SIRAMM

H2020-WIDESPREAD-2018-03

Project No. 857124

3rd International Workshop on

Reliability and Design of Additively Manufactured Materials

Faculty of Mechanical Engineering, Univ. of Belgrade

& online

Belgrade, Serbia, 4th - 6th October 2022

Workshop Programme & Book of Abstracts

Workshop organized by:

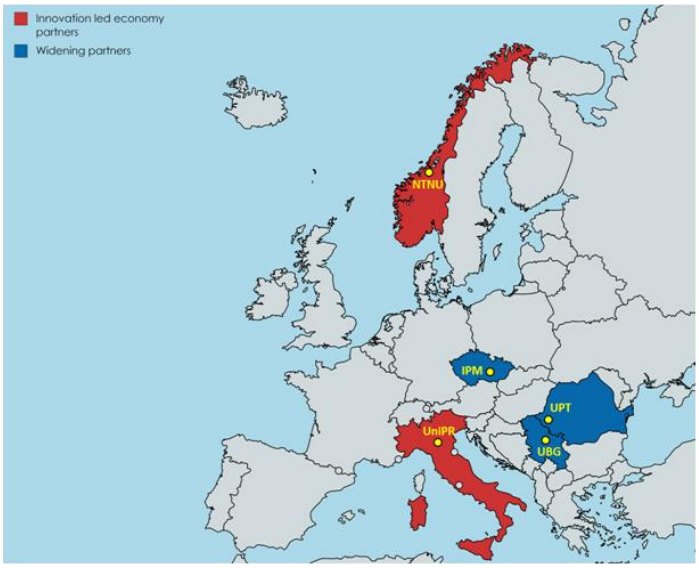
Polytechnic University of Timisoara,
ROMANIA

University of Belgrade,
SERBIA

Institute of Physics of Materials, Brno,
CZECH REP.

University of Parma,
ITALY

Norwegian Univ. of Science and Technology,
NORWAY



Institutions participating in the SIRAMM project

To join the workshop online, please connect to ZOOM Meeting at this link:

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Meeting ID:

Passcode:

Workshop Programme

(Central European Time - Rome, Paris, Prague, Belgrade)

Tuesday, 4th October 2022

17:00-20:30 **Registration** and **Welcome reception**
Faculty of Mechanical Engineering (FME), Univ. of Belgrade
Kraljice Marije 16, Belgrade, Serbia (Google map), **room 211, 2nd floor**

Wednesday, 5th October 2022

8:30-9:00 **Registration**
Faculty of Mechanical Engineering (FME), Univ. of Belgrade
Kraljice Marije 16, Belgrade, Serbia (Google map)

9:00-9:30 **Opening of the Workshop** and presentation of the SIRAMM project (FME & online)
Prof. Liviu Marsavina, Prof. A. Sedmak, Prof. R. Brighenti

09:30-10:00 **1st Keynote lecture** (FME & online) - Chairman Prof. Liviu Marsavina
TBD
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10:00-10:30 *Coffee break* (FME)

10:30-12:45 **1st Session** (FME & online) (12 min presentation + 3 min Qs&As)
Characterization of AM polymer-based materials
Chairman: Prof. Andrea Spagnoli

10:30-10:45 Analysis of printing parameter influence on FDM polypropylene tensile properties
Aleksa Milovanović, Zorana Golubović, Snežana Kirin; Ivana Jevtić, Tamara Smoljanić

10:45-11:00 Investigation on the properties of the Short Carbon Fibre Reinforced Nylon-6 Composite Filaments for 3D printing of the Functional Parts using Fused Filament Fabrication
Vishal Gupta, Prateek Saxena

11:00-11:15 Experimental determination of flexural strength on cylindrical and plate samples produced by additive manufacturing from ABS-X material
Isaak Trajkovic, Aleksandra Joksimovic, Uros Ilic, Marko Djurovic, Tijana Lukic , Jovana Lazovic , Milos Milosevic

11:15-11:30 Penetration testing of 3D printed projectiles made of various types of polymers
Muhamed Bisić, Faruk Razić, Adi Pandžić, Mustafa Bevrnja

11:30-11.45 Static and Fatigue behavior of 3D printed PLA and PLA reinforced with short carbon fibers
Estera Valean, Pietro Foti, Filippo Berto, Liviu Marsavina

11:45-12.00 Effect of manufacturing parameters on the impact fracture properties of DLP 3D-printed specimens
Emanoil Linul, Marian Baban, Sergiu-Valentin Galatanu

12:00-12.15	Designing a test bed and experiments on a 3D-Printed gear bearing. A feasibility study Cristian Moldovan, Carmen Sticlaru
12:15-12.30	Determining fracture mechanics parameters using the digital image correlation method on cylindrical samples produced by different additive manufacturing techniques Isaak Trajković, Miloš Milošević, Milan Travica, Marko Rakin, Ivana Jevtić, Aleksandar Sedmak, Bojan Medjo
12:30-12.45	FDM technology - different aspects of advantages and disadvantages Adi Pandzic
12:45-14:15	*Lunch break* (FME)
14:15-14:45	**2nd Keynote lecture** (FME & online) - Chairman Prof. Aleksandar Sedmak ***3d-printing metal is hard: the role of manufacturing imperfections in the design of high-strength porous biomaterials to replace bone tissue*** D. Melancon, D. Pasini – Polytechnique Montréal, Canada
14:45-16:45	**2nd Session** (FME & online) (12 min presentation + 3 min Qs&As) ***Modeling, simulation and testing of AM materials and processing*** Chairman: Prof. Roberto Brighenti
14:45-15:00	Influence of process parameters on temperature field and residual strain in FFF-printed parts Alberto Corvi, Luca Collini, Corrado Sciancalepore
15:00-15:15	Fatigue-resistant notches design based on data-driven approach for additive manufacturing Qingbo Wang, Chao Gao, Filippo Berto
15:15-15:30	Crack kinetics determination and lifetime estimation of additively manufactured PLA specimens with different layer heights Jan Poduška, Aleksa Milovanović, Lukáš Trávníček, Luboš Náhlík, Aleksandar Sedmak, Pavel Hutař
15:30-15:45	Polymeric 3D printouts as bimodular materials with emphasis on the analytical modeling of their flexural behavior Marius Nicolae Baba
15:45-16:00	Low-cycle fatigue and related fatigue damage mechanisms in additively manufactured IN939 superalloy Tomáš Babinský, Ivo Šulák, Alice Chlupová, Aleksa Milovanović, Luboš Náhlík
16:00-16:15	Evaluation of fatigue life of damaged UAV's attachment produced using additive manufacturing Nikola Raičević, Miloš Petrašinović, Danilo Petrašinović, Gordana Kastratović, Aleksandar Grbović
16:15-16:30	Mechanical characteristics of parts obtained by SLS printing technology Ivana Jevtić, Goran Mladenović, Miloš Milošević, Aleksa Milovanović, Isaak Trajković, Milan Travica
16:30-16:45	Quasi-static and fatigue properties of additively manufactured AlSi10Mg lattice of various scales Zhuo Xu, Ricardo Branco, Luis Borrego, Filippo Berto, Seyed Mohammad Javad Razavi
16:45 -19:00	**1st Belgrade tour (Museum Nikola Tesla, Saint Sava Church)**
20:00 -23:00	***Conference dinner***

Thursday, 6th October 2022

8:45-9:15	**3rd Keynote lecture** (FME & online) - Chairman Prof. Liviu Marsavina ***Wire-Laser Metal 3D Printing. A disruptive directed energy deposition technology by Meltio*** Meltio Svetozar Kolaser - 3D Republic, Serbia
9:15-10:45	**3rd Session** (FME & online) (12 min presentation + 3 min Qs&As) ***Characterization of AM metallic materials and composites*** Chairman: Prof. Aleksandar Sedmak
9:15-9:30	Thermo-mechanical fatigue properties of Inconel 718 manufactured by electron beam melting Ivo Šulák, Tomáš Babinský, Stefan Guth
9:30-9:45	Fabrication and tensile properties of SS 316L specimens obtained via Material Extrusion Additive Manufacturing Saveria Spiller, Sondre Ølsoybakk Kolstad, Seyed Mohammad Javad Razavi
9:45-10:00	Link between surface quality and fatigue properties of IN718 produced by Laser Powder Bed Fusion according to different testing configurations Federico Uriati, Nicoletto Gianni, Martina Meissnar
10:00-10:15	Determination of the impact of glass fiber reinforcement on the tensile properties of printed material obtained by FDM technology Marko Delić, Vesna Mandić, Srbislav Aleksandrović, Dušan Arsić
10:15-10:30	Ultrasonic atomization of magnesium alloy AZ61 based on the TIG melting method Jan Jaroš, Daniel Koutný, Lenka Klakurkova
10:30-10:45	Fracture and fatigue resistance of laser beam welded AA6156 T6 reinforced panels Blagoj Petrovski, Aleksandar Grbovic, Aleksandar Sedmak
10:45-11:15	*Coffee break* (FME)
11:15-12:45	**4th Session** (FME & online) (12 min presentation + 3 min Qs&As) ***Properties and models of AM materials and met materials*** Chairman: Dr. Lubos Nahlik
11:15-11:30	Defect sensitivity mitigation of the mechanical response of 2D multiphase lattice metamaterials Roberto Brighenti, Matteo Montanari, Andrea Spagnoli
11:30-11:45	Fracture resistance of 3D nano-architected lattice materials Marco Maurizi, Chao Gao, Filippo Berto
11:45-12:00	Numerical analysis of cellular structures. Homogenization of cellular structure based on the actual geometry of a unit cell obtained with a CT scanner Kevin Moj, Grzegorz Robak, Robert Owsiński
12:00-12:15	Two-dimensional thermal metamaterials: optimization of thermal conductivity and mechanical stiffness of metaplates Roberto Brighenti, Farzad Tatar, Liviu Marsavina
12:15-12:30	Pressure and shear loading of BCC lattice structures produced by SLM technology using contour scanning strategy Jan Jaroš, Daniel Koutný, Josef Zapletal, Libor Pantělejev
12:30-12:45	Bio-inspired core-shell architectured filament with tunable damage tolerance Li Liang, Filippo Berto, Chao Gao
12:45-14:30	*Lunch break* (FME)

14:30-16:15	**5th Session** (FME & online) (12 min presentation + 3 min Qs&As) ***Applications & advancements in AM materials and structures*** Chairman: Prof. Milos Milosevic
14:30-14:45	Effect of voids and inclusions on the wrinkling pattern of tensile thin sheets: an experimental and numerical study Andrea Spagnoli, Riccardo Alberini, Roberto Brighenti, Matteo Montanari
14:45-15:00	Center for Rapid Prototyping - Challenges in additive manufacturing and testing of materials Milos Milosevic
15:00-15:15	Development and design of a two-armed robot from the aspect of mechatronics Uros Ilic, Aleksandra Joksimovic, Marko Djurovic, Emil Veg, Isaak Trajkovic
15:15-15:30	Significance of designing the filling of an open rapid sand filter when removing impurities from water Marko Djurovic, Aleksandra Joksimovic, Uros Ilic, Emil Veg, Isaak Trajkovic
15:30-15:45	Strategy for wire arc additive manufacturing of thin walls Jakub Slavíček, Jakub Hurník, Daniel Koutný
15:45-16:00	Additive manufacturing of nanometre alignment mechanisms for Croatian National laboratory for length Marko Horvatek
16:00-16:15	Testing climatic stress component in vegetation via AM: challenges and new opportunities Ozge Ogut, Ole Emil Herrmann, Nerantzia Julia Tzortzi, Chao Gao, Chiara Bertolin
16:15-16:30	**Closing of the Conference and presentation of future SIRAMM events** (FME & online) Prof. Liviu Marsavina, Prof. A. Sedmak, Prof. R. Brighenti
17:00-19:00	**2nd Belgrade tour (Kalemegdan, City center)**

List of Keynote lectures

& Abstracts

Keynote lectures

Keynote lecture

1st keynote (TBD)

Keynote lecture

3d-printing metal is hard: the role of manufacturing imperfections in the design of high-strength porous biomaterials to replace bone tissue

David Mélançon[1]; Damiano Pasini[2]

[1] Department of Mechanical Engineering, Polytechnique Montréal, Canada
[2] Department of Mechanical Engineering, McGill University, Canada

E-mail: david.melancon@polymtl.ca, damiano.pasini@mcgill.ca

ABSTRACT

Recent development in additive manufacturing enables fabrication of architected materials whose properties, dependent on their internal architecture rather than their chemical composition, surpass those of conventional materials. Promising applications across multiple scientific fields arise from these engineered materials. In particular, a strong biomedical interest has fueled the development of structural porous biomaterials to build bone replacement implants. Compared to a fully solid implant, a porous implant would allow perfusion and nutrient transport to promote bone ingrowth. Rational design of the biomaterial pore morphology, possible with additive manufacturing, could additionally render an implant with mechanical behavior matching that of the surrounding bone tissue (see Figure 1). This mechanical biocompatibility is a crucial requirement for bone replacement implants to ensure load bearing as well as biological fixation.

One of the biggest challenges with 3D-printed biomaterials is the unavoidable mismatch between design models and manufactured samples. Inaccurate prediction of their mechanical properties could reduce mechano-biological performance and lead to a problematic revision surgery. In this talk, we will discuss how the manufacturing challenge can be tackled on two different fronts.

