

Abstract

In this paper, with reference to the strain controlled fatigue characterization of AISI 304L stainless steel, the correlations between fatigue curves based on different definitions of the strain energy densities, namely, the plastic strain energy density per cycle, the total plastic strain energy density at fracture, the plastic and elastoplastic strain energy density evaluated under the cyclic stress-strain curve, are investigated. On this basis, a diagram showing the link among the different energy-based fatigue curves is proposed and the classical strain-life curve is derived and compared to the experimental results. The proposed diagram is then applied for the analysis of blunt notched specimens to find the correlation between several fatigue design approaches, namely the one based on the experimental evaluation of the energy dissipated per cycle, the Strain Energy Density approach, based on the numerical evaluation of the elastic strain energy density averaged in a structural volume, and the classical strain approach, based on the numerical evaluation of the elastoplastic values of strain amplitude.

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Keywords: Energy Methods for fatigue assessment, fatigue, notches

* Corresponding author. Tel.: /
E-mail address: bruno.atzori@unipd.it

Tomographic investigation of the fracture toughness of the quasi-brittle specimens subjected to four-point bending test

Daniel Vavřík[a,*], Pavel Beneš[a], Tomáš Fíla[a], Petr Koudelka[a], Ivana Kumpová[a], Daniel Kytýř[a], Michal Vopálenský[a], Martin Vavro[b], Leona Vavro[b]

[a]*Institute of Theoretical and Applied Mechanics of the Czech Academy of Sciences, Prosecká 76, Prague 9, Czech Republic*
[b]*Institute of Geonics of the Czech Academy of Sciences, Studentska 1768, 708 00 Ostrava-Poruba, Czech Republic*

Abstract

It is well known that detailed investigation of fracture mechanics of the quasi-brittle materials is rather complicated task as standard loading devices do not allow to interrupt loading test after reaching maximal loading force. The reason is that the point of maximal loading force is followed by the evolution of the fracture processes, due to elastic energy stored in the loading device itself. This fundamental obstacle was overcome in this work thanks to a newly developed compact four-point bending device. We show that shape of the crack can be evaluated on the basis of the so called differential tomography, which compares reference and actual states of the loaded specimen. Similarly, it is possible to evaluate displacement and strain fields by analyzing the series of loading states using the digital image correlation tools. Using such a methodology, local fracture toughness K_{IC} is calculated thanks to information about of the crack path and evaluated CTOD parameter.

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Keywords: Fracture process zone; Crack path; Quasi-brittle material; X-Ray computed tomography; Four-point bending test.

* Corresponding author. Tel.: +420 736 128 638; fax: +420 286 884 634.
E-mail address: vavrik@itam.cas.cz

Effect of high-power nanosecond electromagnetic pulses on the structural, chemical, and technological properties of natural dielectric minerals

Igor Bunin[a,]*, Mariya Ryazantseva[a], Nataliya Anashkina[a]

[a]*Mel'nikov Institute for the Comprehensive Exploitation of Mineral Resources,Russian Academy of Sciences, IPKON RAN, 4, Kryukovsky Tupik, Moscow, 111020, Russia*

Abstract

We studied the mechanism of the structural surface modification, and the subsequent changes of microhardness, physical chemical and technological properties of calcium-bearing minerals (calcite, scheelite, and fluorite) and rock-forming minerals of diamond-bearing kimberlites (olivine and serpentine) under the non-thermal effect of high-voltage nanosecond pulses. X-ray photoelectron spectroscopy (XPS), infrared Fourier spectroscopy (FTIR), analytical scanning electron microscopy (SEM–EDX), atomic force microscopy, microhardness measurements (Vickers hardness test, HV), electrophoretic light scattering experiments (ζ-potential), and other methods were employed to examine the structural, chemical, electrical, mechanical and physicochemical changes in the surface properties of natural dielectric minerals as a result of pulsed energy impacts. According to XPS, DRIFTS, SEM-EDX and microhardness testing data, the effect of high-voltage nanosecond pulses leads to damage the surface microstructure of geomaterials with the subsequent formation of traces of surface breakdowns and microcracks, softening of Ca-bearing minerals and rock-forming minerals of kimberlites, and reducing their microhardness by 40–67% overall. Using the adsorption of Hammett indicators from aqueous media, it has been an established fact that the acceptor properties of calcite and scheelite surfaces grow and the electron donor ability of fluorite increases as a result of pulsed electric field treatment during the first 30 s. Preliminary electromagnetic pulse treatment generally enhances Ca-bearing mineral flotation activity by 5–12%.

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Keywords: High-voltage nanosecond pulses; natural minerals; dielectics; softening; microhardnes; structural and chemical properties; surface

* Corresponding author. Tel.: +7-10-495-360-73-28; fax: +7-10-495-360-89-60.
E-mail address: bunin_i@mail.ru

Mixed-mode cohesive zone parameters from integrated digital image correlation on micrographs only

Johan Hoefnagels[a,*], Andre Ruybalid[a], Olaf van der Sluis[a], Marc van Maris[a], Marc Geers[a]

[a]*Eindhoven University of Technology, Eindhoven, the Netherlands*

Abstract

Mixed-mode loading conditions strongly affect the failure mechanisms of interfaces between different material layers as typically encountered in microelectronic systems, exhibiting complex material stacking and 3D microstructures. The integrated digital image correlation (IDIC) method [1] is here extended to enable identification of mixed-mode cohesive zone model parameters under arbitrary levels of mode-mixity [2,3]. Micrographs of a mechanical experiment with a restricted field of view and without any visual data of the applied far-field boundary conditions are correlated to extract the cohesive zone model parameters used in a corresponding finite element simulation [2]. Reliable or accurate force measurement data is thereby not available, which constitutes a complicating factor [3]. For proof-of-concept, a model system comprising a bilayer double cantilever beam specimen loaded under mixed-mode bending conditions is explored. Virtual experiments are conducted to assess the sensitivities of the technique with respect to mixed-mode loading conditions at the interface. The virtual experiments reveal the necessity of (1) optimizing the applied local boundary conditions in the finite element model and (2) optimizing the region of interest by analyzing the model's kinematic sensitivity relative to the cohesive zone parameters. From a single test-case, exhibiting a range of mode-mixity values, the mixed-mode cohesive zone model parameters are accurately identified with errors below 1%. The IDIC-procedure is shown to be robust against large variations in the initial guess values for the parameters. Real mixed-mode bending experiments are conducted on bilayer specimens comprising two spring steel beams and an epoxy adhesive interface, under different levels of mode-mixity. The mixed-mode cohesive zone model parameters are identified, demonstrating that IDIC is a powerful technique for characterizing interface properties of interfaces, imaged with a limited field of view, as is typically the case in microelectronic applications [2,3].

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Keywords: Digital Image Correlation, full-field identification, Integrated Digital Image Correlation, inverse methods, interface characterization, cohesive zone model, mixed-mode adhesion properties, finite element model, microelectronics

* Corresponding author. Tel.: /
E-mail address: j.p.m.hoefnagels@tue.nl

Micromechanical parameter identification using integrated DIC with accurate kinematic boundary conditions

Johan Hoefnagels[a,]*, Ondrej Rokos[a], Ron Peerlings[a], Marc Geers[a]

[a]Eindhoven University of Technology, Eindhoven, the Netherlands

Abstract

A promising full-field method for micromechanical parameter identification from micro- or nano-scale mechanical tests is Integrated Digital Image Correlation (IDIC),[1] which is more accurate and reliable than FEM-Updating, particularly for challenging cases exhibiting small displacements, complex kinematics, specimen misalignment, and image noise.[2] Still, IDIC suffers from inaccuracies when the Boundary Conditions (BCs) applied to a tested specimen lie outside the Field Of View (FOV).[3] This poses a serious challenge for micromechanical parameter identification from a Microstructural Volume Element (MVE), whereby loads are applied on a much larger scale than the (electron) microscopic images of the MVE. Kinematic Boundary Conditions (BCs) need to be specified for the MVE model, but tiny deviations in these boundary conditions were found to strongly deteriorate the quality of identification.[4]
To this end, the effect of inaccuracies in the prescribed MVE BCs on the accuracy of the identified material parameters is systematic studied. First, three virtual experiment series provide insight on the required level of BC accuracy. Based on this insight, an improved boundary condition identification approach is proposed, which considers constitutive material parameters as well as kinematic variables at the MVE boundary as unknowns in the IDIC procedure. The proposed approach has been systematically tested for three kinds of mechanical tests, various material contrast ratios, and levels of image noise, and is shown to outperform previous approaches in terms of systematic and statistical uncertainty in the obtained material parameters.[5]

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Keywords: Integrated Digital Image Correlation, parameter identification, kinematic boundary conditions, virtual experiment, micromechanics, inverse methods

* Corresponding author. Tel.: /
E-mail address: j.p.m.hoefnagels@tue.nl

Experimental measurement of the plastic zone in fatigue with synchrotron X-ray diffraction on bainitic steel

Pablo Lopes-Crespo[a,*], M. Carrera[a], B. Moreno[a], J. Zapatero[a], P.J. Withers[b]

[a]*University of Malaga, Malaga, Spain*
[b]*The University of Manchester, Manchester, United Kingdom*

Abstract

In this work we present a new methodology to measure experimentally the plastic zone of a fatigue crack. Synchrotron X-ray diffraction allowed the bulk of the material to be probed on a Compact Tension specimen made of bainitic steel. The methodology also included the elastic-plastic curve of the material. A complete 2D map of the strains in the surroundings of the crack tip is measured experimentally with X-ray diffraction. These data are taken at the mid-plane of the specimen through the thickness. The experimental strain data collected in two different directions is used to estimate the Von Mises equivalent strain field. This implies generating artificially the shear strain component. Finally the Von Mises equivalent stress field is obtained making use of the Ramberg-Osgood curve of the material that is used to simulate the elastic-plastic behaviour of the material. The new methodology has been used to estimate the shape and dimensions of the plastic zone and has been validated with Irwin and Dugdale models.