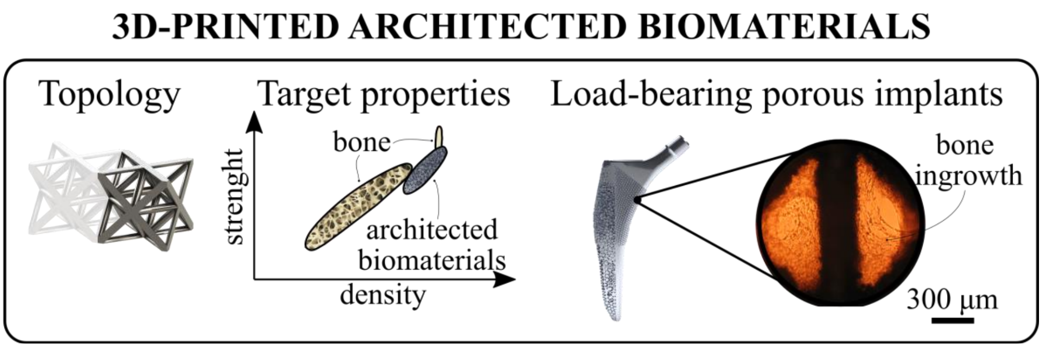

Figure 1: 3d-printed architected biomaterials can be used to fabricate load-bearing implants that mimic bone tissue.

First, imperfections induced by additive manufacturing can be identified and mitigated through a design-oriented strategy. We proposed a compensation strategy to adjust the thickness of the lattice's struts based on their printing angle [1]. For complex micro-architecture, this design strategy can reduce the geometric and mechanical properties mismatches between predicted and measured values from 17% to 6.5% and from 31% to 16%, respectively.

Second, we developed a systematic approach integrating data coming from scanning electron microscopy, electron backscatter diffraction, computed tomography, and mechanical testing, to generate statistically representative numerical models of 3d-printed porous biomaterials with geometric imperfections at different scales [2,3]. This methodology has been used to perform simulated experiments and create accurate design maps of the morphological and mechanical performance of architected materials used for bone replacement implants.

Finally, we showed how manufacturing imperfections can be considered in topology optimization to help the design and fabrication of load-bearing orthopedic implants [4].

References

[1] Bagheri ZS, Melancon D, Liu L, Johnston RB, Pasini D, Compensation Strategy to Reduce Geometry and Mechanics Mismatches in Porous Biomaterials Built with Selective Laser Melting, *Journal of the Mechanical Behavior of Biomedical Materials*, Special issue on the Mechanics of Additively Manufactured Biomaterials and Implants, Vol. 70, pp. 17–27, 2017.

[2] Melancon D., Bagheri Z.S., Johnston R.B., Liu L., Tanzer M., Pasini D., Mechanical characterization of structurally porous biomaterials built via additive manufacturing: experiments, predictive models, and design maps for load-bearing bone replacement implants, *Acta Biomaterialia*, Vol. 63, pp. 350-368, 2017.

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Keynote lecture

Wire-Laser Metal 3D Printing. A disruptive directed energy deposition technology by Meltio

Meltio Svetozar Kolaser - 3D Republic, Serbia

Abstracts

1st Session

1. Characterization of AM polymer-based materials

Analysis of printing parameter influence on FDM polypropylene tensile properties

Aleksa Milovanović[1], Zorana Golubović[2], Snežana Kirin[1], Ivana Jevtić[1], Tamara Smoljanić[1]

[1] University of Belgrade, Innovation Center of the Faculty of Mechanical Engineering, Kraljice Marije 16 street, 11120 Belgrade, Serbia
[2] University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16 street, 11120 Belgrade, Serbia

Email: amilovanovic@mas.bg.ac.rs[1], zzgolubovic@mas.bg.ac.rs[2]

ABSTRACT

Polypropylene (PP) is a non-toxic, lightweight material, produced to a large extent from oil and natural gases through the polymerization of ethylene and propylene. It is a broadly studied polymer with a wide range of applications from product packaging, due to its high resistance to moisture absorption, to biomedical applications- where material biocompatibility and chemical inertness are required. Material is relatively simple to process, affordable and recyclable, and easily able to blend with different filers and agents, in order to obtain better properties[1]. Because PP is environment-friendly material, today's research mostly focuses on the creation and use of combinations of such polymers, that also originate from sustainable resources in order to lower the dependence on petrochemical-based polymers in Fused Deposition Modeling (FDM) technology. Concerning composite structures, PP material is mostly used as a matrix component due to its excellent ductility. In the biomedical field, PP is considered for sutures, surgical meshes, and may also serve as a hernia, ligament, or tendon repair material. Still in the research phase are possible applications for cranial implants, or as a tendon repair material[2].

In FDM, PP materials have substantially higher elongation than any other FDM thermoplastics[2,3]. In this research, four specimen batches are prepared for tensile testing. The batches differ in layer height, infill density, and printing orientation. All tested PP specimen batches show that PP is a ductile material, holding high toughness and elongation values. Engineering Stress-Strain results from one PP specimen batch are shown in Fig. 1. Lowest measured elongation per batch is 206%, with some batches containing specimens that didn't break before reaching maximal tensile machine stroke- which is 500 mm, meaning that those PP specimens can hold more than 450% elongation. Thereafter, the experimental data were analyzed using ANOVA statistical method with Tukey HSD Post Hoc Test. Statistical results show that chosen printing parameters have a significant influence on tensile PP properties, especially in the case of elastic modulus (Fig. 2). Here, we see four homogeneous subsets (as many as tested batches) indicating a significant influence of layer height, infill density and printing orientation on elastic modulus value.

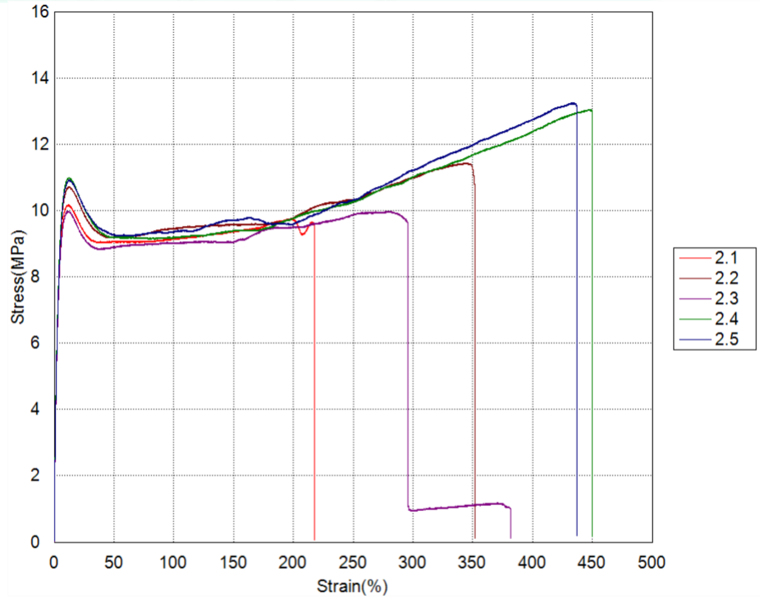

Figure 1 – Engineering Stress-Strain diagrams for one PP specimen batch.

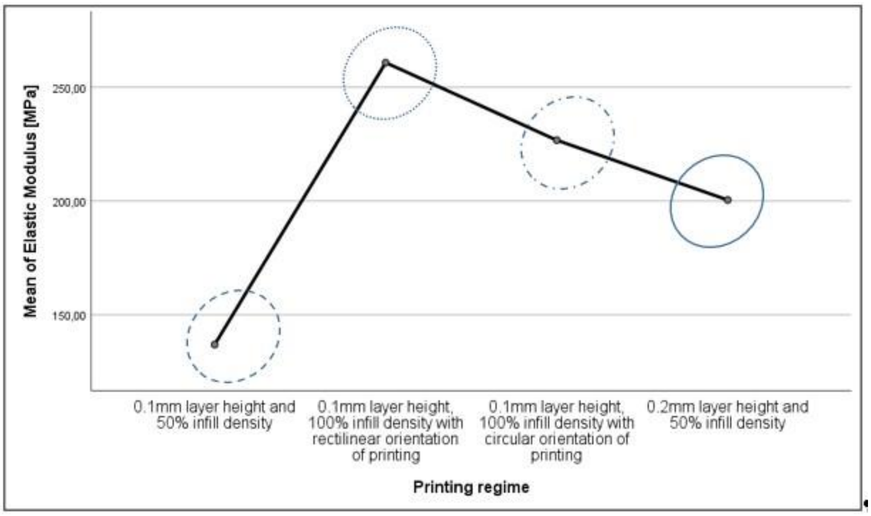

Figure 2 – Elastic modulus of PP with regard to different printing regimes.

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Investigation on the properties of the Short Carbon Fibre Reinforced Nylon-6 composite filaments for 3D printing of the functional parts using Fused Filament Fabrication

Vishal Gupta[1], Prateek Saxena[2]

School of Mechanical and Materials Engineering, Indian Institute of Technology, Mandi, Himachal Pradesh, India, 175005.

Email: d21075@students.iitmandi.ac.in [1], prateek@iitmandi.ac.in [2]

ABSTRACT

Additive Manufacturing (AM) has found its importance in almost all product development and manufacturing domains. A key characteristic of this technology is the ability to design and manufacture intricate customized shapes. With the advancement of AM technology, it is possible to manufacture functional parts using a wide range of materials. Polymer-based materials are largely adapted and used in material extrusion-based AM methods. However, neat polymer parts have relatively lower strength and their durability are often limited to prototypes. The strength of a polymer-based part can be enhanced by reinforcing it with short carbon fibers [1,2]. 3D printing of the short fiber reinforced parts has a huge potential to produce high-quality functional components [3-5]. The main objective of this work is to fabricate a fiber reinforced composite filament for the material extrusion process, which can be used on any Fused Filament Fabrication (FFF) printer to produce functional parts. Composite filaments of short carbon fibers and nylon-6 are manufactured using a single screw extruder setup. Studies on the windability of the filament and its' printability are carried out. The homogeneity of the carbon fiber within the polymer and the rheological, thermal and mechanical behavior of the composite filament are directly linked to the part quality and reliability. The rheological analysis is further done to determine the shear viscosity of the polymer melt inside the heated nozzle. The thermal behavior of the polymer composite filament (the glass transition temperature and the thermal degradation) is also identified and presented in this work. The composite filament's homogeneity directly impacts the performance of the printed object, surface morphology and material characterization results are also discussed.

ACKNOWLEDGEMENT

The authors would like to thank the Science and Engineering Research Board (SERB), Department of Science and Technology (DST) for providing the financial support for carrying out this study. Start-Up Research Grant (SERB-SRG) project number SRG/2022/002225 (3D printing of continuous carbon fiber reinforced polymer composites using Fused Filament Fabrication) is acknowledged.

REFERENCES

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Experimental determination of flexural strength on cylindrical and plate samples produced by additive manufacturing from ABS-X material

Isaak Trajkovic[1], Aleksandra Joksimovic[2], Uros Ilic[2], Marko Djurovic[2], Tijana Lukic[2], Jovana Lazovic[2], Milos Milosevic[2]

[1] Innovation Center of the Faculty of Mechanical Engineering, Kraljice Marije 16, 11100, Beograd, Serbia.

[2] University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11120, Belgrade, Serbia.

Email: trajkovicisaak@gmail.com

ABSTRACT

In this paper the influence of sample infill on the flexural strength will be presented. Plate and pipe-shaped specimens were tested by three-point bending according to the ISO 178:2019 standard. Samples were produced using ABS material with the inclusion of an unknown filler designated as X. The infill during the production of samples was 50% and 100%, while all other parameters such as printing temperature, bed temperature, nozzle width, printing speed and layer height, were the same for both types of samples. Samples were printed vertically, which does not actually refer to the mechanical properties of the material itself, but to the influence of the amount of infill on the strength of the bond between the layers. The tests were performed on a Shimadzu AGS-Ks 100kN universal machine. Test results indicate a significant influence of the infill on the bond strength between the layers and thus on the flexural strength of the samples. Further research will be carried out to measure the influence of samples treatment with acetone on their flexural strength.

Acknowledgment

The authors would like to thank the support from European Union's Horizon 2020 research and innovation program (H2020-WIDESPREAD-2018, SIRAMM) under grant agreement No 857124.

Penetration testing of 3D printed projectiles made of various types of polymers

Muhamed Bisić[1], Faruk Razić[2], Adi Pandžić[3], Mustafa Bevrnja[4]

[1] Department of Defense Technology, Faculty of Mechanical Engineering Sarajevo
[2] Department of Defense Technology, Faculty of Mechanical Engineering Sarajevo
[3] Department of Machinery Production Engineering, Faculty of Mechanical Engineering Sarajevo
[4] Department of Mechanics, Faculty of Mechanical Engineering Sarajevo

Email: mbisic@gmail.com[1], razic@mef.unsa.ba[2], pandzic@mef.unsa.ba[3], mr.mun3@gmail.com[4]

ABSTRACT

Introduction
Additive manufacturing (AM) is gaining massive popularity in many industries around the globe, but one that probably stands out the most is military industry. Accelerated development of new, and better understanding of existing materials for 3D printing, either metal or plastic, are the two most important factors that allow scientists to produce hybrid or fully 3D printed weapons, ammunition and military equipment. Recent experiments conducted by students of Faculty of Mechanical Engineering Sarajevo that included 3D printed sabots made of polylactide (PLA) accidentally showed that sabots have significant penetrating power when it comes to shooting at different targets. Idea to create 3D printed projectiles, potentially lethal using only polymers, was born.

Design and testing
A simple design of static stabilized projectile is created, making sure it is easy to 3D print. Projectiles made of PLA are presented in Fig 1.

Figure 2: 3D printed projectiles

Five different materials were used for 3D printing of projectiles: PLA, Tough PLA, PETG, Nylon and PC, all produced by Ultimaker, as well as the machine used for 3D printing, Ultimaker S5 Pro. Same printing parameters were used for all materials (100% infill, 0.2 mm layer height)

which resulted in diversity of projectiles' mass because of different density of used polymers. In order to create wider mass range, PLA projectiles were also printed with 10% infill, which also helps to analyse whether it is more important to achieve greater mass or muzzle velocity. Projectiles are launched by using force from compressed air (50 bar). Muzzle velocity is measured with standard chronograph, and target is a 1" wooden board. According to one of known standards, if a projectile penetrates through the whole board, it is considered lethal. Each material was tested with 3 projectiles, one board per material. Energy density of each fired projectile is calculated and compared with energy level required for skin penetration.