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Keywords: Plastic zone in fatigue, synchrotron X-ray diffraction, bainitic steel

* Corresponding author. Tel.: /
E-mail address: plopezcrespo@uma.es

Investigation of response of selected quasi-brittle material after thermal load via combination of X-ray computed tomography and four-point bending fracture test

Ivana Kumpová[a,*], Tomáš Fíla[a], Daniel Kytýř[a], Daniel Vavřík[a], Iva Rozsypalová[b], Michal Vyhlídal[b], Zbyněk Keršner[b], Michal Vopálenský[a], Miloš Drdácký[a], Petr Koudelka[a]

[a]*Institute of Theoretical and Applied Mechanics of the Czech Academy of Sciences, 19000 Praha, Czech Republic*
[b] *Brno University of Technology, Faculty of Civil Engineering 60200 Brno, Czech Republic*

Abstract

Cement-based composites and rocks, representative quasi-brittle building materials, are subjected to many environmental influences throughout their life cycle. For example, changes in the ambient temperature acting with these materials (climatic or fire) are causing a variety of physical and chemical processes that result in changes in the structure and affect the mechanical properties. Nowadays physical methods as nondestructive X-ray imaging and computed tomography (CT) provide new information for research of building materials, such as information and feedback on the volume fractions and geometry of the material phases and porosity, mutual mechanical and chemical interactions, properties of phases contact, etc. The possibility to observe structural and mechanical changes during time is crucial task from point of view of environmental loading. This is possible using a very promising combination of apparently unrelated methods: X-Ray tomography and four-point bending fracture test of specimens.
X-Ray investigation is carried out using the patented TORATOM (Twinned ORthogonal Adjustable Tomography) device at the Centre of Excellence Telč. Four-point bending experiments are performed with a newly developed table-top device enabling to perform such tests during X-ray imaging. Within monitoring of mechanical response of selected specimens during the loading process, a time-series of the tomographic data (so called 4D CT) are recorded simultaneously. Development of the mechanical fracture properties and three-dimensional structural changes during time is recorded by this way. Obviously, the information about formation and propagation of cracks and the shape and size of the fracture process zone are obtained as well. Related methodology applied on specimens subjected to various temperature and mechanical loading will be presented.

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Keywords: Quasi-brittle material, temperature loading, four-point bending test, X-Ray tomography

* Corresponding author. Tel.: /
E-mail address: kumpova@itam.cas.cz

Experimental investigation on fatigue properties of FSW in AA 2024-T351

Miodrag Milčić[a], Zijah Burzić[b], Igor Radisavljević[b], Tomaž Vuherer[c], Dragan Milčić[a,*], Vencislav Grabulov[b]

[a]*Faculty of Mechanical Engineering, University of Niš, Aleksandra Medvedeva 14, 18000 Niš, Serbia*
[b]*Military Technical Institute, Ratka Resanovića 1, 11000 Beograd, Serbia*
[c]*University of Maribor, Faculty of Mechanical Engineering, Smetanova17, 2000 Maribor, Slovenia*

Abstract

The fatigue properties of friction stir welds (FSW) in 2024-T351 alloys have been investigated. In this paper, the influence of rotation speed and welding speed on the fatigue properties of friction stir welds (FSW) in EN AW-2024 T351 an aluminum alloy is investigated. The paper presents the results of structural and mechanical testing of the alloyed aluminum alloys AA 2024 welded by the FSW process. Using the optimized tool and welding, 6 mm thick plates were connected. The following welding parameters were used: the rotation speed of the tool did not change and amounted to 750 rpm, and the welding speed was 73, 116, 150 mm/min. The compounds were obtained without the presence of errors and with an acceptable flat surface of the compound.

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*Keywords:*friction stir welding; AA 2024-T351; fatigue properties

* Corresponding author. Tel.: /
E-mail address:dragan.milcic@masfak.ni.ac.rs; dragan.milcic@gmail.com

Ductile fracture of advanced pipeline steels: study of stress states and energies in dynamic impact specimens - CVN and DWTT

Letícia dos Santos Pereira[a,*], Rodrygo Figueiredo Moço[a], Gustavo Henrique Bolognesi Donato[a,*]

[a]Centro Universitário FEI, Humberto de A. Castelo Branco Av., 3972, São Bernardo do Campo, 09850-901, Brazil

Abstract

The development of robust protocols for assessing the structural integrity of gas pipelines is of paramount relevance, since failures can lead to financial and human losses. In this scenario, the material's ability to slow down the propagation of a running crack (crack arrest) becomes a design requirement. Several empirical models and criteria, calibrated by real pipeline burst tests, have been developed, being the Battele Two Curve Method (BTCM) one example of technique widely employed during decades. With the evolution of steels, there was a significant increase of ductility and toughness, in a way that such semi-empirical models usually based on the energy absorbed in the Charpy impact test (ISO 148-1, ASTM E-23) began to present unsatisfactory predictions. This may be explained by the fact that in current high-ductility and high-toughness materials (e.g.: API-5L X65, X80, X100), the dominant mechanism of fracture propagation is plastic collapse. Consequently, the energies involved in deforming and fracturing a laboratory specimen are remarkably altered and transferability to pipelines by means of the aforementioned models can be lost. Therefore, for a better phenomenological comprehension of the ductile fracture process under such circumstances, this work investigates Charpy and DWTT (ASTM E-436) dynamic tests assessing stress fields and respective energies involved in deformation and fracture. It is of great interest to evaluate the energy associated to steady state ductile fracture and thus try to characterize the energy available to slow down an ongoing fracture. Pipelines are references for the developments and support assumptions and some conclusions. Based on these golas, numerical analyses including damage models (XFEM and GTN) were implemented, including parameters' calibration and sensitivity analyses. The methodology closely reproduced available experimental results. Besides that, stress fields and energies could be quantified for the studied geometries and such analyses indicated the potential and limitations of Charpy and DWTT specimens to characterize the energies required to describe steady state ductile crack propagation and crack arrestability. Results support further developments related to pipeline integrity assessments.

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Keywords: Gas pipelines; Crack arrest; Advanced steels; Damage models; Energy assessment.

* Corresponding author. Tel.: /
E-mail address: le.s.pereira@terra.com.br

Robust reference system for Digital Image Correlation camera recalibration in fieldwork

Francisco Barros[a], Pedro J. Sousa[a], Paulo J. Tavares[a,*], Pedro M.G.P. Moreira[a]

[a]*INEGI, Universidade do Porto, Rua Dr. Roberto Frias, 400, Porto 4200-465, Portugal*

Abstract

Digital Image Correlation (DIC) is a modern powerful tool to acquire displacement fields in both laboratory and field work. Still, a number of severe limitations persist that can hinder the application of the method to objects in field work, where perfect stability of the cameras or the object itself cannot be enforced, or image acquisition is to be performed during long periods and the equipment has to be moved in the meantime.

A common example of this problem is found in large structure monitoring, such as auto or railway bridges, landslides, peers or any other structure that requires displacement monitoring due to damage, often associated with fatigue and fracture in metallic structures.

Accurate detection of camera movement across images of the same surface enable the computation of 3D point clouds with correct camera calibration values and geometrically aligned with other point clouds from previous time instants.

An algorithm, which uses feature detection to recalibrate a stereo camera-pair after movement, was developed in this work. The cameras are originally calibrated in their initial position, and the world coordinates of detected features in the background are computed to serve as reference. In subsequent image capture following camera setup movement, the new camera positions are computed using the new coordinates of the featured reference points, as well as newly detected point correspondences between images from both cameras.

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Keywords: Digital image correlation; Camera calibration; Auto-calibration; Structural monitoring

* Corresponding author. Tel.: +351-22-9578710.
E-mail address: ptavares@inegi.up.pt

Viscoelastic behaviour of self-reinforced polypropylene composites under bending loads

P.N.B. Reis[a,*], L. Gorbatikh[b], J. Ivens[b], S.V. Lomov[b]

[a]C-MAST, Dep. of Electromechanical Engineering, University of Beira Interior, Covilhã, Portugal
[b]Department of Materials Engineering, KU Leuven, Kasteelpark Arenberg 44, Belgium

Abstract

The viscoelastic behaviour of self-reinforced polypropylene (SRPP) was investigated under bending loads. For this purpose, an overfed Twill 2/2 weave pattern was used, which in the hot compacted form is known under the trade name of Curv®. The areal density of the SRPP fabric is 130 g/cm^3 and the density of this grade polypropylene is 0.92 g/cm^3. Three point bending (3PB) static tests were performed with a span length of 20 mm, according to the EN ISO 178:2003 recommendations. The strain rate effects on the flexural properties were obtained by the 3PB static tests carried out at room temperature with a displacement rate of 200, 20, 2, 0.2 and 0.02 mm/min. Finally, tests of stress relaxation were also performed, where a fixed strain was applied and the stress was recorded during the loading time. It was possible to conclude that higher strain rates promote higher maximum bending stresses and bending modulus. For both cases, a linear model fits successfully the data and the strain-rate effect on the bending strain at a maximum bending stress showed that SRPP composites are strain rate sensitive. The stress relaxation tests evidence a decrease of the stress with time, and this tendency further persists with the increase of the strain values. Maxwell and Kohlrausch-Williams-Watts (KWW) equations were used to fit the data obtained from the stress relaxation tests and, while the Maxwell model was not good enough to predict the stress relaxation time, the KWW model could fit the data with good accuracy.

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Keywords: Self-reinforced composites; Strain-rate sensitivity; Stress relaxation; Experimental tests.

* Corresponding author. Tel.: +351 275329948; fax: +351 275240895
E-mail address: preis@ubi.pt

Theoretical investigation of structural, mechanical, elastic and vibrational properties of advanced materials under extreme conditions

D. Zagorac[a,b,*], J. Zagorac[a,b], M.B. Đukić[c], D. Jordanov[a], M. Rosić [a,b], M. Cebela[a,b], J. Luković[a,b], V. Maksimović[a,b], B. Matović[a,b]

[a] *Institute of Nuclear Sciences Vinca, Materials Science Laboratory, University of Belgrade, Belgrade, Serbia*
[b] *Center for synthesis, processing and characterization of materials for application in the extreme conditions, Belgrade, Serbia*
[c] *University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia*

Abstract

One of the recent trends in materials science and technology is the research of the behavior of the materials under the extreme conditions both on the theoretical and experimental basis. There are limitations of the experimental methods, however, theoretical approach can be used as a supplement to the experimental results. As a consequence, in the last two decades a vast number of structure prediction calculations have been performed on chemical systems, focusing on the high-pressure and high temperature phases. In this work, we would like to present several computational studies and their connection to the actual synthesis routes: lead sulfide (PbS), barium sulfide (BaS), and aluminum nitride (AlN). The investigated compounds were calculated on ab initio level using the most advanced tools in quantum chemistry and computational material science including Hartree-Fock Theory, Density Functional Theory (DFT) and Hybrid (B3LYP) Approximation. Their structural, mechanical, elastic and vibrational properties have been investigated and in addition, we show structure candidates as the function of size, pressure and temperature and not previously observed in any of the investigated materials thus creating new possibilities for synthesis of advanced materials with improved physical, chemical, and/or mechanical properties.

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Keywords: ab initio ; properties ; advanced materials ; extreme conditions.

* Corresponding author. Tel.: +381-11-340-8545; fax: +381-11-644-7335.
E-mail address: dzagorac@vinca.rs

Dispersion of graphene nanoplatelets reinforcing type II cement paste

Zoi S. Metaxa[a,b,*], Stavros K. Kourkoulis[a]

[a] *Laboratory of Testing and Materials, National Technical University of Athens, 9 Heroes Polytechniou Str., 15780 Athens, Greece*
[b] *Hephaestus Laboratory, Eastern Macedonia and Thrace Institute of Technology, Agios Loukas, 65404, Kavala, Greece*

Abstract

One of the most recent, affordable and at the same time cutting-edge class of carbon nanostructures are the graphene nanoplatelets (GnPs). They depict multifunctional capabilities such as improved mechanical properties in conjunction with high electrical and thermal conductivity making them suitable for the development of multifunctional materials. One of the most essential parameters, to successfully exploit the GnPs characteristics, is their homogeneous distribution inside the matrix. In this direction, the applicability of a method, similar to the one applied for the preparation of carbon nanofiber and carbon nanotube reinforced Type I cement nanocomposites, is here investigated. Ultrasonic processing and treatment with a 3rd generation superplasticizer was used to uniformly disperse the GnPs (of lateral size equal to 8 μm) in the mixing water. This admixture was exploited as a GnPs dispersing agent, as it is commonly used, to improve the workability of cementitious materials and is fully compatible with the matrix. The nanocomposites were prepared using Type II cement. The electrical resistivity of the nanocomposites developed was evaluated. Three-point bending tests were performed at prismatic beam specimens with an artificial notch at the age of 28 days. Both the effects of dispersing agent (superplasticizer) concentration and ultrasonication energy application were investigated. It was concluded that both the admixture concentration and ultrasonic energy application strongly affect the GnPs dispersion and reinforcing efficiency.

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Keywords: Graphene nanoplatelets; dispersion; type II cement; mechanical performance; electrical resistivity

[*] Corresponding author. Tel.: +30-210-7721310; fax: +30-210-7721264.
E-mail address: zmetaxa@central.ntua.gr

Defects and fatigue failure

Uwe Zerbst[a,*], Mauro Madia[a]

[a]*BAM Berlin,10115 Berlin, Germany*

Abstract

The topic of the presentation is a discussion on defects which can cause failure in cyclically loaded metallic components. These comprise material defects such as non-metallic inclusions, pores or micro-shrinkages, etc. and geometric defects such as surface roughness and secondary notches (which are not considered in the design process) which origin in manufacturing, and defects such as surface damage due to scratches, dents, impact events or contact fatigue as well as corrosion pits which arise in service. Emphasis is put on the fact that only cracks which are not arrested during one of their distinct propagation stages can grow to a critical size what conversely means, that not any imperfection at which a fatigue cracks initiate is a defect in that it causes component failure. The explanations are supplemented by examples from failure analyses.

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Keywords: fatigue failure, non-metallic inclusions, porosity, dents, scratches, corrosion pits

* Corresponding author. Tel.: /
E-mail address: uwe.zerbst@bam.de

Fatigue life prediction of girth welded pipes under constant and variable amplitude loading

Yanhui Zhang[a,*]

[a]TWI limited, Cambridge, United Kingdom

Abstract

For welded joints, fatigue life is dominated by crack propagation process because crack-like flaws are unavoidably introduced. Metallography conducted on "sound" welds indicates that they contain undercut and intrusions at the weld toe about 0.1mm deep. For single-sided girth welds in pipelines and risers, fatigue cracking is often found to initiate from weld toes on the root side, rather than on the weld cap side. To account for the effect of stress concentration at the weld toe on stress intensity factor range, solutions for stress intensity magnification factor, MK, have been developed and are included in BS 7910. However, they are only applicable for assessing flaw at the weld cap, not suitable for assessing flaw at the weld root. In this paper, a newly developed Mk solution is described and used to predict fatigue life of girth welded pipes under constant and variable amplitude loading. The predictions are compared with the experimental data and show a good agreement between the two.

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Keywords: girth weld, welding flaw, stress intensity magnification factor, fatigue life prediction

* Corresponding author. Tel.: /
E-mail address: yanhui.zhang@twi.co.uk

Stress intensity factors of the rib-to-deck welded joint at the crossbeam conjunction in OSDs

Weijian Wu[a,*], Henk Kolstein[a], Milan Veljković[a]

[a]*Faculty of Geoscience and Engineering, Delft University of Technology, Delft 2628 CN, Netherlands*

Abstract

The orthotropic steel decks (OSDs) are one of the most widely used bridge components, especially in moveable and long span bridges. Numerous cracks have been detected in this type of deck in existing bridges, mainly in the welded joints. The fatigue performance of the bridge deck dominates its design. Among them, the crack at the rib-to-deck joint is one of the most representative types. At the crossbeam conjunction, high stress concentration makes the joint more sensitive to fatigue loading. In this paper, finite element models are built using software program Abaqus integrated with FRANC3D. The calculated stress at uncracked stage is validated with measured data obtained from laboratory tests. Afterwards, cracks are inserted at the weld root and the stress intensity factor ranges in mode I (ΔK_I) are calculated. Parametric analysis with various cracks is carried out. General correction factors are calculated from the finite element calculation with the power fit values.

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Keywords: OSDs, rib-to-deck joint, weld root crack, stress intensity factors;

* Corresponding author. Tel.: +31-152784752.
E-mail address: W.Wu-1@tudelft.nl

Determination of maximum allowed internal stress of heat exchanger

Nenad Gubeljak[a,*], Borut Žužek[a], Rajko Habjanič[b], Jožef Predan[a], Janko Ferčec[b]

[a]*University of Maribor, Faculty of Mechanical Enginering, 1000 Maribor, Slovenia*
[b]*Talum d.d. Kidričevo, 2325 Kidričevo, Slovenia*

Abstract

Aluminium and its alloys are widely used material for a heat exchanger in thermal-solar applications. The development of heat exchangers aims at greater performance, which requires temperature increase of the transmission medium in heat exchanger. It is thin-walled structure which contains spiral tubes manufacturing by blowing after cold rolling process. Internal pressure of 13 bars and temperature up to +280°C significantly reduce pressure capacity and lifetime of heat exchanger. Together with combination of pressure of transmission medium, residual stresses and micro-cracks due forming process can cause material damage and after certain time the cracks can occurre. In order to describe the aluminium and aluminium alloys behaviour at elevated temperature the numerical modelling of stress-strain behaviour for all manufacturing cycle from room to operate temperature has been performed. Also, the creep tests by using pre-cracked compact tension specimens and smooth tensile specimen have been conducted. Obtained results give a maximum internal pressure regarding to defect size and also maximum membrane stress in thin-wall of heat exchanger in order to avoid thermal creep crack initiation.

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Keywords: Aluminium, heat, exchanger, pressure, creep

[*] Corresponding author. Tel.: /
E-mail: nenad.gubeljak@um.si

Experimental characterisation of perfobond shear connectors through a new one-sided push-out test

Mohammed A. Al-Shuwaili[a,*], Alessandro Palmeri[a], Mariateresa Lombardo[a]

[a]*School of Architecture, Civil and Building Engineering, Loughborough University, Loughborough, LE11 3TU, UK*

Abstract

In steel-concrete composite beams, the perfobond shear connectors (PSCs) are commonly utilised as an alternative to the widely used headed studs, as the latter have limited shear capacity and susceptible to fatigue problems. The structural assessment of the PSCs is typically obtained experimentally, and mainly through a type of destructive test known as push-out test (POT). POT specimen typically consists of an I- steel section attached to two concrete slabs through the connectors under investigation, the slabs are then simultaneously tested by the application of a direct shear force to the steel section until the fracture of the specimen is reached. The shear strength of PSCs can be evaluated from the POT results. However, the weaker of the two concrete slabs tend to fail before the other side, which thus inevitably affects the results. In this paper, an efficient one-sided POT (OSPOT) is used to characterise the behaviour of the PSCs in composite steel-concrete beams. POT and OSPOT specimens are similar, but the shear force in the OSPOT is directly applied to one slab each test. As a part of this study, ten OSPOT have been carried out to investigate the behaviour and the shear resistance of the PSC. The results were compared against POT results from other researchers and the predictions offered by several shear resistance equations. It has been found that the OSPOT results are consistent with the analytical predictions offered by these expressions compared to the previous research using POT. Among the key advantages of the proposed OSPOT procedure: similar to the traditional POT, it is possible to quantify the relationship between applied loads and displacements in the shear connectors, which is the most important information for the structural design of composite steel-concrete beams; it is effectively doubled the number of results for the same research resources; the fabrication of the samples is simplified.

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Keywords: shear connectors, push-out test, perfobond connectors, one-side push-out test, composite beams

* Corresponding author. Tel.: /
E-mail address: m.a.al-shuwaili@lboro.ac.uk

Fatigue fracture behaviour of asymmetric spur gear tooth under cyclic loading

Seyit Mehmet Demet[a,*], Ali Serhat Ersoyoğlu[a]

[a]*Konya Technical University Engineering and Natural Science Faculty Mechanical Engineering Department*

Abstract

When the research on the gears are investigated, it is seen that there are different studies on the design and analysis. In the majority of research studies, the tooth root curve is designed as a trochoid curve as a results of production method. According to literature, application of the circular fillet method instead of the trochoid curve in the tooth root would increase the strength of the tooth root.

Fatigue life will also be positively affected with increase of tooth strength. Because the less stress will develop in the tooth root, the fatigue life of the gear tooth will increase. In this study, we have designed and manufactured involute profile asymmetric spur gears using the circular fillet method in tooth root region.

Involute profile asymmetric gears tooth have lower contact stress and superior tooth root strength than symmetric gears tooth. In this work, fatigue damages on asymmetric gear tooth caused by cyclic loads and effects of material hardness on fatigue life of gear tooth were investigated.

In the extent of the study, a new single-tooth bending fatigue test apparatus (STBFT) was developed to investigate the fatigue performance of the gears. Low-cycle and high-cycle tests were done to detect the fatigue performance of the asymmetric gears.