Results

The greatest depth of penetration is achieved by using PLA with 10% infill, with average muzzle velocity of 126.3 m/s. When it comes to projectiles printed with 100% infill, best overall is Tough PLA. This paper gives detailed explanation of design process and 3D printing parameters, with the main review of achieved results by using mechanic calculations and material analysis of each material. The emphasis is only on the depth of penetration because it would be almost impossible to compare and predict all terminal parameters of different materials. Average values of penetration depth are graphicly represented on Fig 2.

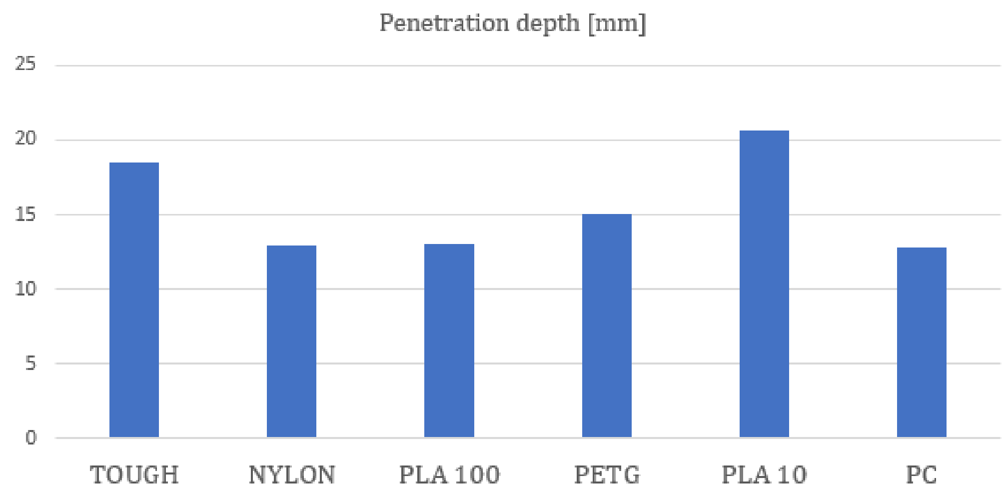

Figure 3: Graphic represtation of average penetration values

This research is a solid foundation for further optimisation of 3D printed projectiles, as well as finding new solutions when it comes to creating non-metal lethal projectile which represents a completely new area of AM use in the defense sector.

Static and Fatigue behavior of 3D printed PLA and PLA reinforced with short carbon fibers

Estera Valean[1*], Pietro Foti[2], Filippo Berto[2], Liviu Marsavina[1]

[1] Politehnica University Timișoara, Department of Mechanics and Strength of Materials, 1 Mihai Viteazu Avenue, Timișoara 300222, Romania
[2] Norwegian University of Sience and Technology, MTP Gloshaugen, Richard Birkelands vei 2B, Trondheim 7491, Norway

Email: estera.valean@student.upt.ro*

ABSTRACT

Fabrication based on additive manufacturing (AM) process from a three-dimensional (3D) model has received significant attention in the last few years [1]. The present paper presents the mechanical characterization of 3D printed specimens based on fused deposition modeling (FDM), which is one of the most commonly used AM methods [2]. Tensile and fatigue tests were performed to characterize the static mechanical properties and to analyze the durability behavior of FDM thermoplastic materials, respectively. The materials used to manufacture the specimens were polylactic acid (PLA) and a PLA reinforced with short carbon fibers. All tests were performed at room temperature. For the tensile test the loading speed was 2 mm/min and the fatigue tests were conducted under positive stress ratios, R = 0.1 at a frequency of 5 Hz. Good correlations were obtained between fatigue resistance and tensile strength for each type of material. It was also observed that the samples reinforced with carbon fibers present a lower resistance to both tensile and fatigue. This could be attributed to defects such as high porosity, compaction and poor adhesion between filament layers.

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Effect of manufacturing parameters on the impact fracture properties of DLP 3D-printed specimens

Emanoil Linul[1,2,a], Marian Baban[1,b], Sergiu-Valentin Galatanu[1,c]

[1] Department of Mechanics and Strength of Materials, Politehnica University Timisoara, 1 Mihai Viteazu Avenue, 300 222 Timisoara, Romania
[2] National Institute of Research for Electrochemistry and Condensed Matter, Aurel Paunescu Podeanu Street 144, 300 569 Timisoara, Romania

Email: emanoil.linul@upt.ro[a], marian.baban@yahoo.com[b], sergiu.galatanu@upt.ro[c]

ABSTRACT

Additive manufacturing (AM) or additive layer manufacturing (ALM) is the 3D printing computer controlled process in which complex parts are created layer by layer, whether the material is plastic, metal, ceramic, concrete, composite, and other material [1]. There are a number of distinct AM processes with their own standards, however the parts obtained through Digital Light Processing (DLP) are deprived of comprehensive characterization [2]. The main advantages of DLP technology over other AM processes are highlighted by excellent accuracy of laying, high print speed, high level of detail, material diversity, very good surface quality, lower unit price and the low cost of printers [3].
The present work investigates the impact behavior of the Ultraviolet (UV) sensitive resin specimens obtained through DLP. The impact tests were performed on an instrumented Charpy hammer, CEAST 9050 Pendulum Impact System, according to the ISO180-00 standard [4]. The specimens were provided with a lateral notch. The influence of several parameters such as printing direction (horizontal, inclined at 45° and vertical), curing time (2, 4 and 6 minutes), specimens thickness (4, 6, 8 and 10 mm), and different notch geometries (U, V and O) was investigated. Properties such as absorbed energy, impact strength, deflection and fracture surface were determined within the mentioned parameters. All the investigated parameters show major influences on the main impact properties, the optimal parameters being highlighted. Regardless of the manufacturing parameters used, all the specimens showed a brittle fracture without plastic deformation.

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Designing a test bed and experiments on a 3D-Printed gear bearing. A feasibility study

Cristian Moldovan, Carmen Sticlaru

Universitatea Politehnica Timisoara, Romania

Email: Cristian.moldovan@upt.ro, Carmen.sticlaru@upt.ro

ABSTRACT

In the last decade Additive Manufacturing – AM has become increasingly popular in the engineering community. Using this type of manufacturing complex shapes can be produced which are generally used as structural or design elements in a machine but for the bearing elements (kinematic joints) there are still used steel classically machined elements. In this paper we explore the possibilities of using a 3d printed gear bearing under different radial loading conditions and rotational speeds to be used in machines. In the process we introduce a failure criterion for the bearing and present the lifetime estimation for this type of bearings in the presented loading conditions. It is also to note that this gear bearing was not assembled but rather built in one piece directly by the 3d printer.

Bearings are used in a machine every time there is the need for relative motion between two elements. Bearings can have many designs, plain bearings, rolling element bearings, jewel bearing, fluid bearing, magnetic bearing or other types. The **gear bearing** is a type of rolling element bearing, where the rolling elements take the shape of gears. For better understanding, a roller bearing is presented in Fig. 1.

Fig.1. Gear Bearing. Herringbone gear pair

It can be observed that the gears alignment is similar to a planetary gear arrangement, but compared to the planetary gear, it has a different function. The planetary gear reduces or amplifies the input motion and it is a mechanism, whereas the gear bearing has to function as a bearing, allowing relative motion between two elements as smooth as possible. This smoothness is assured due to the rolling motion of the engaged gears. The gears are classic

involute gears with herringbone profile teeth which also provides some axial resistance, basically resulting in a radial bearing with some axial resistance properties.
The 3d printer used to execute the gear bearing was CREALITY 3D Ender 5 Pro and the material used was PLA from purchased from the company LTHD.
The test bed allows the assembly of a gear bearing and it's loading with different loads at different speeds. A kinematic setup is presented in Fig. 2 where can be identified the electric motor (1), motor shaft (2), fixed supports (3,5), gear bearing (4), F being the applied load.

Fig. 2. Test bed for the gear bearing

Normally, in a machine, the bearing is mounted in the fixed support and the shaft applies a load on it, in our case we considered the inverse situation, where the shaft is fixed using steel bearings but still rotates and the gear bearing is pressed radially on the shaft, thus obtaining equivalent loading characteristics. A similar approach is presented in [1]
Some results from a preliminary experiment are shown in Table 1

Rotational velocity [rpm]	Applied Load [N]	Duration [min]	Starting play [mm]	Ending play [mm]
400	10	15	0.05	0.06

For this experiment, there was measured the starting and end play in the gear bearing in radial direction with a comparator gauge, after the bearing was subjected for 15 minutes to a load of 10N and a rotational velocity of 400 rpm.

Conclusion

In this paper is presented a testing method to determine the feasibility of a 3d printed gear bearing. The 3d printed gear bearing can be used as a bearing but it has some drawbacks. During the tests it has been observed substantial vibration and wear for high rotational speeds and loads. One big disadvantage is the scaling of this type of bearing because it requires a rather laborious design process. Overall we conclude that the use of a gear bearing is feasible under restricted conditions.

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Determining fracture mechanics parameters using the digital image correlation method on cylindrical samples produced by different additive manufacturing techniques

Isaak Trajković[1,*] Miloš Milošević[1], Milan Travica[1], Marko Rakin[2], Ivana Jevtić[1], Aleksandar Sedmak[3], Bojan Medjo[2]

[1] Innovation Center of the Faculty of Mechanical Engineering in Belgrade, Kraljice Marije 16, 11120, Belgrade, Serbia.
[2] University of Belgrade, Faculty of Technology and Metallurgy, Karnegijeva 4, 11120, Belgrade, Serbia.
[3] University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11120, Belgrade, Serbia.

Email: trajkovicisaak@gmail.com

ABSTRACT

This work presents the difference in the values of fracture mechanics parameters obtained by testing of cylindrical specimens with a sharp notch, cut on the tip of a wider groove. The samples were obtained using two different additive manufacturing techniques. The first type of samples was obtained by the FDM (Fused Deposition Modeling) method, on the German REPRAP X400 device with an average accuracy of 0.25 mm. The second type of samples was made using the SLS (Selective Laser Sintering) method on the EOS Formiga P100 device with a production precision of 0.08 mm. Regardless of the difference in manufacturing techniques, the direction and orientation of the samples was identical. The samples were prepared so that during loading the fibers are loaded in tension, i.e. axially. Different lengths of the sharp notches were fabricated axially on the samples. The values of fracture mechanics parameters such as CMOD (Crack Mouth Opening Displacement) and CTOD-δ_5 (Crack Tip Opening Displacement obtained using the -δ_5 technique) were obtained using the digital image correlation method. The obtained parameters, except for mutual correlation, were also used for the verification of numerical results. In the future work, a procedure for determination of energy-based fracture mechanics parameters will be developed for this sample geometry.

Acknowledgment
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2nd Session

2. Modeling and simulation of AM materials processing

Influence of process parameters on temperature field and residual strain in FFF-printed parts

Alberto Corvi[1], Luca Collini[1], Corrado Sciancalepore[1]

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

Email: alberto.corvi@unipr.it[1]

ABSTRACT

Among low-cost AM technologies, the deposition of a fused filament (FFF) is widely employed, not only in prototyping but also to create functional components. Many studies are available in literature about the mechanically anisotropic behavior of FFF-printed parts [1-4]. Despite its wide diffusion, numerical instruments helping the complete structural optimization of components produced with this technology still lack. Only recently some studies have been developed to model the filament deposition to understand and monitor the temperature distribution inside the component [5-7].

In this work the numerical approach to perform a thermo-structural simulation of the deposition process is presented. The temperature distribution at every time of the printing process is first computed, considering the overall heat transfer conditions and the phenomena that can take place during the deposition. This is then given as input in the mechanical simulation to obtain the internal stress distribution inside the component and its process-induced deformation (warping).

The finite-elements simulation relies on a model of sequential elements activation [8-9], which is ruled by the intersection between the mesh of the component and the trajectory of the extrusion nozzle, stored in the Gcode file of the printer.

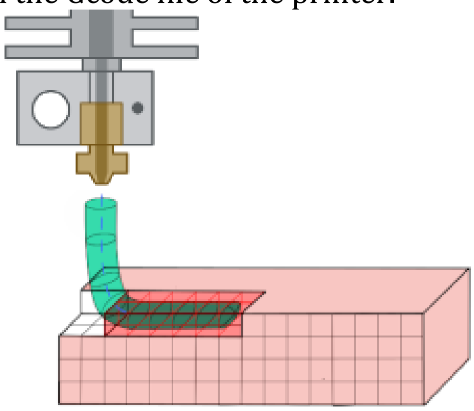

Figure 4: *Element activation process*

Both thermal and mechanical results are validated against experimental measures. A thermographic record with IR-camera is conducted to compare the time-dependent temperature distribution with values of the respective nodes from the FE simulation; material parameters and heat transfer conditions are properly evaluated. The part distorsion is

measured via 3D laser profilometer and again verified with the numerical prediction. Both matches are encouraging.