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Keywords: Asymmetric gear; Cyclic loadings; Fatigue; Fatigue life; STBFT

* Corresponding author. Tel.: +903322233452.
E-mail address: smdemet@gmail.com

Experimental study on fatigue fracture damage of symmetric spur gear tooth

Seyit Mehmet Demet[a,*], Ali Serhat Ersoyoğlu[a]

[a]*Konya Technical University Engineering and Natural Science Faculty Mechanical Engineering Department*

Abstract

There are many studies on the involute profile symmetric gears in the literature. In many studies done, the critic tooth root stress was emphasized. Studies have been carried out on the calculations of tooth root stress and these studies have been tried to be verified by using the finite element method. Although there are different approaches to calculate the tooth root stress, the most widely used equations are those expressed in ISO and AGMA standards.
The studies in the literature have mostly been carried out on the gears that have trochoid curve in the tooth root. In parallel with these studies, experimental studies were done to determine the fatigue life performance of these gears.
In this work, involute gears tooth root was manufactured using the circular fillet method which have better tooth root stress than trochoid according to static analyses in literature. Fatigue damage on symmetric gear tooth under cyclic loading and effect of material hardness on fatigue life of gear tooth were investigated.
Fatigue tests were performed with specially designed single-tooth bending fatigue test (STBFT) apparatus. The results obtained from fatigue tests at low cycles and high cycles were evaluated comparatively.

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Keywords: Symmetric gear; Fatigue; Cyclic loadings; STBFT

* Corresponding author. Tel.: +903322233452.
E-mail address: smdemet@gmail.com

ECF22 - Loading and Environmental Effects on Structural Integrity

Steam turbine moving blade failure caused by corrosion fatigue – case history

Marko Katinić[a,*], Dražan Kozak[a]

[a]*Mechanical engineering faculty in Slavonski Brod, Trg Ivane Brlić Mažuranić 2, Slavonski Brod 35000, Croatia*

Abstract

Corrosion fatigue has been identified as one of the leading causes of steam turbine rotor blades failure. Despite of numerous research and development in the area of preventing sudden rotor blades failure due to corrosion fatigue, in the practice these failures continue to occur. This paper just describes one of number historical cases of rotor blade fracture that was caused by corrosion fatigue. It was an industrial turbine installed in fertilizer production plant Petrokemija Kutina, Croatia. The broken blades were belonged to the turbine stage located in the phase transition zone (salt zone) of the turbine. The paper also describes the analysis of the failure cause and the modification of the turbine stage that was failed.

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Keywords: Corrosion fatigue; steam turbine; balde; failure

* Corresponding author. Tel.: /
E-mail address: mkatinic@sfsb.hr

Comparison of 1D truss and 3D solid finite elements in developing a simplified finite element model for ballistic impact response of Kevlar fabrics

Norberto Feito Sánchez[a], Raj Das[b,]*, Ali Daliri[b]

[a]*Department of Mechanical Engineering, University Carlos III of Madrid, Madrid, Spain*
[b]*School of Engineering, RMIT University, Swinburne, Australia*

Abstract

A finite element model for impact in Kevlar soft fabrics is presented in this paper. Two approaches were used for the model development. Firstly, a 3D model was developed for which the yarns were represented at meso-level, taking into account the geometry. Secondly a simplified model, assuming the yarns as wires, was developed. Both models were compared and validated in terms of residual velocity prediction and computational time against literature data. The simplified model, based on 1D elements, slightly underestimates the value of velocity, but with errors less than 2.5%. This result is especially significant when the complexity and the computational cost of both models are compared. Simplified model based simulations need considerably lower times relative to the complete 3D models. For this reason this model could be very well suited to large scale practical engineering problems and can serve as an effcient design tools simple and fast assessment of impact behaviour of soft fabrics. The simplified model was subsequently used to conduct a parametric study of the impact process under ballistic conditions, and the effect of several factors, such as the projectile geometry, number of layers and impact angle, on the impact response and failure modes was evaluated.

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Keywords: Composites, Aramid, Kevlar, fabric, failure, impact, numerical modelling, finite element method*

* Corresponding author. Tel.: /
E-mail address: r.das@auckland.ac.nz

A microstructure sensitive modeling approach for fatigue life prediction considering the residual stress effect from heat treatment

Chao Gu[a,b], Junhe Lian[b,c,d,*], Yanping Bao[a], Sebastian Münstermann[b]

[a]*State Key Laboratory of Advanced Metallurgy, University of Science and Technology Beijing, Beijing 100083, China*
[b]*Steel Institute, RWTH Aachen University, Intzestraße 1, Aachen 52074, Germany*
[c]*Impact and Crashworthiness Lab, Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA* [d]*Department of Mechanical Engineering, Aalto University, Otakaari 4, 02150 Espoo, Finland*

Abstract

A multiscale numerical method to study the high cycle fatigue (HCF) and very high cycle fatigue (VHCF) properties of bearing steels is proposed in this study. The method is based on the microstructur sensitive modeling approach resulting from the integrated computational materials ensfginerrring concept, and further consider the effect of residual stress generated from the prior heat treatment processes. The microstructure features, including the grain size and shape distribution and inclusion size and shape description, are represented by the representative volume element (RVE) models. The matrix mechanical response to the cyclic loading is described by the crystal plasticity (CP) model. The CP material parameter set is calibrated inversely based on the strain-controlled low cycle fatigue tests. The results show that the residual stresses, especially those around the inclusion, have a great effect on the fatigue properties, which provides the key factor to give the correct prediction of the fatigue crack initiation site.

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Keywords: fatigue life; modeling; residual stress; microstructure

* Corresponding author. Tel.: +49-241-8092912; fax: +49-241-8095553.
E-mail address: junhe.lian@iehk.rwth-aachen.de, lianjh@mit.edu

On the effect of weld defects on the fatigue strength of beam welded butt joints

Ann-Christin Hesse[a,]*, Thomas Nitschke-Pagel[a], Klaus Dilger[a]

[a]Institute of Joining and Welding, TU Braunschweig, Langer Kamp 8, 38106 Braunschweig, Germany

Abstract

Modern guidelines concerning the fatigue strength of welded components are often based on the nominal stress concept. These guidelines are valid for fusion welded steels but do not distinguish between different welding processes. However, different welding processes can lead to significant differences in the resulting weld geometry. This is particular true for arc welded components in comparison to beam welded components. Furthermore, it is well known, that the geometry of welded joints effects the fatigue strength severely. Therefore, it can be expected that beam welds behave differently to arc welds in fatigue tests. In this study, electron beam and laser beam welded samples of different thicknesses made from fine-grained steels were tested in fatigue tests under a constant amplitude loading. In order to assess the effects of weld defects on the fatigue strength, samples with defined weld defects (e.g. axial misalignment) were included in the study as well. The weld geometry of each sample was measured and evaluated according to the quality groups in ISO 13919-1. Additional numerical notch stress calculations were performed. Finally, a correlation between the quality groups according to ISO 13919-1 and the nominal cyclic stress at $2*10^6$ load cycles with a survival probability of 97,5% was proposed. This correlation allows users of beam welding processes to predict the fatigue strength of components under the condition that certain quality levels according to ISO 13919-1 are met.

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Keywords: beam welds; fatigue strength; high cycle fatigue; weld imperfections; butt welds; steels

* Corresponding author. Tel.: /
E-mail address :a.hesse@tu-braunschweig.de

Fracture mechanic and Charpy impact properties of a crack in weld metal, HAZ and base metal of welded armor steel

Aleksandar Čabrilo[a,*], Katarina Gerić[a]

[a]*Faculty of Technical Sciences, Trg Dositeja Obradovica 6, Novi Sad 21000, Serbia*

Abstract

Welding of armored steel is complicated by the high percentage of carbon in the base metal, the presence of defects in the form of cracks and pores that occur in the weld metal and heat affected zone (HAZ) during the welding process. For heavy structural engineering such as military armored vehicles that are frequently under the influence of impact loads, it is important to know the fracture toughness in all zones of the welded joint. The crack formed in base metal or HAZ, due to dynamic or impact loads, can easily continue to propagate to the fusion line, after which its accelerated growth may occur. The fracture mechanics testing was applied to SEN (B) test specimens, which investigated cracks initiation and certain fracture mechanics parameters. Due to the significant interest in quantifying the resistance of material to initiation and propagation of cracks, the impact energy was measured with instrumented pendulum in the zone of base metal, weld metal and HAZ, at temperatures of -40 °C, -20 °C, 0 °C and 20 °C , while the fracture mechanics parameters in these zones were tested at room temperature. The impact energy tests showed high energy for initiation as well as crack propagation in weld metal and HAZ zones, while the lowest energy was in the base metal. The fracture toughness in the base metal is 86.1 $MPa*m^{1/2}$, while in HAZ and weld metal zones is 286 $MPa*m^{1/2}$ and 355 $MPa*m^{1/2}$, respectively.

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Keywords: GMAW welding, Armor steels, Austenitic stainless steel, Fracture mechanics, Instrumented Charpy tests,

* Corresponding author. Tel.: /
E-mail address: cabrilo@uns.ac.rs

ECF22 - Loading and Environmental Effects on Structural Integrity

Impact toughness of components made by GMAW based additive manufacturing

Ali Waqas[a,]*, Qin Xiansheng[a], Xiong Jiangtao[a], Yang Chaoran[a], Liu Fan[a]

[a]*North Western Polytechnical University, Xi'an 7100072 China*

Abstract

Additive manufacturing of metals is an innovative near-net-shaped manufacturing technology used for producing final solid objects by depositing successive layers of material melted in powder or wire form using a focused heat source directed from an electron beam, laser beam, or plasma or electric arc. Wire arc additive manufacturing (WAAM) techniques, although have lesser precision as compared to laser or electron beam techniques but have the advantage of lower cost and lesser time required. In this research, gas metal arc welding (GMAW) process has been used using AWS ER70S-6 electrode wire to create a multi-layer single pass structure after controlling the parameters including current, voltage and travel speed so that uniform height is attained throughout the weld bead. The resulting material may have different directional mechanical properties because of factors including different penetration properties and bonding strength and also preheating and post-heating effects of successive layers. This study focuses on the impact toughness of the resulting material. Charpy impact test is carried out on the samples taken in both along the direction of deposition and in the direction perpendicular to it to analyze the impact toughness in different directions. To further investigate the behavior of the structure, Brinell hardness, metallography and fractography have been performed. The results show that material has high impact toughness with very ductile behavior.

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Keywords: Additive manufacturing; GMAW; Charpy impact test; impact toughness; ductile

* Corresponding author. Tel.: +86-15502970710;.
E-mail address: aliwaqas@mail.nwpu.edu.cn

Experimental setup development of additively manufactured mandible with teeth and compensations subjected to compressive load

Miloš Milošević[a,*], Srđan Poštić[b], Nenad Mitrović[c], Aleksa Milovanović[a], Milan Travica[a], Zorana Golubović[c], Goran Mladenović[c]

[a]*Innovation Centre of the Faculty of Mechanical Engineering, University of Belgrade, 11120 Belgrade, Serbia*
[b]*School of Dental Medicine, University of Belgrade, 11000 Belgrade, Serbia*
[c]*Faculty of Mechanical Engineering, University of Belgrade, 11120 Belgrade, Serbia*

Abstract

Examination of strain field underneath the teeth created due to influence of bite force in ''in vitro'' conditions requires thorough preparation of the examinee and equipment. Failure of tooth-compensation bond is often caused as a consequence of inadequate processed tooth design causing uneven strain distribution. In this paper design solutions for examination of strain field located underneath the teeth have been shown for different types of teeth and compensations. Strain measurement was performed using contactless optical 3D system ARAMIS 2.0. Mandible model with teeth was additively manufactured using SLA technology. Cap shape compensations are made of silver. Measurement of force was performed on a dynamometer, with a maximal capacity of 800N. Obtained results show how developed experimental setup enables comparison of influence of different shapes of teeth and compensations on strain distribution.

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Keywords: dental, experimental setup, strain field, additive manufacturing, optical 3D measurement, ARAMIS

* Corresponding author. Tel.: /
E-mail address: mixmilosevic@gmail.com

Very high cycle fatigue behaviour of 42CrMo4 steel with plate-like alumina inclusions

M. Seleznev[a,]*, J. Gleinig[a], K. Y. Wong[b], A. Weidner[a], H. Biermann[a]

[a]*Institute of Materials Engineering, Technische Universität Bergakademie Freiberg, Gustav-Zeuner-Str. 5, 09599 Freiberg, Germany*
[b] *Institute of Stochastics, Technische Universität Bergakademie Freiberg, Gustav-Zeuner-Str. 5, 09599 Freiberg, Germany*

Abstract

Recent progress in steel refining shows significant reduction of non-metallic inclusions (NMIs) of which alumina (Al_2O_3) is one of the most problematic. Among other refining methods, metal melt filtration by ceramic foam filters shows promising results in steel cleaning. In the present work the influence of alumina inclusions on the fatigue behavior is investigated after the reaction of steel melt with filters. Different batches are compared where carbon-bonded alumina foam filters with different coatings were introduced into the steel melt of 42CrMo4 for 10 s (so called "finger test"). Fatigue tests were performed using ultrasonic fatigue testing (USFT) up to 10^9 cycles. Specimens were nitrided in order to prevent crack initiation from the surface and to study internal failure on NMIs. Surface hardening of quenched steel increased fatigue limit significantly. Metallographic sections were analyzed using optical and scanning electron microscopy (SEM) for the estimation of NMIs distribution properties. NMI size distribution analysis based on maximum Feret diameter (instead of area) is found to be an effective method for detecting plate-shaped inclusions. Fracture surfaces after fatigue tests were investigated by methods of SEM and confocal laser scanning microscopy (CLSM), revealing that plate-like NMIs initiate crack with all their area even being inclined to the crack plane. Properties of crack initiating NMIs – alumina plates and MnS dendrites – are compared and analyzed. Formation of alumina NMI as plate lead to significant enlargement of its stress-concentrating area in comparison to the spherical shape of the same volume. Thus, total NMI content reduction in steel could give no fatigue limit improvement if NMI morphology changes from spherical to plate-like.

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Keywords: Ultrasonic fatigue testing (USFT), very high cycle fatigue (VHCF), confocal laser scanning microscopy (CLSM), non-metallic inclusions (NMI), plate-like inclusions

* Corresponding author. Tel.: +49-3731-39-4034.
E-mail address: Mikhail.Seleznev@iwt.tu-freiberg.de

Effect of surface finish on the fatigue strength of pushbelt components

M.D. Tran[a,]*, B. Pennings[a], S.V. Kamath[a]

[a]*Bosch Transmission Technology B.V., Tilburg, the Netherlands*

Abstract

The Bosch pushbelt is the most important part of the Continuously Variable Transmission (CVT) which can be found in increasing number of passenger cars due to its advantage regarding the fuel consumptions e.g. CO_2 emissions and superior comfort. The pushbelt consists of hundreds of individual elements made of 75Cr1 tool steel which are held together by two sets of maraging steel loops. In operation, high cyclic loads are acting which severely affect the lifetime of these components.

In the case of the elements, the most critical region is the notched area which is formed now by the fine blanking process. In order to guarantee the reliability of the pushbelt during its whole life time, controlling the surface finish in this particular area is of utmost importance. In this paper, the influence of different surface finish processes on the fatigue strength of the element has been experimentally determined. After this, a common geometrically defect parameter has been found enabling us to construct the Kitagawa-Takahashi diagram relating the fatigue strength to the surface quality parameters. Using this diagram, a specification for the notch surface quality has been established which can be used for quality control purposes. Furthermore this surface specification can be used to investigate new process or process settings without resorting to time-consuming and expensive fatigue tests.

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Keywords: High-strength steel, surface finish, blanking grooves, surface roughness, fatigue strength

* Corresponding author. Tel.: /
E-mail address: minhduc.tran@nl.bosch.com

Effect of friction in gear tooth bending fatigue test with three point load application

Ivan Čular[a], Krešimir Vučković[a,*], Dragan Žeželj[a], Željko Božić[a]

[a]*University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, 10000 Zagreb, Croatia*

Abstract

Gear tooth bending fatigue test, as opposed to the running gear test, is conducted to generate fatigue data at a comparatively low price while retaining the overall material fatigue relevance of the data. Since the effect of friction on bending fatigue life of the gear specimen is often assumed as negligible, the test itself is usually performed under dry conditions. The aim of this study is to evaluate tooth flank friction effect on steel spur gear bending fatigue life. Unlike the standard single tooth bending fatigue tests, numerical simulations conducted in this study are done on a similar experimental setup by utilizing three point load application simultaneously loading two gear teeth at the highest point of single tooth contact, while the reaction force is provided by the gear shaft. Assuming plane stress conditions, the tooth root stresses are numerically predicted by two-dimensional elastic finite element analysis. The gear tooth bending fatigue life is predicted by imploring stress-life approach with consideration of mean stress, surface finish and size effects. The results of the computational model are validated against experimental fatigue lives from the available literature. The study revealed that tooth flank friction has notable impact on gear tooth bending fatigue life.

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Keywords: gear tooth bending fatigue test, stress-life approach, finite element analysis, friction

* Corresponding author. Tel.: /
E-mail: kresimir.vuckovic@fsb.hr

Modeling and simulation for aluminium profile extrusion

Admir Šupić[a,*], Almir Bečirović[a], Aldin Obućina[a], Milorad Zrilić[b]

[a]*University of Travnik, Faculty of Technical Studies, Aleja konzula No. 5, 72270 Travnik, Bosnia and Herzegovina*
[b]*University of Belgrade, Faculty of Technology and Metallurgy, Karnegijeva No. 4, 11000 Belgrade, Serbia*

Abstract

Global aluminium consumption in the last decade followed by an overview of deformation theory and extrusion process basics are presented in the Introduction of this paper. The components of the extrusion press with additional equipment and integrated systems are presented in the next chapter of this work. The extrusion die design is described in detail, from the designing to the manufacturing process of the extrusion die. This is followed by an introduction to the theory of the finite element method and numerical analysis. The extrusion process simulation represents the final part of this work; in this work, the “L” profile, manufactured by the German company “HUECK GmbH”, with the profile number P447937 is used for the simulation. The extrusion is simulated in the COMSOL software. Following the end of the simulation process, referent measurements like billet temperature, extrusion velocity, isothermal exchange of extrusion and deformation are presented. The simulation results are used to help in predicting die damage, so it could be eliminated and corrections could be made at the right time. In this way, it is possible to save time and money.

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Keywords: deformation, extrusion, simulation, COMSOL

* Corresponding author. Tel.: /
E-mail address: admirsupic@gmail.com

Pressurized Thermal Shock analysis of the reactor pressure vessel

Peter Trampus[a,]*

[a]Professor emeritus, H-2401 Dunaújváros, University of Dunaújváros, Hungary

Abstract

PTS analysis is a substantial part of the technical analyses supporting the license application for operation beyond design life. Guidance for the analysis' concept is given by the Hungarian nuclear regulator which is in line with the relevant international rules. Involving technical support organizations and independent consultants as well as taking into account the changes in fuel management Paks NPP, Hungary, compiled a new PTS analysis. Subjects of the analysis were the RPV belt line region components as well as other circumferential welds of the RPV including nozzle region. Beyond the PTS initiating events selected on the basis of engineering judgment a PSA provided additional transients which showed a higher frequency than 10^{-5} /year. Thermal-hydraulic calculations completed for each selected PTS initiating event provided the necessary input for the structural analysis. Based on core configurations end-of-life fluence were calculated. Neutron dosimetry surveillance results were used to verify the calculations. Temperature and stress field calculations were performed by solving the system of equations of elasticity. Underclad crack was postulated for fracture mechanics calculation. K_I was calculated at the crack tip and the boundary between the cladding and base / weld metal; K_{Ic} was calculated on the basis of the reference curve. Comparison of these two parameters ($K_I \leq K_{Ic}$), i.e. evaluation of whether the postulated defect stability criteria was met, gave the result.

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Keywords: life extension; pressurized thermal shock; plant transients; fast neutron fluence; linear elastic fracture mechanics; underclad crack.

* Corresponding author. Tel.: +36-20-985-5970
E-mail address: trampus@uniduna.hu

Strain-life fatigue curves on the basis of shear strains from torsion

Andrzej Kurek[a,*], Marta Kurek[a], Tadeusz Łagoda[a]

[a]*Opole University of Technology, ul.Mikołajczyka 5, 45-271 Opol, Poland*

Abstract

The study is about the determination of the fatigue life curves for strain-controlled torsional loads on the basis of 6082-T6 aluminium alloy experimental data. 'Diabolo' type full specimens have been tested on newly designed test stand. Tree models and two fitting methods were used to determine strain-life curve constraints. The models used in this paper were: Kandil, Langer and recently proposed Kurek-Łagoda. And the methods were standard least squares approach and bisquare waged approach. MATLAB software was used for curve fitting for this article.