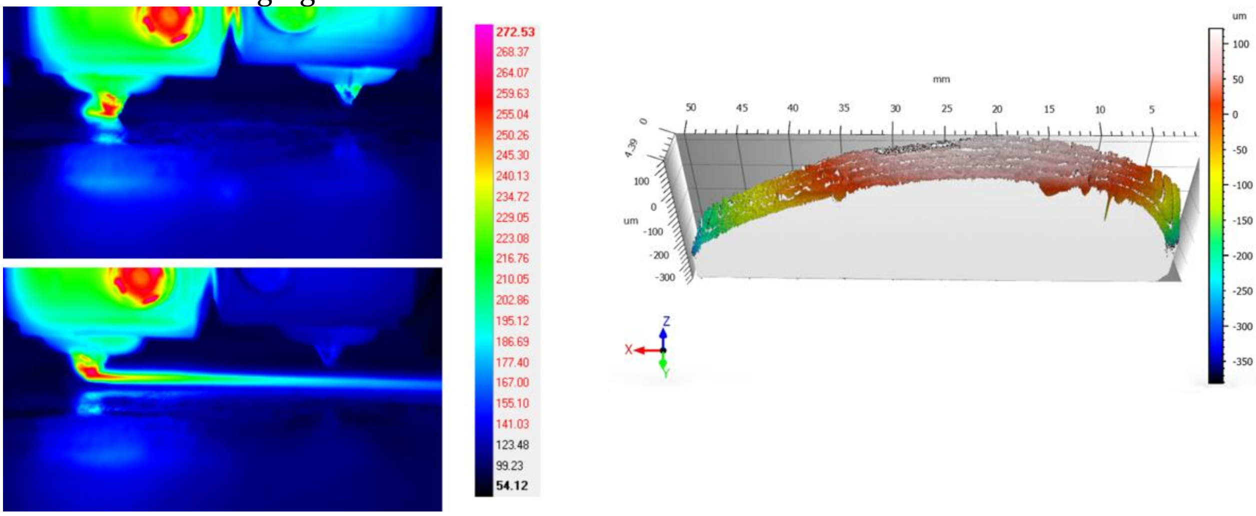

Figure 5: *Experimental validation*

After the experimental validation, this work aims at understanding the influence of printing and environmental parameters on the resulting process-induced mechanical characteristics of the component. In particular, the focus concerns the analysis of the deposition trajectory effect on the internal stress field, in order to optimize the pattern choice as function of generated stress and strain.

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Fatigue-resistant notches design based on data-driven approach for additive manufacturing

Qingbo Wang[1], Chao Gao[1], Filippo Berto[1]

[1] Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology, Trondheim 7491, Norway

Email: qingbo.wang@ntnu.no, chao.gao@ntnu.no, filippo.berto@ntnu.no

ABSTRACT

With the superiority in customized fabrication, additive manufacturing has been widely applied in complex geometries. However, fatigue is still unavoidable in additive manufacturing, and the design of fatigue-resistant structures with fast, inexpensive, and efficient strategies is necessary and significant. In this paper, a modified strain energy density (SED) fatigue analysis approach based on a deep learning framework is proposed for the design strategy of fatigue-resistant notches. This design strategy can be verified through mechanical experiments of traditional and novel designed notches fabricated by additive manufacturing. At first, the finite element (FE) simulations of notched structures including elastic-perfectly plastic material constitutive law are performed for the strain energy density analysis of notched structures under uniaxial tension, in-plane bending and out of plane bending conditions. And the SED was utilized to analyze the influence of notch size effect on fatigue. Second, deep learning is served as the data-driven approach owing to its capability to establish a deep network architecture that contains notch structures information and corresponding SED values to discover the deep information embedded in huge data. Finally, some selected notches with obviously high fatigue resistance and traditional notches are fabricated within the fused deposition modeling and evaluated under different loading conditions.

Keywords: Additive manufacturing; Fatigue-resistant; Strain energy density; Deep learning; Finite element.

Crack kinetics determination and lifetime estimation of additively manufactured PLA specimens with different layer heights

Jan Poduška[1], Aleksa Milovanović[2], Lukáš Trávníček[1,3], Luboš Náhlík[1], Aleksandar Sedmak[4], Pavel Hutař[1]

[1] Institute of Physics of Materials, Czech Academy of Sciences, Brno, Czechia
[2] University of Belgrade, Innovation Center of the Faculty of Mechanical Engineering, Belgrade, Serbia
[3] CEITEC BUT, Brno University of Technology, Brno, Czechia
[4] University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia

Email: poduska@ipm.cz[1], amilovanovic@mas.bg.ac.rs[2]

ABSTRACT

One of the most widely used additive manufacturing technologies is the fused deposition modeling (FDM) technique, where the physical model is directly created by subsequently extruding layers of melted thermoplastic onto a build platform [1,2]. Many types of thermoplastic materials are commonly used in FDM, such as polylactic acid (PLA), various types of polyamides (PA), acrylonitrile butadiene styrene (ABS), polyethylene terephthalate (PET), polypropylene (PP) [1]. As several studies have shown, the material properties of the printed part always depend on the setting of the printing parameters – mainly the building direction, layer thickness, infill density, and extrusion temperature [3–7].
This contribution is dealing with the fracture mechanical properties of additive manufactured PLA, as one of the most frequently used materials. Measurements of crack growth rate da/dN on CT specimens printed with different layer heights were carried out. It was found that the layer height influences the crack propagation rate and direction quite significantly. See Fig. 1, where the crack growth rates are plotted versus the respective stress intensity factors KI,max (v-K curve).

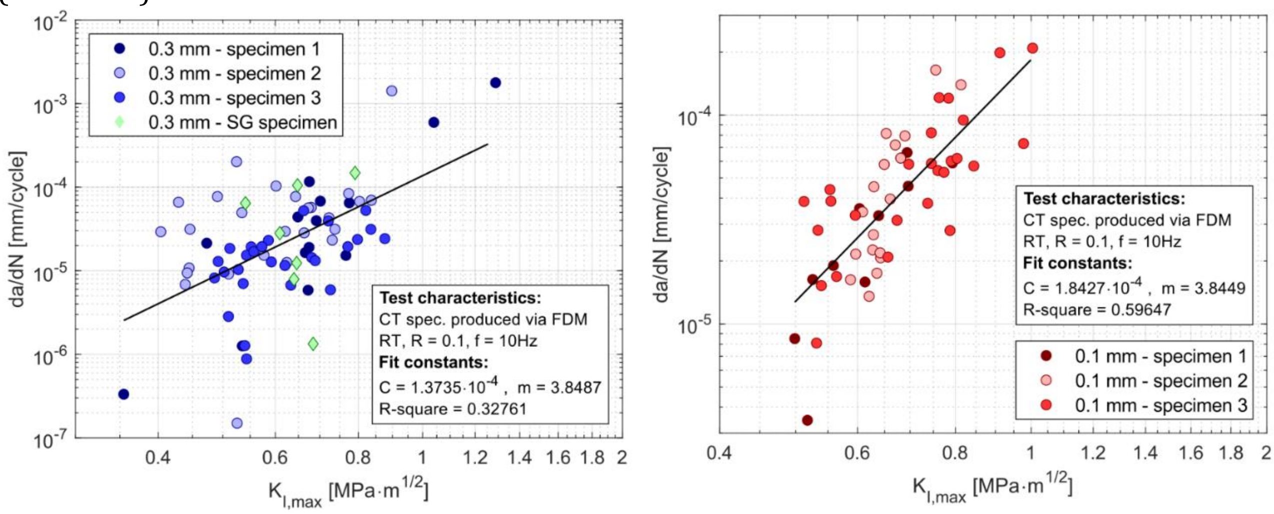

Fig. 1: The v-K curves of CT specimens printed from PLA with a different layer height, i.e., 0.3 mm on the left-hand side, and 0.1 mm on the right-hand side.

It was attempted to fit these data with Paris-like exponential equation to describe the crack kinetics in the stable crack propagation regime as in [8]. The acquired fits were used to estimate the lifetimes of the CT specimens and then compared to another set of experimental results, which refer to cycle number calculation on fatigue-tested CT specimens up to failure. This comparison procedure allows for the accuracy assessment of obtained results.

It was concluded that a reasonably accurate lifetime prediction in the sense of damage tolerance methodology is possible with the data acquired on the specimens with lower layer height, i.e., 0.1 mm.

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Polymeric 3D printouts as bimodular materials with emphasis on the analytical modeling of their flexural behavior

Marius Nicolae Baba

Department of Mechanical Engineering, Faculty of Mechanical Engineering, Transilvania University of Brașov, România

Email: mariusbaba@unitbv.ro

ABSTRACT

Introduction

Different strengths and elastic constants observed for polymeric 3D printout specimens submitted to tension and compression tests warn us about distinct failure mechanisms these materials undergo under uniaxial loading conditions. Such materials are known as bi-modulus or bimodular materials.

Many studies have been conducted to investigate the mechanical behavior of materials with different moduli in tension and compression [1]. Ambartsumyan and Khachatryan [2] made pioneering contributions to this field and published the first monography on the bi-modulus elasticity theory. Later his works were extended from different perspectives, such as: modifying constitutive relations, obtaining analytical solutions, using numerical methods, etc. However, since the bi-modulus constitutive relations imply some non-smooth property, which makes this topic even more challenging, analytical solutions are currently available only for a few bending problems involving beams, columns, and thin plates. Chamis [3] used continuum mechanics to derive the formula of maximum deflection in three-point bending of beams made of materials with unequal compressive and tensile moduli. Yao and Ye [4] derived the analytical solutions of a bimodular beam carrying combined bending and compression for the bending problem of bimodular beams and columns. To simplify the derivation, He et al. [5] proposed that the bimodular beams may be turned into classical beams by an equivalent section method. They also obtained the approximate elasticity solution of a bimodular deep beam under a uniformly distributed load. Nonetheless, neither Yao nor He did not derive in their works the analytical solutions related to the particular case of a simply supported beam carrying a point load at the midspan. More recently, closed-form solutions for displacements and position of the neutral axis were derived by Misseri and Rovero [6] from the expressions of displacement field assuming both Euler-Bernoulli and Timoshenko beam models, and hence retrieving the value of Young's modulus in tension.

Materials and methods

A couple of common AM polymer materials (i.e., PA12, ABS, PLA, etc.) for which the complete pair of data in uniaxial tension, compression, and bending were chosen from the mainstream scientific literature to be used in this investigation, with the aim of finding the appropriate analytical approaches that can be employed when modeling their flexural behavior. For the sake of data completeness, the testing standards and dimensions of specimens are gathered together and reported in line with the relevant information about the printing platform, bulk material (filament or powder), printing pattern, build orientation, and the related processing parameters. The tension and compression data are presented in terms of ratios between the modulus of elasticity in tension (E_t) and the modulus of elasticity in compression (E_c), as the degree of departure from unity indicates the amount of bimodularity of the involved AM material.

A benchmark study based on the previously described analytical formulations applied to each of the aforementioned AM polymeric materials is conducted to approximate the slope of the linear part of their load-deflection curves for a simple loading state represented by the well-known three-point flexure configuration. Critical comparisons are made concerning the specific basic assumptions the concerned analytical models are based on, as well as the influence of material properties and the related geometric parameters. Some typical results from these comparisons follow that the maximum tensile (or compressive) stress, bending deflection, and flexural modulus can be significantly underestimated or overestimated when equal tension and compression moduli are assumed to model the elastic response of 3D polymeric printouts.

Research outcomes

The work mentioned in this paper helps to predict the flexural response of polymeric 3D printouts that typically exhibit unequal tension and compression properties. It can also be used to reduce test data from three-point bending experiments or to validate the results of finite element analyses. Last but not least, the reported equations and graphs can be readily used to extract the data, which are useful for design purposes or as a guide to instrumenting the flexure tests of polymeric 3D printouts as bimodular materials.

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Low-cycle fatigue and related fatigue damage mechanisms in additively manufactured IN939 superalloy

Tomáš Babinský[1*], Ivo Šulák[1], Alice Chlupová[1], Aleksa Milovanović[2], Luboš Náhlík[1]

[1] Institute of Physics of Materials, Czech Academy of Sciences, Žižkova 513/22, 61600 Brno, Czech Republic
[2] University of Belgrade, Innovation Centre of the Faculty of Mechanical Engineering, Kraljice Marije 16, 11120 Belgrade, Serbia

Email: babinsky@ipm.cz

ABSTRACT

Fatigue behaviour of IN939 superalloy, commonly used for manufacturing parts of industrial gas turbines, turbochargers or process industry parts, was studied. To clarify the fatigue performance of 3D-printed to conventional cast superalloy, three thermodynamical states were considered: cast heat-treated, printed as-built and printed heat treated. A three-step heat treatment was performed (1160 °C/4h + 1000 °C/6h + 800 °C/4h). Cylindrical specimens were machined out of blocks which were printed in horizontal and vertical building direction using laser powder bed fusion. For the purpose of subsequent surface analysis, specimens were mirror polished. Fatigue tests were performed at room temperature in low-cycle fatigue regime. Tests were controlled with total strain amplitude; strain rate was constant ($2 \cdot 10^{-3}$ s^{-1}). Subsequently, specimens were analysed by means of scanning and transmission electron microscopy. Microstructure of cast IN939 comprised polyhedral dendritic grains with casting defects and coarse cubic-shaped carbides. The printed microstructure comprised columnar grains alongside building direction as an effect of epitaxial growth. Internally, grains comprised dislocation cells elongated in <001> direction. As a result, lifetime exhibited dependence on building direction which can be related to the number of grain boundaries in the loading direction. Building direction was not however found to influence deformation behaviour, the dislocation cells remained stable. Heat treatment introduced γ' precipitates which acted as effective barriers to dislocation movement, thus increasing strength while reducing ductility. All the tested printed states exhibited better fatigue properties than the cast counterpart. The resulting fatigue behaviour was discussed considering conventional material and existing literature [1; 2].

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Evaluation of fatigue life of damaged UAV's attachment produced using additive manufacturing

Nikola Raičević[1], Miloš Petrašinović[1], Danilo Petrašinović[1], Gordana Kastratović[2], Aleksandar Grbović[1]

[1] University of Belgrade, Faculty of Mechanical Engineering
[2] University of Belgrade, Faculty of Transport and Traffic Engineering

Email: nraicevic@mas.bg.ac.rs[1], g.kastratovic@sf.bg.ac.rs[2]

ABSTRACT

To become a reliable and widely accepted production process, additive manufacturing (AM) must provide metal structures with the same or better structural integrity than those produced using traditional methods. In the AM process, multiple build attempts are often required to obtain the part of standardized quality. Another crucial issue is the fatigue behaviour of AM structures (particularly in the presence of voids) which must be assessed and predicted with satisfactory accuracy. There are several major challenges connected to this issue, including obtaining the exact material properties and assessing the life of the complex shapes produced using AM.
Bearing this in mind, numerical simulations of AM processes, as well as of the fatigue crack growth in structures of complex shapes, become crucial factors in speeding up the industrial implementation of AM. The aim of this paper is to demonstrate current abilities and performances, as well as the restrictions of the numerical methods in simulating AM processes and fatigue crack growth in metallic structures of complex geometry. In this study, numerical simulations were first carried out on the standard CT specimen (Fig. 1), and then on the real shape of an UAV's attachment used to hold the composite arm and transfer loads to the main body of the UAV (Fig. 2, 3). For this purpose, the finite element method (FEM) was used, and the results of 3D numerical analyses, performed in Ansys Workbench software, were compared to experimental findings.

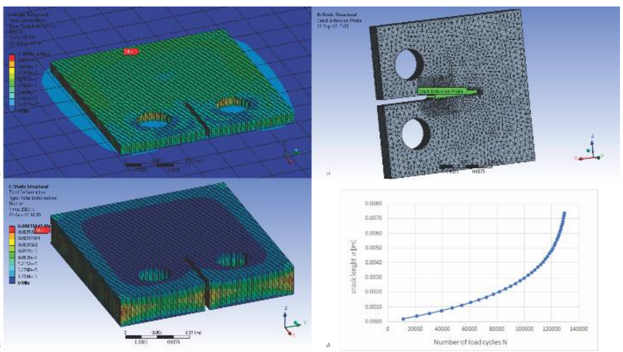

Fig. 1 CT specimen: a) AM numerical simulation, step 14 (of 49); b) AM numerical sumulation, finish; c) crack propagation; d) fatigue life

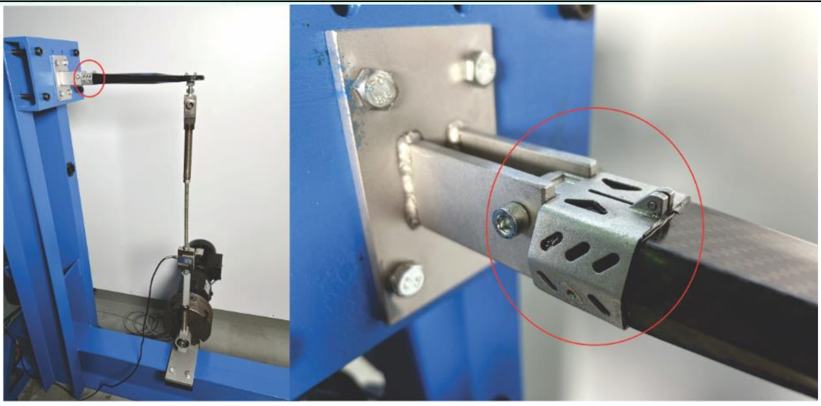

Fig. 2 UAV's attachment

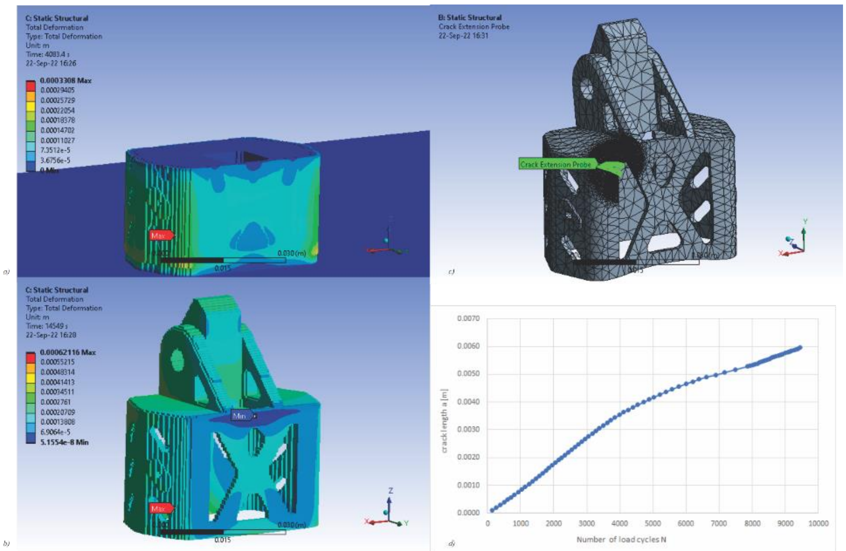

Fig. 3 UAV's attachment: a) AM numerical simulation, step 106 (of 251); b) AM numerical sumulation, finish; c) crack propagation; d) fatigue life

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Mechanical characteristics of parts obtained by SLS printing technology

Ivana Jevtić[1], Goran Mladenović[2], Miloš Milošević[1], Aleksa Milovanović[1], Isaak Trajković[1], Milan Travica[1]

[1] Innovation Centre of The Faculty of Mechanical Engineering, University of Belgrade, Kraljice Marije 16 street, Belgrade 11120, Serbia
[2] Faculty of Mechanical Engineering, University of Belgrade, Kraljice Marije 16 street, Belgrade 11120, Serbia

Email: ijevtic@mas.bg.ac.rs[1]

ABSTRACT

The aim of this paper is to determine the mechanical characteristics of parts obtained by Additive Manufacturing (AM). All specimens were printed on a Fuse 1 (FormLabs, Summerville, MA) 3D printer. This AM technology is SLS (Selective Laser SIntering). With this technology, objects of different shapes and dimensions can be produced at the same time. The only condition is that during printing, the parts must be at least 5 [mm] apart from each other. The thickness of the powder layer during printing was 110 microns. In this paper, one type of specimens are used to determine the mechanical characteristics, the dimensions of which were chosen according to specific standard. This standard is ISO 178 for 3-point bending specimens. The dimensions of the bending specimens are 96x8x4 [mm]. These specimens were produced in four batches, differing in printing orientation (horizontal and vertical) and printing location (printed on the edge and in the middle of the powder bed). The material used for printing the specimens is polyamide (PA 12). The flexural strength of this material is 66 MPa. After printing, specimens were tested on a standard tensile testing machine (SHIMADZU AGS-X 100kN).
In the case of vertical bending specimens printed in the middle, the flexural strength after the test was 65.15 MPa, and for this type of specimens this is the smallest deviation from the value given in the literature. The greatest deviations of the flexural strength values are for vertical specimens printed on the edge, where the flexural strength is 58 MPa, and for horizontal specimens printed in the middle, the flexural strength is 81.7 MPa.

Quasi-static and fatigue properties of additively manufactured AlSi10Mg lattice of various scales

Zhuo Xu[1], Ricardo Branco[2], Luis Borrego[2], Filippo Berto[1], Seyed Mohammad Javad Razavi[1*]

[1] Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology, Richard Birkeland vei 2B, 7491, Trondheim, Norway
[2] University of Coimbra, CEMMPRE, Department of Mechanical Engineering, Coimbra, Portugal

Email: javad.razavi@ntnu.no

ABSTRACT

Additive Manufacturing (AM) has demonstrated significant advancements in fabricating metallic components recently since it has gained popularity due to the invention in the 1980s. It has been providing new possibilities in industries with complex geometries such as lattice structures, which are considered excellent candidates for numerous applications from relatively small to large scales such as biomedical implantations, energy absorption, and heat dissipation. According to recent literature studies, the mechanical properties of components fabricated AM technique are highly dependent on the thickness and scales of the parts. For metallic structures, the importance of the thickness and scale effect on lattice structures has not been fully investigated yet. Therefore, this research aims to evaluate the wall thickness and scale effect on the mechanical properties of uniform sheet-based gyroid lattice structures under quasi-static compression and cyclic loading conditions. First, specimens were designed and divided into three categories with the dimensional constraints of keeping the constant porosity, wall thickness, and cubic size in each category. Then all the lattice structures were fabricated via selective laser melting (SLM) technique with the material of AlSi10Mg powder. All the manufactured specimens are subjected to quasi-static and cyclic compressive loading conditions to evaluate the mechanical strength and fatigue properties. The experimental results from the compression tests were compared under each category and further investigated with scanning electron microscope (SEM) to observe the fracture locations in a more detailed manner, as well as analyze the overhang regions and surface roughness. Furthermore, CT scans were also used for the purpose of measuring geometrical deviations of the lattice structures. Finally, conclusions are obtained based on the analysis of surface roughness, failure locations, internal porosities as well as geometrical accuracy.

3rd Session

3. Characterization of AM metallic materials

Thermo-mechanical fatigue behaviour of Inconel 718 manufactured by electron beam melting

Ivo Šulák[1], Tomáš Babinský[1], Steffen Antusch[2], Alexander Klein[2], David Kuntz[2], Stefan Guth[2]

[1] Institute of Physics of Materials, Czech Academy of Sciences, Žižkova 22, 616 00 Brno, Czech Republic

[2] Karlsruhe Institute of Technology, IAM-WK Institute for Applied Materials, Engelbert-Arnold-Straße 4, 76131 Karlsruhe, Germany

Email: sulak@ipm.cz[1], babinsky@ipm.cz[1], steffen.antusch@kit.edu[2], alexander.klein@kit.edu[2], david.kuntz@kit.edu[2], stefan.guth@kit.edu[2]

ABSTRACT

The reliable and safe sustainable service of high temperature facilities represents requirements that have become decisive nowadays. Hand in hand with the perpetual need for more powerful energy and propulsion facilities with increased efficiency, the assessment of degradation mechanisms and their use in design is indispensable. Under service, components are often imperilled by high variable strains combined with harsh environments where fatigue, creep, and oxidation damage can cause premature failure. The most challenging conditions are those where stress or strain vary simultaneously with temperature, i.e., in the case of thermo-mechanical fatigue (TMF). Additionally, during steady-state service, other transient processes lead to synergetic creep-fatigue damage. In this study, the effect of TMF and creep interaction on the deformation behaviour, damage evolution and lifetime of Inconel 718 manufactured by electron beam melting was in particular interest. After 3D printing, the material was hot isostatically pressed to reduce amount of printing defects and subsequently heat treated according to the standard ASTM procedure for this alloy. The relative density was (99.63 ± 0.2) %. The investigated material is typical of columnar grains with preferential [001] orientation (Fig. 1). The microstructure of 3D printed Inconel 718 consists of γ matrix, coherent γ´ and γ´´ precipitates and occasionally η phase (Fig. 2). TMF tests with different loading parameters were performed in strain control mode in laboratory air under in-phase conditions with a temperature range of 300 to 650 °C. A constant heating and cooling rate of 5 °C/s was applied. To initiate sever creep damage, 10 minute long dwell times were introduced at the maximum temperature. Additional slow-fast TMF tests with 0.5 °C/s heating rate and 5 °C/s cooling rate were conducted. The fatigue life curves in the representation of mechanical strain amplitude vs. the number of cycles for all three loading scenarios were obtained. Due to increased inelastic strain and time-dependent damages associated with dwells, the fatigue life is expected to be reduced. The results show however an interesting shift in lifetime for dwell-TMF and slow-fast TMF loading to higher lifetimes. This finding is discussed based on microstructure and damage observations using scanning and transmission electron microscopy.

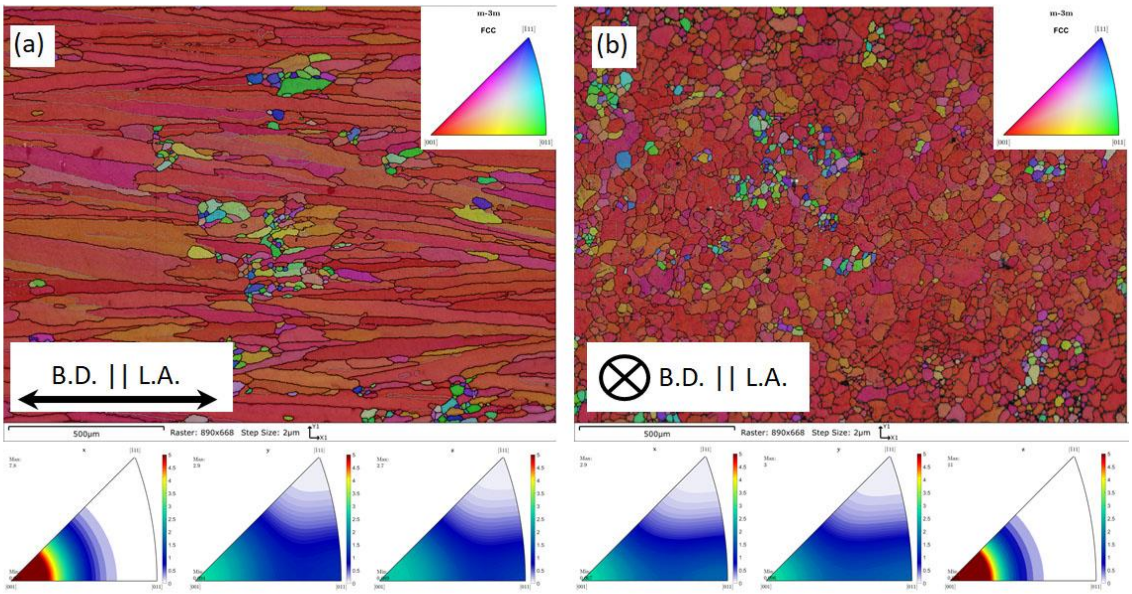

Fig. 1 – EBSD maps with grain boundaries and IPF colouring showing strong texture in [001] direction along building direction of EBM manufactured Inconel 718 (a) longitudinal cut (b) transversal cut.