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Keywords: fatigue characteristics, strain-life curve, torsion, shear strain;

* Corresponding author. Tel.: +48 77 449 84 19.
E-mail address: a.kurek@po.opole.pl

Model and software for fatigue test planning and damage assessment from a probabilistic approach

Sergio Blasón[a,*], Alfonso Fernández-Canteli[a], Enrique Castillo[b]

[a]University of Oviedo, 33001 Oviedo, Spain
[b]Royal Academy of Engineering and Royal Academy of Science, 39050 Santander, Spain

Abstract

A reliable definition of the so-called S-N field is a key task in the design of components susceptible to fatigue damage. As consequence, to have a model which allows the evaluation of fatigue behaviour of elements subjected to variable loading histories is essential, besides to determine the scatter inherent to this kind of deterioration during the operating life of components. This work shows the use of the probabilistic model developed by Castillo-Canteli for the characterization of the fatigue behaviour of materials regardless of the type of variable used in the evaluation (stress, strain or even an energetic parameter range) in the HCF regime. The model is based on both physical and statistical conditions: limited ranges of the number of cycles and also the range of the driving force, stability against dimensional change, size effect, limiting behaviour and compatibility condition between distributions in both axis. These solid premises lead to the extreme value distribution of Weibull for minima as a solution (the Gumbel family is also feasible if some requirements are relaxed). In this way, the entire GP-N field (i.e. Generalized Parameter versus Number of cycles until failure) can be reduced to a single cumulative distribution function by using a normalizing variable which combines the information from both GP and N. The capabilities of the model are proved through two different perspectives: a) test planning and optimization to obtain the GP-N field under constant amplitude ranges of loads; b) probabilistic description of damage parameters (linear or non-linear rules) under variable amplitude ranges. The implementation of this methodology in free software, ProFatigue and ProMiner, is also described and shown.

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Keywords: Probabilistic fatigue model, test planning, probabilistic damage, software for fatigue assessment

* Corresponding author. Tel.: /
E-mail address: blasonsergio@uniovi.es

Load and temperature assessment in sandwich structured composite using embedded optical sensors

Michal Jurek[a,*], Katarzyna Majewska[a], Magdalena Mieloszyk[a], Wieslaw Ostachowicz[a]

[a]*Institute of Fluid Flow Machinery, Polish Academy of Sciences, Fiszera 14, 80-231 Gdansk, Poland*

Abstract

Sandwich structured composites are widely used in many industry applications especially where high strength to weight ratio is required. Sandwich panels are used in e.g. aeronautics, civil engineering road vehicles and ships. In such applications it is often important to control the loads and operation conditions e.g. temperature. The layered structure consisted of two thin laminate outer skins and lightweiht (e.g., honeycomb or foam) internal core layer. Due to structural and geometrical properties these composites are light, have a relatively high flexural strength and have high thermal insulating characteristics. The paper presents an application of fibre Bragg grating (FBG) sensors for assessment of load and temperature influencing on the sandwich composite sample.

For this purpose glass fibre – foam sandwich composite specimen with embedded FBG sensors was fabricated. The temperature influence on embedded sensors' Bragg wavelength changes was analysed. Moreover various loading scenarios were considered. The aim of the experiment was to determine whether, based on Bragg wavelength changes for individual sensors, it is possible to detect the occurrence of strain/ stress field concentration and determine its localisation. To achieve the goal of the experimental investigation - series of measurements with specimens' point loading of were performed.

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Keywords: Composite, bragg grating sensors, temperature assessment

* Corresponding author. Tel.: +48-17-865-16-22; fax: +48-17-865-16-22.
E-mail address: mjurek@imp.gda.pl

Non-contact excitation and focusing of guided waves in CFRP composite plate by air-coupled transducers for application in damage detection

Michal Jurek[b,*], Maciej Radzienski[a], Pawel Kudela[a], Wieslaw Ostachowicz[a]

[a]*Institute of Fluid Flow Machinery, Polish Academy of Sciences, Fiszera 14, 80-231 Gdansk, Poland*
[b]*Rzeszow University of Technology, Poznanska 2, 35-959 Rzeszow, Poland*

Abstract

Guided waves have been utilized in Structural Health Monitoring (SHM) and Non-Destructive Testing (NDT) for many years. The vast majority of applications are based on contact wave excitation by using a group of piezoelectric transducers attached to the surface of a structure. However, in some cases piezoelectric transducers cannot be used directly on the structure and noncontact wave excitation methods are preferable. The paper presents the results of laboratory investigations utilizing air-coupled excitation with the use of ultrasound transmitters. The response of the specimen under various excitations by ultrasound transmitter array (UTA) was investigated. Various number of actuators and their configurations were considered. Moreover, various methods of wave focusing have been analysed. Next, the experimental verification of guided wave based damage detection system with proposed air-coupled excitation is presented. The wave sensing was non-contact as well. For this purpose the Scanning Laser Doppler Vibrometer (SLDV) was used. Full wavefield images and wave profiles for various excitation were prepared. The influence of ultrasound transmitter configuration and focusing method on the energy of induced wave was highlighted on RMS maps. Tests were carried out on the CFRP plate with dimension 500 x 500 x 1.5 mm. The delamination damage in a form of 15 x 15 mm Teflon tape insert was analysed.

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Keywords: guided waves; air-coupled excitation; non-destructive testing; ultrasound transmitter

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* Corresponding author. Tel.: +48-17-865-16-22; fax: +48-17-865-16-22.
E-mail address: mjurek@imp.gda.pl

Pressure vessels that explode after many years of service. Is there a common cause?

Donato Firrao[a,*], L. Marmo[a], P. Matteis[a]

[a]DISAT, Politecnico di Torino, Torino, Italy

Abstract

On August 3, 2013, at 5 am a sudden strong noise rattled the Science Museum in downtown Turin, Italy. The Museum was hosted into a XVII century building.
A gas bottle belonging to a fire-safety system had burst. The 80 l gas bottle did contain inert gas, pressurized at 200 bar. It was in continuous operation since the year 2000, alongside many other bottles belonging to the same fire-extinguishing system.
Gas-bottles were propelled all around causing serious damage to the exposition stands. The Museum is still closed for extensive repair.
Environment assisted cracking having been ruled as the cause of the fracture process, the question arises: is 13 years too long a time for an EAC gas bottle burst?
On July 11, 2016, at 18:30, a sudden strong noise rattled the balcony of a 1st floor mountain house in Melezet, a small village outside Bardonecchia, in the province of Turin, Italy. Altitude 1,500 m (4,500 ft). A LPG filled bottle had exploded, destroying the wood cabinet, in which it was located, as well as, partially, the wood railing of the balcony. The bottle flew into the down court.
The bottle had been filled in March 2016, but almost 15 years had elapsed since previous pressure testing. It had been fabricated in the 50's. Internal pressure in this type of bottles is dictated by the propane (which constitutes most of the LPG) vapour pressure which is controlled by the temperature. Internal pressure is slightly less than 10 bar.
Here again EAC was ruled as the cause of the burst, and again the time since last water inlet (15 years ca.) was apparently too long for EAC.
A model to explain the long corrosion process under pressure has been envisaged; it calls for water vapour condensation and therefore corrosion under pressure in cold days, followed by internal pressure raising in hot days. In the last winter before burst, the EAC crack reaches the critical dimension that allows maximum summer driven pressure to have the gas bottle explode.

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Keywords: Pressure vessels, corrosion, LPG

[*] Corresponding author. Tel.: /
E-mail address: donato.firrao@polito.it

High speed observation of fast crack propagation and arrest behaviors in 3D transparent structures

Fuminori Yanagimoto[a,*], Kazuki Shibanuma[a], Katsuyuki Suzuki[b]

[a]*Department of Systems Innovation, Graduate School of Engineering, the University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo, Japan*
[b]*Research into Artifacts, Center for Engineering, the University of Tokyo, 5-1-5, Kashiwa-shi, Chiba, Japan*

Abstract

Crack arrester is employed for preventing brittle cracks from causing catastrophic failure of large steel structures. In large container ships, so called “structural crack arrest design” utilizing welded joint has been recently used to improve brittle crack arrestability of the structures. Although such design is already applied to commercial ships, the mechanism of crack arrest in such design has not been clear because crack behavior in the joint is 3D and hard to measure by conventional methods. Therefore, in order to clarify crack arrest mechanism in structural crack arrest design, 3D rapid crack propagation and arrest behavior was observed in T-joint-like structures made of transparent elastic material by using high speed camera. The observation showed that the crack front shape was significantly important to consider crack arrest mechanism because the semi-elliptical-like crack front shape in flange plates caused reduction of SIF and crack arrest.

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Keywords: Brittle crack propagation and arrest behavior; Rapid crack propagation; Steel;

* Corresponding author. Tel.: +81-3-5841-6554
E-mail address: yanagimoto@struct.t.u-tokyo.ac.jp

Experimental investigation of the displacement field in a circular disc drilled eccentrically

Ermioni D. Pasiou[a], Stavros K. Kourkoulis[a,*], Maria G. Tsousi[a], Christos F. Markides[a]

[a]*Laboratory for Testing and Materials, Department of Mechanics, School of Applied Mathematical and Physical Sciences, National Technical University of Athens, Theocaris Building, Zografou Campus, 157 73 Athens, Greece*

Abstract

The aim of the present study is to experimentally quantify the role of potential eccentricities of the ring's hole on the overall displacement field developed in a circular ring under diametral compression. In this context, circular rings, made of PMMA, were subjected to diametral compression using the device suggested by the International Society for Rock Mechanics (ISRM) for the standardized implementation of the Brazilian-disc test. The specimens were circular discs, drilled throughout their thickness, forming either perfect rings (zero eccentricity) or discs with an eccentric hole. The parameters considered included the angle, θ, between the line of centers and the loading axis and the distance, d, between the centers of the disc and the hole. The displacement field developed all over the surface of the specimens was determined using the 3D Digital Image Correlation (DIC) technique. The experimental protocol proved that for small and medium values of the parameter d the influence of eccentricity is described by a linear law independently of the value of angle θ, while for relatively high d-values the phenomenon becomes strongly nonlinear.