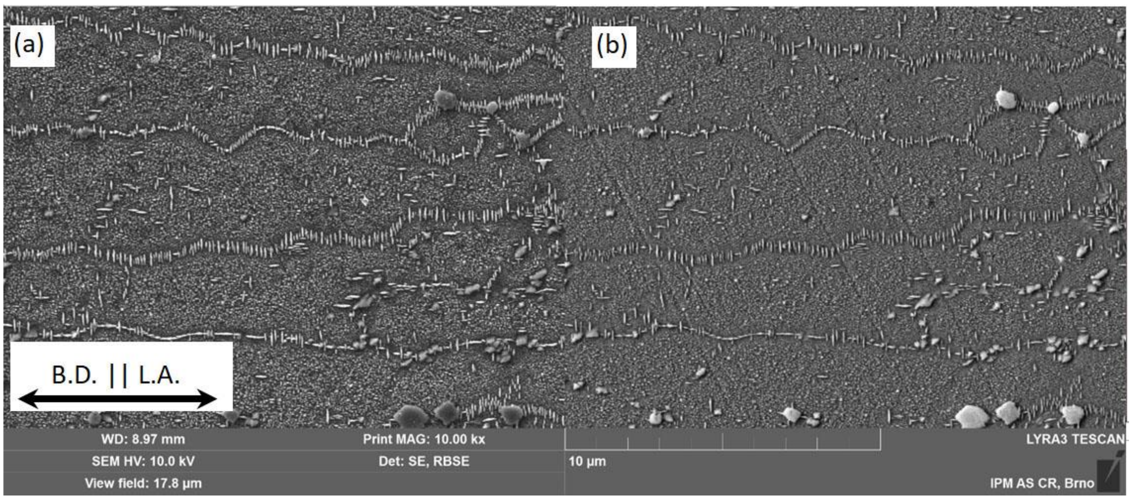

Fig. 2 – SEM image of initial microstructure of EBM manufactured Inconel 718 (a) secondary electron imaging (b) back scattered electron imaging.

Fabrication and tensile properties of SS 316L specimens obtained via Material Extrusion Additive Manufacturing

Saveria Spiller[1], Sondre Ølsoybakk Kolstad[1], Seyed Mohammad Javad Razavi[1]

[1] Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology, Richard Birkelands vei 2B, 7491 Trondheim, Norway

Email: saveria.spiller@ntnu.no

ABSTRACT

Material Extrusion Additive Manufacturing (MEAM) is an emerging technique in which the additive manufacturing process called Fused Deposition Modelling is modified to allow the production of metal and ceramic components. The filament used is composed of metal or ceramic powder dispersed in a polymeric matrix. After the shaping, two additional phases are required, that are called debinding and sintering. With the former, the polymer is removed from the parts, while the latter is an established process to allow the metal or ceramic particles to bond together.
This work is only focused on metals, and a special filament containing 88wt% of 316L stainless steel powder was used. Some tensile specimens were fabricated to evaluate the mechanical behavior of such material after debinding and sintering. The main issues of the fabrication process are described with particular attention to the prevention of the most common defects related to the printing phase. The mechanical properties obtained are compared with the results of other similar works on 316L tensile specimens obtained with MEAM and other conventional techniques.

Link between surface quality and fatigue properties of IN718 produced by Laser Powder Bed Fusion according to different testing configurations

Federico Uriati[1], Nicoletto Gianni[2], Martina Meissnar[3]

[1,2] Università degli Studi di Parma - Dipartimento di Ingegneria e Architettura, Via delle Scienze, 181/a, 43124 Parma
[3] European Space Agency, NL-2200, AG, Noordwijk, The Netherlands

Email: federico.uriati@unipr.it[1], gianni.nicoletto@unipr.it[2], martina.meisnar@esa.int[3]

ABSTRACT

The manufacturing flexibility provided by additive manufacturing technologies is especially intriguing for space applications, where the highest performance must be balanced with the structure's dependability and lightness. A larger application of AM(additive manufacturing), and specifically laser powder bed fusion (LPBF), is being considered for this industry since it offers the best mix of advantages for designing optimal structures and manufacturing them utilizing high-resistance alloys.
Since the manufacturing technology is relatively new, it still needs to be properly understood as well as rigorously confirmed and unified before it can be utilized to fabricate structural components.
To fully characterize the material properties of the metals produced by this cutting-edge technology, extensive research is ongoing, and several research institutes are interested in examining the impact of the orientation of the parts in the build chamber and the effect of the surface quality on the final properties.
The present activity was conducted by ESA and focused on the characterization of the fatigue properties of in718. Two specimen types were fabricated along vertical and horizontal built directions and post processed to obtain three different surface finishing conditions.
The samples were put to the test to learn more about fatigue qualities and assess the impact of post-processing, specifically how well the support structures were removed and how that affected the final behaviour. The final outcomes were evaluated in term of differences between fatigue testing methodologies and consistency of the results.

Determination of the impact of glass fiber reinforcement on the tensile properties of printed material obtained by FDM technology

Marko Delić[1], Vesna Mandić[1], Srbislav Aleksandrović[1], Dušan Arsić[1]

[1] Faculty of engineering University of Kragujevac

Email: marko.delic@kg.ac.rs, mandic@kg.ac.rs, srba@kg.ac.rs, dusan.arsic@fink.rs

ABSTRACT

Introduction
FDM technology is among the most widely used additive manufacturing technologies [1]. The most popular materials are ABS, PLA, PETG, etc. but lately nylon has been used more often. In order to improve the tensile properties, it is possible to use reinforcing fibers. The aim of the paper is to determine the impact of glass fibers on the tensile properties of the printed material: yield strength, tensile strength and tensile strain at break. The samples were made of onyx (micro carbon fiber filled nylon) on a Markforged Onyx Pro 3D printer according to the ISO 527 standard, without and with varying proportions of glass fibers to reinforce the samples. Uniaxial tensile testing was performed on a Zwick/Roell 100 testing machine.

Experiment plan and results
All samples are made of onyx, with a triangular infill pattern and a recommended infill density of 37% [2], raster angle 45°/-45°, layer thickness 0.1mm, while the amount of reinforcement is varied. A concentric type of reinforcement was used to strengthen the samples. The proportion of glass fibers in the base material is defined by the number of concentric rings and layers of glass fiber reinforcement. The number of reinforced rings is varied (R=2, R=4) as well as the number of reinforced layers (L=2, L=4 and L=6). Due to the reproducibility of the results, three samples were made for each combination of influencing factors. A printed sample and view of reinforced rings and layers are shown in Figure 1.

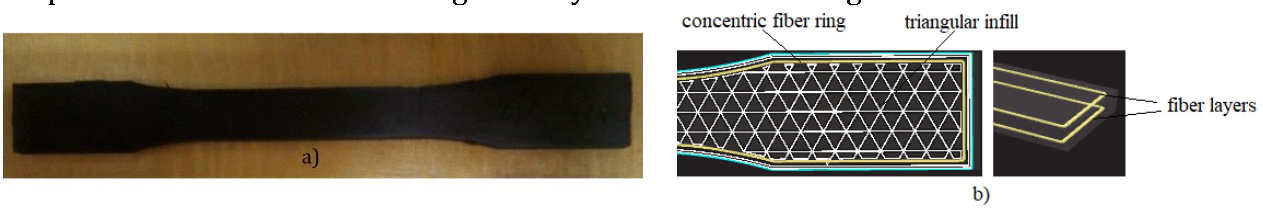

Figure 1. a) printed sample b) glass fiber reinforcement

The results of the conducted experiments and the values of the mechanical characteristics of the printed materials (yield strength, tensile strength, tensile strain at break) are shown in table 1, together with the measured mass of the printed sample and information on the material consumption (onyx, glass fibers). The stress-strain diagrams are shown in Figure 2 for all combinations of influencing factors. Increasing the number of rings and layers of glass fibers in the composite leads to an increase in stress and tensile strength, but this is not directly proportional to the amount of glass fibers used. Sample mass and material consumption will be used to calculate the S/M or S/C ratio (strength to sample mass or glass fiber content) and for techno-economic analysis.

Table 1. Experimental results

Experiment	R_p, MPa	R_M, MPa	Tensile strain at break, %	Mass, g	Consumption, cm^3 (onyx/glass fibers)
without reinforcement	8,48	17,66	22,26	6,69	5,26
R2L2	24,46	32,69	5,15	6,6	7,47/0,13
R2L4	27,37	36,95	4,41	6,71	7,43/0,26
R2L6	32,48	41,27	3,65	7,04	7,39/0,38
R4L2	28,56	31,49	9,18	6,93	7,70/0,25
R4L4	39,6	48,1	6,3	6,97	7,61/0,5
R4L6	51,04	69,23	6,53	7,35	7,52/0,75

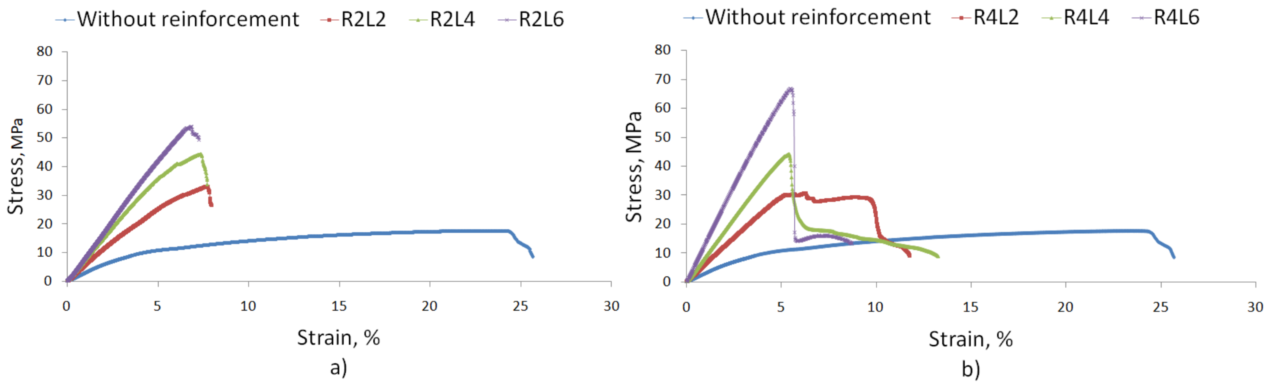

Figure 2. Stress – strain diagram a) two concentric rings R2 and b) four concentric rings R4

Conclusion

The results showed a significant impact of glass fiber reinforcement on the tensile properties of the material. An increase in the consumption of glass fibers leads to an increase in yeald and tensile strength, but leads to a decrease in the ductility of the printed material, i.e. the value of the tensile strain at break. Reinforcement with glass fibers enables the production of functional parts from polymer materials. With their use, it is possible to meet the requirements for the production of polymer and composite tools for sheet metal forming in small series or parts of clamping accessories.

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Ultrasonic atomization of magnesium alloy AZ61 based on the TIG melting method

Jan Jaroš[1], Daniel Koutný[2], Lenka Klakurkova[3]

[1,2] Brno University of Technology, Faculty of Mechanical Engineering, Institute of Machine, and Industrial Design, Technicka 2896/2, 616 69 Brno, Czech Republic
[2] Central European Institute of Technology, Research Group of Materials Characterization and Advance Coatings, Brno University of Technology, Brno 60190, Czech Republic

Email: Jan.Jaros2@vut.cz[1], Daniel.Koutny@vut.cz[2], Lenka.Klakurkova@ceitec.vutbr.cz[3]

ABSTRACT

Introduction
Ultrasonic atomization based on the TIG (Tungsten Inert Gas) melting method is one of the laboratory technologies which can be used for production of metal powder from wire [1]. This technology allows atomization of wide range of materials from aluminium to titanium. Main advantages are the laboratory size of machine and possibility of setting process parameters i.e., amplitude of ultrasonic platform, current of TIG torch, feeder speed of wire and inert gas inflow. The magnesium alloy AZ61 was used with the aim of further research in the additive technology. Production of magnesium powder is complex task, because magnesium is flammable, reacts with oxygen and has a narrow range between melting (650°C) and boiling point (1107°C) [2]. The possibility to set process parameters is, therefore, necessary for atomization of magnesium alloy [3].

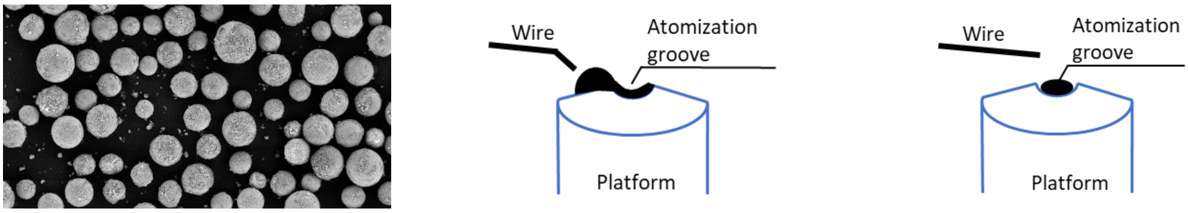
Materials and methods
ATO Lab machine with ultrasonic atomization system and TIG melting method with argon inert gas was used. Magnesium alloy AZ61 in the form of wire with diameter of 1.6 mm was used. The wire is guided to the melting point above atomization platform where the wire is melted by TIG torch. Atomization platform with melted material on the top moves at an ultrasonic frequency of 35 kHz which causes the atomization of material by stream of gas from TIG torch. The atomization process was observed by Phantom V710 high speed camera. The picture was taken with resolution of 1280x800 at 7500 fps. The dimensions and surface morphology of powder particles were analysed by SEM (Scanning Electron Microscope) TESCAN LYRA 3.

Results and discussion
The process of atomization captured by high-speed camera shows formation of powder particles (Figure 6). On the atomization platform only the local region of melted material was formed (a). Melted material moves by ultrasonic frequency and stream of inert gas blew away powder particles (b). Surface tension formed particles into the round shape (c, d).

(a) (b) (c) (d)

Figure 6 Process of atomization

Powder particles had round shape (Figure 7a) and were covered by thin oxidic layer. The particle size distribution was in the range of 28-92 μm which corresponds to the powder used for the production of parts by SLM (Selective Laser Melting) technology.



(a) (b) (c)

Figure 7 (a) Shape and dimension of atomized powder particles; (b, c) scheme of atomization of magnessium alloy

Low efficiency of atomization was caused by melting only the local region of material instead of whole material on the platform. High temperature of TIG torch led to fast creation of oxidic layer on the wire and melted material which prevent the atomization process (Figure 7a). After the melting of wire, the big blob was formed on the side of atomization groove covered by oxidic layer and part of the blob flow into the atomization groove, where the atomization of local region took place. Normally, the whole material in atomization groove is in the melt form and atomization process is more effective (Stainless steel 316L – efficiency of 210 g/hour).

Conclusions

- Ultrasonic atomization of magnesium alloy AZ61 based on the TIG melting method led to production of round shape powder particles with efficiency of 0.22 g/hour. Powder particles had dimension in the range of 28-92 μm.
- Atomization of magnesium alloy is specific because high temperature of process causes fast formation of oxidic layer on the surface of wire and melted material which prevents the atomization process.

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Fracture and Fatigue Resistance of Laser Beam Welded AA6156 T6 Reinforced Panels

Blagoj Petrovski[1], Aleksandar Grbovic[2], Aleksandar Sedmak[2]

[1] Innovation Center of the Faculty of Mechanical Engineering, Kraljice Marije 16, 11100, Beograd, Serbia.

[2] University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11120, Belgrade, Serbia.

Email: aleksandarsedmak@gmail.com

ABSTRACT

Riveting has been the state of the art joining technology in the aeronautical industry for decades, mainly due to difficulties in welding of Al allows, even though the necessary overlap joint demands large amounts of material and its production chain is also time consuming. Recently, new welding processes such as Laser Beam Welding (LBW) and Friction Stir Welding (FSW) provided new solutions to overall weight savings and process time reduction for Al alloys. It has been shown in large aeronautical structures, such as in the A318, A340 and A380, that LBW has advantages compared to conventional riveted fuselages. Regarding the production of structures, LBW can be up to 20 times faster than riveting, since it uses high energy concentration with high welding speed. Another advantage is that the process only requires one-sided access. Lower fuselage panels made of AA6xxx series (Al-Mg-Si-Cu) and processed with LBW as an efficient joining technology are already established in the market. In fact, LBW has been applied with AA6013 and AA6056 as part of the skin and AA6110 or AA6056 for the stringer. In this paper, experimental and numerical investigation is presented for panels with stringers and clips to assess their fracture and fatigue resistance.

Acknowledgment
The authors would like to thank the support from European Union's Horizon 2020 research and innovation program (H2020-WIDESPREAD-2018, SIRAMM) under grant agreement No 857124.

4th Session

4. Properties and models of AM materials and metamaterials

Defect sensitivity mitigation of the mechanical response of 2D multiphase lattice metamaterials

Roberto Brighenti[1], Matteo Montanari[1], Andrea Spagnoli[1]

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

Email: andrea.spagnoli@unipr.it, roberto.brighenti@unipr.it, matteo.montanari@unipr.it

ABSTRACT

Nowadays “architected” materials represent an expanding galaxy of engineered materials, displaying a variety of features like tailorable stiffness and strength [1], auxetic behaviour [2, 3], energy absorption [4, 5], and multifunctionality [6, 7]. In the present work, the classical two-dimensional configuration of lattice metamaterials with triangular unit cells is considered. A combination of two dissimilar materials is designed: the “primary” material, that comprises the lattice structure elements, is made of thermoplastic polyurethane (TPU) while the “secondary” functional material, manually poured inside the lattice cells to form a regular filling pattern, kept the same for all cases, consists of an incompressible silicone elastomer.

Geometrical imperfections are introduced in the lattice structure to study the sensitivity of its mechanical response to the presence of intrinsic defects. In particular, three different types of geometric anomalies have been randomly introduced, namely: 1) curvature (whose amount is defined by a small lateral shift of the beam element’s midpoint) attributed to some of the elements; 2) reduced thickness of the beam elements; 3) lateral shift of some nodes of the lattice. Overall, the total amount of lattice’s beams elements containing defects is maintained constant irrespectively of the type of imperfection (Figure 1).

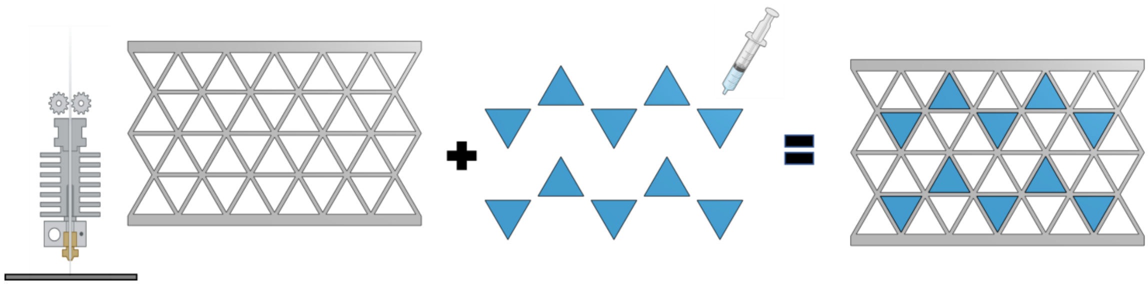

Figure 1. Schematic of a lattice 2D material with an embedded regular filling pattern of a second nearly incompressible highly deformable material.

Compressive tests are performed on additively manufactured perfect and defective lattices before and after creating the filling pattern with the second incompressible material.

In Figure 2 the response of an imperfect lattice (the defect consists in shifting some nodes from the nominal geometrical positions) without and with filling pattern, is shown for a complete loading cycle.

It can be appreciated that the perfect lattice does not show significant difference between the response of the unfilled or filled case, while the imperfect cases present a noticeable response improvement (irrespectively of the defect case considered) by adopting the same assumed

reinforcing filling pattern, which mainly operates by hindering the buckling collapse of the defective beams of the lattice under compression.

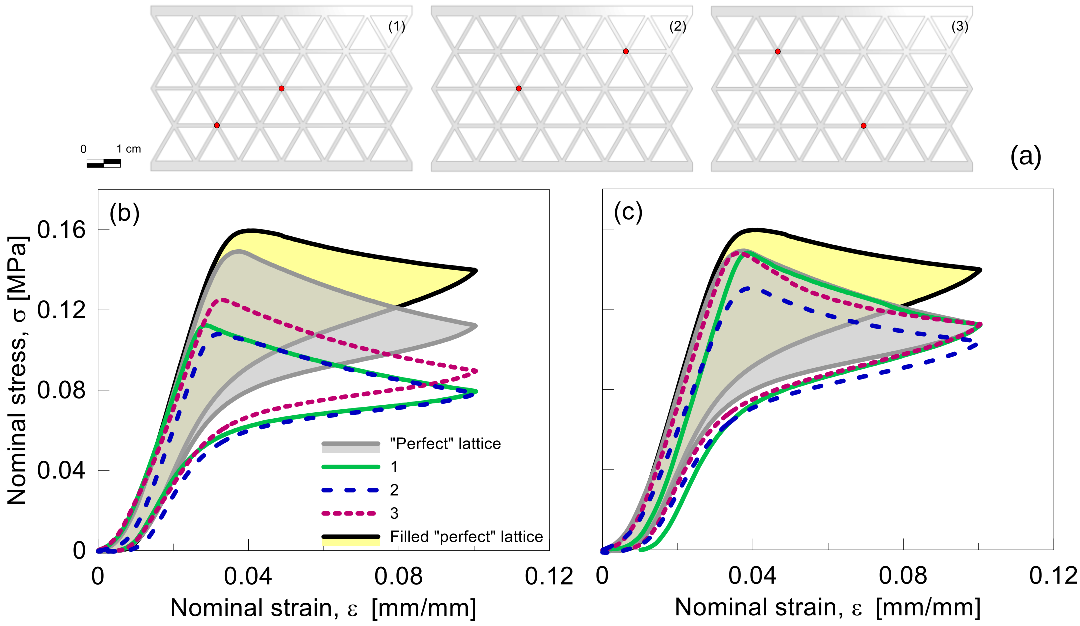

Figure 2. Response of the lattice with node position imperfections (a) under one compression load cycle: empty lattices (b) and filled ones (c).

Finally, some FE analyses are performed in order to highlight the effect of the filling pattern in improving the overall defect tolerant capability of the structure.

ACKNOWLEDGEMENT
The authors would like to thank the support from European Union's Horizon 2020 research and innovation program (H2020-WIDESPREAD-2018, SIRAMM), grant agreement No 857124.

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Fracture resistance of 3D nano-architected lattice materials

Marco Maurizi[1,*], Chao Gao[1], Filippo Berto[1]

[1] NTNU - Norwegian University of Science and Technology —Department of Mechanical and Industrial Engineering, 7491 Trondheim, Norway

Email: marco.maurizi@ntnu.no*

ABSTRACT

Exploiting small scale material effects and structural topology, nano-architected lattices represent a recent novel class of mechanical metamaterials, which exhibit unprecedented combination of mechanical properties. Together with scarce resistance to fracture and catastrophic failure, understanding of the fracture characteristics and properties of 3D nano-architected lattices still represents a limiting factor for the design and realization of future engineering applications. Here, using a combination of in-situ tensile fracture experiments and finite element simulations, we first show the possibility to reach stable crack growth in nano-architected materials harnessing only the intrinsic plastic toughening mechanism. Exploring the effect of lattice topology on the fracture properties, we then demonstrate similar performance between the octet and 3D kagome architecture (along one direction). Based on the experimental and numerical results, a power-scaling law of normalized crack initiation toughness with relative density $\bar{\rho}$ (i.e., fraction of material per unit volume) $K_{IC}/\sigma_y\sqrt{l} \propto \bar{\rho}^{1.11}$, $\bar{\rho}^{1.17-1.27}$ is exhibited by the octet and 3D kagome topology, respectively, given the yield strength σ_y and the unit cell size l. Owing to the combination of the parent material's size effect and plasticity (3D-printed photo-resist polymer), the fracture initiation toughness (considering σ_y = 27 MPa) of our octet nanoarchitected lattices is ~ 8 times that of previously realized macroscopic octet titanium structures. After crack initiation, the two architectures manifest rising (in average ~ 18 %) fracture resistance curves (i.e., R-curves), without catastrophic failure. In addition, we find that the fracture toughness of architected lattices, measured by means of compact tension specimens, seems not to be dependent on the sample's thickness, forcing to re-think the plain strain toughness definition for this class of materials. Our results uncover the basic fracture characteristics of 3D architected materials exhibiting stable crack growth, providing insights for the design of light-weight, tough materials, with implications for future macro-scaled structural applications.

Numerical analysis of cellular structures. Homogenization of cellular structure based on the actual geometry of a unit cell obtained with a CT scanner

Kevin MOJ[1], Grzegorz ROBAK[1], Robert OWSIŃSKI[1]

[1] Opole University of Technology, Faculty of Mechanical Engineering, Department of Mechanics and Machine Design, ul. Mikołajczyka 5, 45-271 Opole

Email: k.moj@doktorant.po.edu.pl[1]

ABSTRACT

1. Introduction

The paper presented here concerns issues related to the numerical analysis of cellular structures. When choosing 3D printing instead of a traditional manufacturing method (injection molding, CNC machining or casting), it is worth considering optimizing spatial models for weight reduction. One method of reducing weight is to adapt cellular structures in the designed component. Cellular structures, which enable innovative applications in many fields, are characterized by low density and weight, as well as high strength, stiffness and thermal conductivity. The use of such structures leads to a high stiffness-to-weight ratio. In addition, the weight savings result in lower manufacturing costs for additive manufacturing. Due to the potential associated with the realization of complex cellular structures using additive techniques, intensive work is being carried out to develop methodologies for numerical analysis of cellular structures. There are three main methods for simulating cellular structures in numerical analysis software. These are element-based methods: solid, beam and homogenization.

2. Numerical analysis of cellular structures

One of the key processes in finite element analysis is the development of a material model. The material model was determined from a uniaxial tensile test of a solid material. Hardening behavior is modeled using an isotropic Voce-type law, which is defined as follows:

$$\sigma_y = \sigma_0 + R_0\varepsilon^{pl} + R_\infty\left(1 - e^{-b\varepsilon^{pl}}\right) \tag{1}$$

where σ_0 is the yield stress, b is the exponential saturation parameter, ε^{pl} equivalent plastic strain, R_0 and R_∞ and are the linear and exponential coefficients, respectively. The yield parameters, shown in Table 1, were determined by fitting equation (1) to an experimental stress-strain curve obtained by uniaxial stretching.

Table 1 Applied parameters of isotropic hardening law

σ_0 [MPa]	R_0 [MPa]	R_∞ [MPa]	b
1030	660	110	375

Simulation of cellular structures can be carried out by three main methods. An analysis based on solid elements, beam elements or homogenization are used. Certainly, the most accurate method is based on solid elements, but this also involves a large computational time (Fig. 1). It is also worth mentioning the method based on beams, where accurate results are also obtained. However, the analysis can only be performed on structures consisting of Strut - based cells. This paper focuses mainly on the homogenization method. When considering this method, it was assumed that the modeling of cell structures involves determining constitutive equations on a macroscopic scale based on knowledge of the material properties of the individual unit cell. Knowledge of the properties of the cell structure on a macroscopic scale and its failure mechanism is crucial in engineering applications. Determination of material parameters (e.g. Young's modulus, Poisson's ratio) is carried out by appropriate averaging against a selected representative volume. Numerical homogenization aims to determine the effective elastic parameters for a heterogeneous material, based on knowledge of the properties of the unit cell forming the material. This paper compares different methods for simulating cellular structures, highlighting homogenization. Numerical homogenization was carried out based on the ideal geometry of the unit cell and the actual geometry of the unit cell (Fig. 2.). The actual geometry was obtained using a CT scanner.