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Keywords: Brazilian-disc test; ring test, eccentricity, displacement field; Digital Image Correlation; PMMA

* Corresponding author. Tel.: +30-210-772-1263; fax: +30-210-772-1302.
E-mail address: stakkour@central.ntua.gr

Comparison of SIF solutions obtained by XFEM and conventional FEM for cracks in complex geometries like valve body

Ivica Galić[a,]*, Ivan Čular[a], Krešimir Vučković[a], Zdenko Tonković[a]

[a]*University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Ivana Lučića 5, Zagreb 10000,Croatia*

Abstract

Globe valve is a type of industrial valve used to obstruct or regulate flow of the fluid in pipelines via linear motion of the plug. The main component of the valve, the valve body, is the carrier of the internal and often variable pressure. The body itself is usually made by sand casting which may result in impurities and metallurgic or shrinkage defects. The above-mentioned, coupled with the relatively geometrically complex shape of the valve bodies, makes the accurate determination of the crack formation and growth often challenging. Additionally, formation of the cracks in a pressure vessel such as globe valves usually leads to one of the two outcomes. If the crack reaches its critical size under specified loading conditions, a catastrophic failure may occur. On the other hand, the preferred option of stable crack growth can lead to the effect known as leak-before-break. Therefore, it is necessary to accurately determine stress intensity factors (SIF) for cracks in such geometry. This determination is usually made by classical finite element method, and it is very hard to do on complex shape. In addition, it is possible to determine SIF using eXtended Finite Element Method (X-FEM) which is proved on simple geometry. In this paper, the verification of the X-FEM has been conducted by comparison of results obtained by this method and by the classical method on valve body. Presented computational model suggest the possibility of accurately determining fracture mechanics parameters for cracks in geometrically complex components such as those of valve bodies.

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Keywords: Pressure valve; X-FEM; FEM; stress intensity factor; leak-before-break

* Corresponding author. Tel.: +385 1 61 68 230; fax: +385 1 61 68 284.
E-mail address: ivica.galic@fsb.hr

Applied problems of fracture mechanics, resource and safety of technical systems

V. Moskvichev[a,*]

[a] *Institute of Computation Technologies SB RAS, Mira, 53, Krasnoyarsk, 660049, Russia*

Abstract

The development trends of technical systems from point of view of reliability, risk-analysis and safety are considered. The types of limit states are formulated and the results of experimental determinations of fracture toughness characteristics are given. Also examples of using the reliability theory, risk-analysis and fracture mechanics methods are presented to solve various applied problems.

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Keywords: structural materials, life time, safety, technical systems

* Corresponding author. Tel.:+7-391-227-29-12; fax: +7-391-212-42-88.
E-mail address: krasn@ict.nsc.ru

Effect of polymeric interlayer on wave propagation in transparent soda-lime glass

Muhammad Zakir Sheikh[a], Zhen Wang[a], Tao Suo[a,*], Yulong Li[a], Sohail Ahmed[a], Uzair Ahmed Dar[a]

[a]*School of Aeronautics, Northwestern Polytechnical University, Xi'an, 710072, Shaanxi, PR China.*

Abstract

The transparent armor and aircraft windshields are comprising of glass or transparent ceramic laminates joined with the polymeric interlayer. The interlayer thickness plays a vital role in improving the damage, impact, and wave propagation response of transparent laminates. The edge-on-impact simulations on monolithic ballistic soda-lime glass are performed first to investigate and verify the wave propagation using ANSYS/Autodyn. Secondly, to lessen the wave speed and damage area in the glass, the different thicknesses of PU interlayer were incorporated in the numerical model and analyzed. The delay time in wave arrival time as a function of interlayer thickness was estimated. Additionally, the influence of PU interlayer orientations and a number of layers (single & double) on longitudinal wave propagation and damage are also studied numerically and discussed.

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Keywords: Transparent armor; Wave propagation; Edge-on-impact; PU interlayer; Damage;

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* Corresponding author. Tel.: +86-29-88494381; fax: +86-29-88491544.
E-mail address: suotao@nwpu.edu.cn

Designing and testing characteristics of thin stainless steel diaphragms

B. Perić[a,*], A. Simonović[a], T. Ivanov[a], S. Stupar[a], M. Vorkapić[b], O. Peković[a], J. Svorcan[a]

[a]*University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11120 Belgrade, Serbia b University of Belgrade, ICTM - CMT, Njegoševa 12, 11000 Belgrade, Serbia*

Abstract

Metal membranes are defined as thin steel circular plates. The metal membranes are widely used in the measurement technique and they are constantly loaded over the entire surface. In case that a membrane is loaded with uniform load over the entire surface. In case that the membrane is stiffened over the edge, then it is called a diaphragm. According to the making method membranes are divided into flat and corrugated. Corrugated membranes are used mainly in a low pressure area. Membranes are most commonly made of firm alloy austenitic steel. In this paper numerical and experimental analysis of a thin corrugated diaphragm 24 mm diameter is presented, with variable material thickness and variable corrugations geometry. Experimental tests are conducted on a corrugated stainless steel (AISI 316) diaphragm. Experimental results are compared with numerical results in ANSYS software package. A comparative analysis of the sinusoidal and toroidal diaphragms has shown that there is a higher sensitivity of the sinusoidal diaphragm, that is, if the thickness of the diaphragm increases, and their stiffness is increased. In general, for small pressure ranges from 10 mbar to 50 mbar, the sinusoidal diaphragms have a faster response.

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Keywords: Transparent armor; Wave propagation; Edge-on-impact; PU interlayer; Damage;

* Corresponding author. Tel.: +381 (11)3302242;
E-mail address: bperic@mas.bg.ac.rs

Peridynamic modelling of delamination in DCB specimen

U. Yolum[a], E. Gök[a], D. Coker[b], M.A. Guler[a,*]

[a]*Dept. of Mechanical Engineering, TOBB University of Economics and Technology, Söğütözü, Ankara 06560 Turkey*
[b]*Dept. of Aerospace Engineering, Middle East Technical University, Ankara, 06800 Turkey*

Abstract

Peridynamics is a robust theory to capture failure initiation and failure propagation in both isotropic and orthotropic materials. This paper present a method to model Mod I delamination failure in composite materials using PD approach implemented in FEA. A bilinear PD damage law is formulated for PD interface by modifying the original failure formulation of Silling. That bilinear PD interface behavior is inspired by the bilinear damage law of CZM models. A MATLAB code is generated to generate PD interactions and corresponding surface correction factors. Proposed formulation is adapted to FEA code ABAQUS. Using generated MATLAB pre-processing code, PD model of a DCB specimen is generated. In addition, the same problem is solved using Cohesive Zone Modelling approach in ABAQUS. PD and FEA results are compared with results from literature. Obtained results indicate that PD solutions correlate well with CZM and results from literature.

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Keywords: Peridynamic Theory; Failure; Composite Materials; DCB Test; Mode I

* Corresponding author. Tel.: +90-312-292-4088; fax: +90312-292-4091.
E-mail address: mguler@etu.edu.tr

Influence of pyrolysis parameters on the efficiency of the biochar as nanoparticles into cement-based composites

Isabella Cosentino[a], Luciana Restuccia[a], Giuseppe Andrea Ferro[a,*], Jean-Marc Tulliani[b]

[a]*DISEG-Politecnico di Torino, C.so Duca degli Abruzzi 24, Turin 10129, Italy*
[b]*DISAT-Politecnico di Torino, C.so Duca degli Abruzzi 24, Turin 10129, Italy*

Abstract

In this research, a particular kind of biochar provided by UK Biochar Centre has been added as nanoparticles into cementitious composites. Its principle characteristic lies in the standardization of its process production, that makes it suitable to been used as filler in cement-matrix composites, ensuring the reproducibility of the cement mix (I. Cosentino "The use of Bio-char for sustainable and durable concrete", 2017). The pyrolysis parameters and the content of carbon in the standardized biochar influenced its efficiency to enhance the mechanical properties of the cement composites: the results, in terms of flexural strength and fracture energy, have been worse than those obtained in previous studies (L. Restuccia "Re-think, Re-use: agro-food and C&D waste for high-performance sustainable cementitious composites", 2016), in which particles have been produced with higher temperature. However, also with standardized biochar a general enhancement of mechanical properties has been recorded, a sign that they can be used to create new green building materials.

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Keywords: pyrolysi; biochar; cement-based composites; carbon nanoparticles; mechanical properties; flexural strength; fracture energy;

* Corresponding author. Tel.: +39 0110904885;
E-mail address: ferro@polito.it

Effect of sand particles on the erosion-corrosion for different locations of carbon steel pipe elbow

M. Amara[a,b], B.G.N. Muthanna[b,c], M. Tahar Abbes[a], M. Hadj Meliani[b,]*

[a]Laboratory of Mechanics and Energetics, Hassiba Benbouali University of Chlef. Hay salem, 02000, Algeria
[b]Laboratory of Physics and Theoretical Physics of Materials, Hassiba Benbouali University of Chlef. Hay salem, 02000, Algeria.
[c]Laboratory of Rheology and Mechanics, Hassiba Benbouali University of Chlef. Hay salem, 02000, Algeria.

Abstract.

Erosion combined with corrosion becomes the most problem in the seawater desalination plant due to the fast deterioration of the internal line pipe. Corrosion products were characterized for surface morphology, phase composition and element concentration. In this paper, the prediction of erosion of solid particles in geometry of the elbow is performed by means of a numerical simulation. Fluid Dynamics (CFD) simulations with FLUENT software are performed to study erosion prediction in 3-D, 90° elbow for phase (liquid and solid particles), For a range of particle sizes from 2 mm, 0.4 mm and 4 µm for different valve opening angles in order to obtain the real tool failure reasons of erosion. The obtained conclusion by analyzing the reasons, applies in the middle make downhole tools to control and prevent erosion failure phenomenon.

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Keywords: Erosion-corrosion, pipeline erosion, fluid flow, sea sand.

* Corresponding author. Tel.: 213 796281441.
E-mail address: m.hadjmeliani@univ-chlef.dz

The development and application of the new methodology for conveyor idlers fits testing

Žarko Mišković[a,*], Radivoje Mitrović[a], Zoran Stamenić[a], Gordana M. Bakić[a], Miloš B. Đukić[a], Bratislav Rajičić[a]

University of Belgrade – Faculty of Mechanical Engineering, Kraljice Marije 16, 11120 Belgrade 35, Serbia

Abstract

The proper interference fit between the joined parts is a prerequisite for an effective pressure joint. The main purpose of the pressure joint is to transfer tangential, radial and axial loads between the joined parts. In order to provide proper functioning of the machine assembly (whose component parts are connected by the pressure joints), i.e. the transfer of loads without skidding, it is essential to determine the pressure joints interference fit parameters. The new methodology for the conveyor idlers pressure joints quality control is presented in this paper. The procedure for the analytical determination of the expected disassembling force (limiting value) in the pressure joints between the shaft – rolling bearing and the bearing – idler shell is described in detail. The analytically calculated boundary values are compared with the experimental ones. According to the presented criteria, the evaluation of the conveyor idler fits quality was performed and reliable conclusions were successfully adopted.

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Keywords: conveyor idlers; experimental testing; testing methodology; interference fits;

* Corresponding author. Tel.: /
E-mail address: zmiskovic@mas.bg.ac.rs

Comparative examination of the strengthened and non-strengthened NIMONIC specimens with laser shot peening method

S. Petronić[a,*], K. Čolić[b], B. Đorđević[b], Ž. Mišković[c], Đ. Katanić[a], F. Vučetić[c]

[a]*University of Belgrade, Institute of Nuclear Science "Vinča", Serbia*
[b]*Innovation Centre of Faculty of Mechanical Engineering, University of Belgrade, Kraljice Marije 16, 11120 Belgrade 35, Serbia*
[c]*Faculty of Mechanical Engineering, University of Belgrade, Kraljice Marije 16, 11120 Belgrade 35, Serbia*

Abstract

Laser shot peening (LSP) of material strengthening is nowdays widely used method in various branches of industry. In this paper are presented comparative examinations of specimen made of NIMONIC and strengthened specimen on which laser shot peening method was performed. Specimens were made as thin plates with holes. Macrostructural surface tests were performed around the specimens holes with different magnifications for both specimens as well as certain damages on the specimens. 3D images of specimens damages provide insights into the its dimensions. In addition, the roughness of non-strengthed and strengthed specimens was also performed. Hardness tests using the Rockwell C method of both specimens show a difference in the hardness of both samples and the main characteristics of the laser shot peening method. Also, the analysis on how the damage of samples could represent the location of initial cracks that could cause failure of the specimens or generally machine part is given as well.

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Keywords: Laser shot peening; Nimonic; Macrostructural surface tests.

* Corresponding author. Tel.: /
E-mail address: sanjapetronic@yahoo.com

Validation of BS 7910; assessing the integrity of pipes containing axial flaws

Konstantinos Kouzoumis[a,c,*], Isabel Hadley[b], Mahmoud Mostafavi[c]

[a]*NSIRC, Granta Park, Great Abington, CB21 6AL, Cambridge, UK*
[b]*TWI Ltd., Granta Park, Great Abington, CB21 6AL, Cambridge, UK*
[c]*University of Bristol, Queens Building, University Walk, BS8 1TR, Bristol, UK*

Abstract

The results of hundreds of large scale fracture tests have been collected from various sources and analyzed in accordance with the latest version of the BS 7910 fitness for service (FFS) standard and, in selected cases, with R6 and/or the API 579-1/ASME FFS-1 fitness for service standard. This analysis aims to provide further validation of BS 7910 and identify where modification is needed. The tests cover a wide variety of materials, flaw geometries (surface, embedded, through thickness) and loadings (pressure, bending, residual stress), thus validating the standard over a wide spectrum of applications. All the tests are analyzed with the use of the basic assessment option (Option 1), which requires only the basic tensile properties and fracture toughness of the component, and selected tests are re-analyzed using more advanced methods.
During the analysis, close attention was paid to the results of 173 tests on pipes with axial flaws, where an apparently arbitrary safety factor on reference stress is included in BS 7910, but not in other standards, leading to apparently lower defect-tolerance when BS 7910 is used. The history of this part of the standard, along with approaches used in other standards, was investigated. A modified equation, without this safety factor, was used in the analysis of the tests, where applicable, and compared with results from other standards. The comparison between the approaches shows the BS 7910 safety factor to be unnecessary, with all test results falling outside the failure assessment diagram (FAD), but with less conservatism, as they lie closer to it.

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Keywords: Fitness For Service; BS 7910; Integrity assessment; R6; API 579-1/ASME FFS-1

* Corresponding author. Tel.: +44-122-394-0401.
E-mail address: k.kouzoumis@bristol.ac.uk

Assessing fracture surface ductility by confocal laser scanning microscopy

E.D. Merson[a,*], V.A. Danilov[a], M.L. Linderov[a], P.N. Myagkikh[a], D.L. Merson[a], A. Vinogradov[b]

[a]*Institute of Advanced Technologies, Togliatti State University, Belorusskaya str. 14, Togliatti 445667, Russian Federation*
[b]*Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology – NTNU, N-7491 Trondheim, Norway*

Abstract

Hitherto there is no generally accepted quantitative parameter which, on the one hand, would reliably characterize the ductility of the whole fracture surface, and, on the other hand, could be relatively quickly measured. This circumstance substantially affects the objectivity of the fractographic analysis which effectiveness is still strongly dependent on the experience and skills of an expert. Recent studies showed that the value of the normalized fracture surface area *Rs* can serve as the measure of the fracture surface ductility. This parameter can be evaluated by the quantitative confocal laser scanning microscopy (CLSM). In the present study we investigated the *Rs* value for the fracture surfaces of the low carbon steel specimens tested in the temperature range from 200 to -196 °C where the steel undergoes ductile-to-brittle transition accompanied by the alternation of the fracture mode from ductile to brittle. The temperature dependence of the *Rs* value is found to have a sigmoidal shape with the sharp drop in the range from 100 to -100 °C. It is demonstrated that the *Rs* is strongly correlated with the fracture surface appearance: the *Rs* decreases concurrently with increasing brittleness of the fracture surface.

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Keywords: confocal laser scanning microscopy; fracture surface; quantitative fractography; normalized surface area; low-carbon steel

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* Corresponding author. Tel.: /
E-mail address: Mersoned@gmail.com

Experimental approach to fracture mechanics in nanometer scale

Takayuki Kitamura[a], Takashi Sumigawa[a,*]

[a]*Department of Mechanical Engineering and Science, Kyoto University, Kyoto, 615-8540, Japan*

Abstract

The experimental requirements to understand the strength of bulk material have been intensively investigated in terms of the solid mechanics and the knowledge for evaluating the main characteristics are already standardized from macroscopic viewpoints. On the other hand, in recent years, industrial needs as well as academic interests require the mechanical testing in micro- and nano-scale materials and extensive effort has been conducted for the development of methodology. It is not only because of further evolution in small devices such as electronic devices and MEMS/NEMSs but also because of multiscale modelling for a large component for precise design based on the numerical simulations. The miniaturization scale in testing methodology is reaching at almost nanometer order.

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Keywords: nano-scale, crack propagation, continuum mechanics

* Corresponding author. Tel.: /
E-mail address: sumigawa@cyber.kues.kyoto-u.ac.jp

Structural-time nature of the dynamic instability of the fracture process

Yuri Petrov[a,b,c], Nikita Kazarinov[a,b,*]

[a]*Saint Petersburg State University, Saint Petersburg 199034, Russia*
[b]*Institute of problems of mechanical engineering, Saint Petersburg 199178, Russia*
[c]*Research Institute for Mechanics, National Research Lobachevsky State University of Nizhnii Novgorod, 603600, Nizhnii Novgorod, Russia*

Abstract

Principal effects of dynamic instability of the fracture process are investigated. Particularly an issue of a dependence of stress intensity factor (*K*) on crack velocity (*v*) is discussed. Uniqueness, related to the given material, and even existence of this dependence has been a matter of discussion among researchers, since contradicting experimental results have reported in the literature over last decades. In this paper results of numerical simulations of the crack propagation process are presented. A numerical scheme based on finite element method and incubation time fracture criterion was developed. Scattering of *K* values during the propagation process is considered to be a feature principally related to a spatial-temporal nature of the fracture process. It is found that quasistatic loading is characterized by a small scatter of the SIF values and fitting of the data can be performed in order to obtain some well-known *K*-*v* curve. In the case of a pulse loading the scatter is much higher and it can be concluded that a wide range of *K* values corresponds to a particular crack velocity and no unique continuous *K*-*v* curve can be associated with the process. These results are supported by well known experimental observations. Thus, it is proved that incubation time fracture criterion makes it possible to investigate dynamic crack movement for a wide variety of loading conditions (quasistatic, high rate and short pulse loading) and only one extra material parameter – incubation time is needed to predict a big variety of effects of the dynamic instability of the fracture process. This is a huge advantage comparing to a widespread approach, which involves complicated experimental determination of material strain rate dependencies and an a priori given *K*-*v* relationship.

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Keywords: Dynamic fracture, crack propagation, K-v dependence, incubation time, FEM

[*] Corresponding author. Tel.: +7-964-366-64-64.
E-mail address: n.kazarinov@spbu.ru

ECF22 - Loading and Environmental Effects on Structural Integrity

A new local approach to cleavage fracture and its application in a reactor pressure vessel

Guian Qian[a,*], Wei-Sheng Lei[b,*], Shunpeng Zhu[c,d,*], José Correia[e], Abílio De Jesus[e]

[a]*State Key Laboratory for Nonlinear Mechanics (LNM), Institute of Mechanics, Chinese Academy of Sciences, Beijing 100190, China*
[b]*Applied Materials, Inc., 974 East Arques Avenue, Sunnyvale, CA 94085, USA*
[c]*School of Mechanical and Electrical Engineering, University of Electronic Science and Technology of China, Chengdu 611731, China*
[d]*Department of Mechanical Engineering, Politecnico di Milano, Milan 20156, Italy*
[e]*INEGI, Faculty of Engineering, University of Porto, Porto 4200-465, Portugal*

Abstract

The paper presents and applies a local approach to correlate the fracture behavior of a notched and fracture mechanics specimen. The random nature of cleavage fracture process determines that both the microscopic fracture stress and the macroscopic properties including fracture load, fracture toughness and the ductile to brittle transition temperature are all stochastic parameters. This understanding leads to the proposal of statistical assessment of cleavage induced notch toughness of ferritic steels according to a new local approach to cleavage fracture. The temperature independence of the two Weibull parameters in the new model induces a master curve to correlate the fracture load at different temperatures. This proposed index is applied to compare the notch toughness of a ferritic steel with two different microstructures.

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Keywords: Ferritic steels, cleavage fracture, notch brittleness, statistical model

* Corresponding author. Tel.: +86 10-82543841.
E-mail address: qianguian@imech.ac.cn (G. Qian), Leiws2008@gmail.com (W.S. Lei), zspeng2007@uestc.edu.cn (S.P. Zhu)