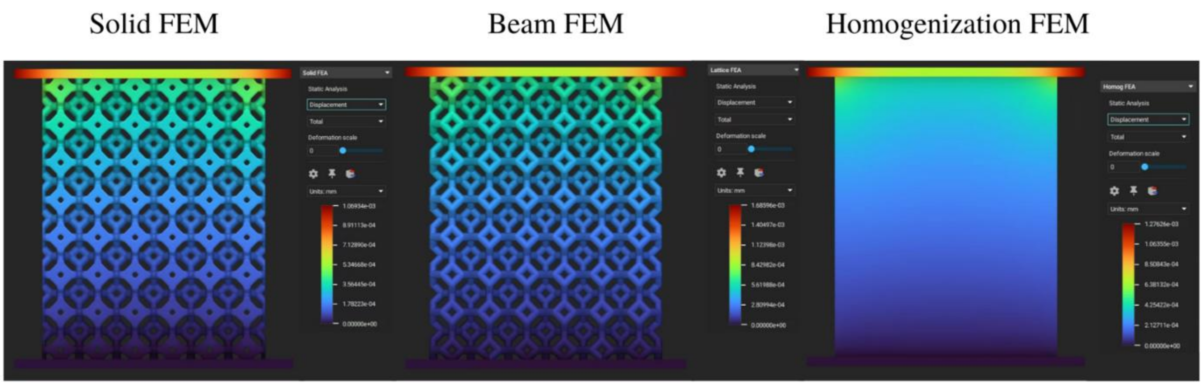

Fig. 1. Comparison of different methods for numerical analysis of cellular structures

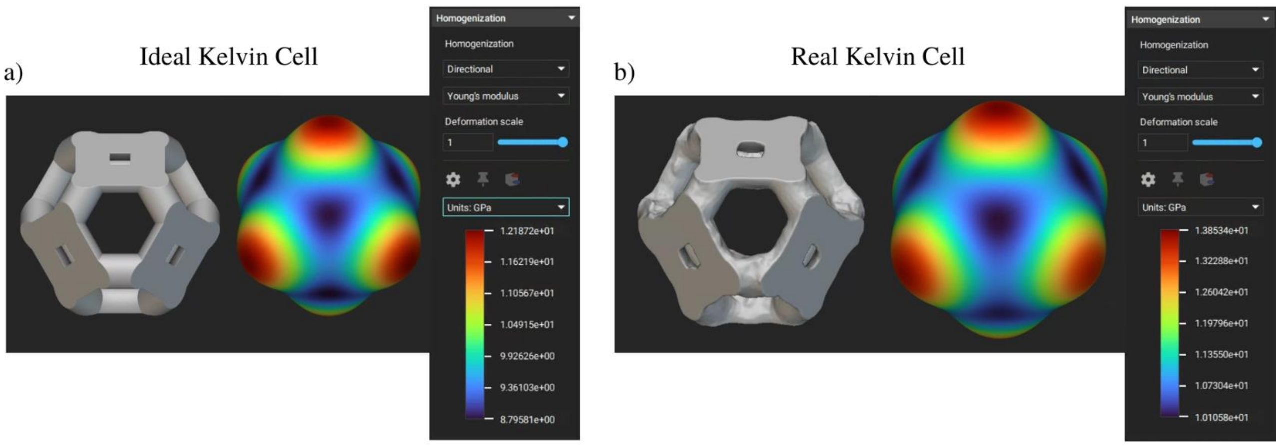

Fig. 2 Numerical homogenization method: a) on an ideal unit cell, b) on the real geometry of the unit cell

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Two-dimensional thermal metamaterials: optimization of thermal conductivity and mechanical stiffness of metaplates

Roberto Brighenti[1], Farzad Tatar[1], Liviu Marsavina[2]

[1] University of Parma: Parma, Italy
[2] Polytechnic University of Timisoara: Timisoara, Romania

E-mail: roberto.brighenti@unipr.it[1], farzad.tatar@unipr.it[1], liviu.marsavina@upt.ro[2]

ABSTRACT

Metamaterials, whose thermo-mechanical properties derive more from their mesostructure than the constituent material, have evolved significantly with the advent of new methods for analyzing and manufacturing [1, 2]. Using proper techniques for designing and manufacturing such materials, scientists have developed novel functional materials with characteristics having going beyond nature [3].
Thermal insulators have long been used in the construction industry for centuries [4]. Even though some mechanically enhanced insulators have been proposed, a material with optimized thermo-mechanical behavior has not yet been proposed. In the present work, the thermo-mechanical response of printed two-dimensional porous metamaterials is studied. In such a metamaterial it is desirable to lower the heat flux passing throughout the material; from a purely thermal perspective, this implies an increasing of the porosity as much as possible, i.e. decreasing the relative density. On the other hand, the optimum mechanical stiffness is obtained when a bulk rigid structure is designed, i.e., no voids are present in the material.
Both behaviors are influenced by the shape, number, orientation, and location of pores which can affect both the thermal and mechanical response of the metaplate. The voids pattern is of particular interest when they are randomly organized within the material; for this purpose, a numerical algorithm was coded to randomize all the mentioned geometrical parameters for investigating their effect on the thermo-mechanical response. The sought functionality can be designed either for improving stiffness or to obtain higher insulation properties. In Figure 1 the general structure of the metamaterial plate is shown. Then, some of the designed metaplates were printed by using FDM AM technology with PLA filament to prove the accuracy of the simulations.

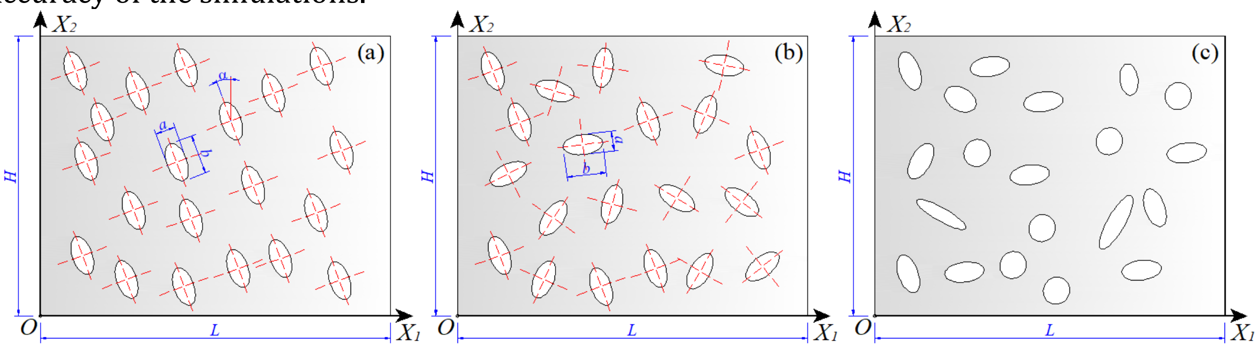

Figure 8. The designed metaplates with random positioning, orientation and shapes of voids.

Figure 2 shows the general trend of the dimensionless stiffness and thermal resistance by increasing the number of voids N created in the plate, here measured through the fictitious plate-unit cell size ratio, $\gamma' = \sqrt{N}$.

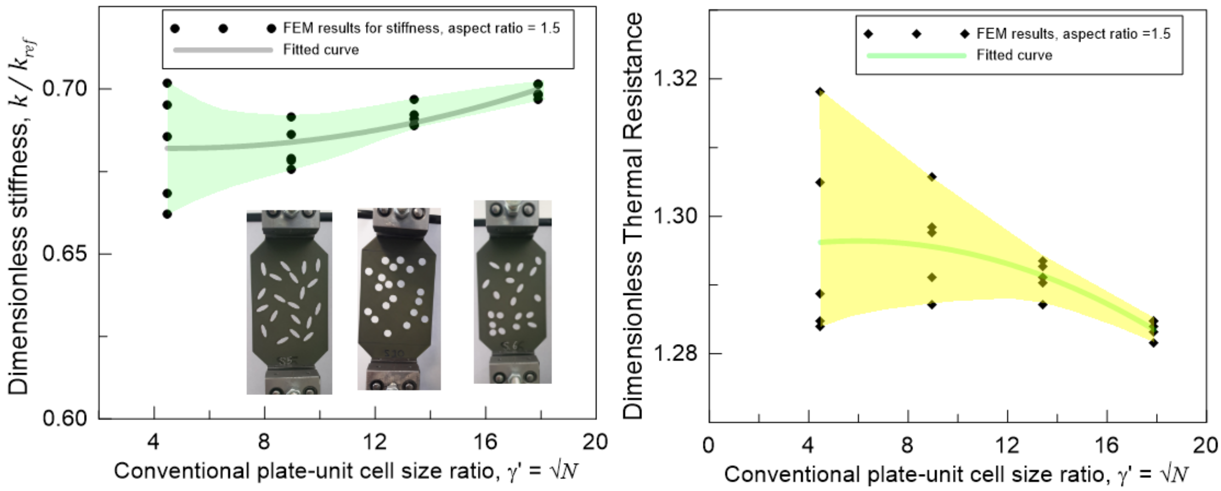

Figure 9. Dimensionless stiffness and dimensionless thermal resistance vs the parameter $\boldsymbol{\gamma'}$ *(corresponding to the number of holes with afixed value of the porosity) for metaplates containing randomly generated voids.*

With the increase of aspect ratio, the larger the intersecting area against the heat flux, the larger the thermal conduction would be. Regarding the mechanical stiffness, when the stress pattern results to be as regular as possible, i.e. without interruptions or large deviation from the straight path, the stiffness is increased. Finite Element results showed good agreements with experiments.

ACKNOWLEDGEMENT

The authors would like to thank the support from European Union's Horizon 2020 research and innovation program (H2020-WIDESPREAD-2018, SIRAMM), grant agreement No 857124.

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Pressure and shear loading of BCC lattice structures produced by SLM technology using contour scanning strategy

Jan Jaroš[1], Daniel Koutný[2], Josef Zapletal[3], Libor Pantělejev[4]

[1,2] Brno University of Technology, Faculty of Mechanical Engineering, Institute of Machine, and Industrial Design, Technicka 2896/2, 616 69 Brno, Czech Republic
[3,4] Brno University of Technology, Faculty of Mechanical Engineering, Institute of Materials Science and Engineering, Technicka 2896/2, 616 69 Brno, Czech Republic

Email: Jan.Jaros2@vut.cz[1], Daniel.Koutny@vut.cz[2], zapletal@fme.vutbr.cz[3], pantelejev@fme.vutbr.cz[4]

ABSTRACT

Introduction
Selective Laser Melting (SLM) technology as a part of Laser Powder Bed Fusion (LPBF) technology can produce complex shape parts inspired by nature. Example of such part can be a lattice structure which is composed of specifically oriented struts with small diameters [1]. However, design of part with lattice structure needs to be based on mechanical properties which should have been known [2]. According to the loading applied on the part, the mechanical properties of lattice structure should have been measured. Therefore, the basic compression loading will be compared with the shear loading and impact of loading on lattice structure will be observed.

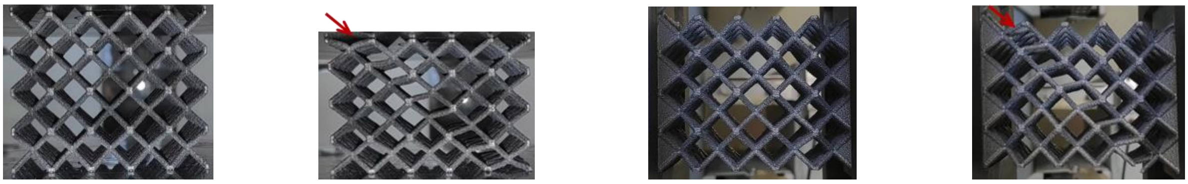
Materials and methods
Lattice structures with the size of 40x40-50 mm and with BCC unit cell size of 10x10 mm were used. Struts diameter was 1.25 mm. Four structures were produced where two structures were dedicated for pressure testing and two for shear testing. The mechanical testing was performed on Zwick/Roell Z250 testing machine. The loading speed was set to 1 mm/min. Deformation of structures was measured by extensometers and loadcell of 150 kN was used.
Lattice structures were produced on SLM 280^{HL} machine. Contour strategy with laser power of 300 W, laser speed of 950 mm/s was used. Contour distance and beam compensation were applied according to the track width [3].

Results and discussion
The compression behaviour of lattice structures is shown in Figure 1a. The maximum compression elastic modulus of BCC lattice structure for pressure loading was 55.36 MPa and the maximum standard force for pressure loading was 3298 N. Behaviour of lattice structures under the shear loading is shown in the Figure 1b. The maximum elastic modulus of BCC lattice structure for shear loading was 79.40 MPa. The maximum standard force for shear loading was 2682 N.

(a) (b)

Figure 1 (a) Force vs. deformation from pressure testing; (b) force vs. deformation from shear testing

The behaviour of BCC lattice structure under the pressure and shear loading is quite different. The pressure loading shows more pronounced transition between elastic and plastic regions (Figure 1). The load was transmitted by bending of struts throughout whole structure. After the reach of bearing capacity of struts the entire structure collapsed on diagonal (Figure 2b – red arrow). The shear loading led to bending of struts directly on diagonal (Figure 2d). Therefore, the struts on diagonal were overloaded which cased to fracture of structure. The lattice structure under the shear loading has more rigid behaviour in elastic region and insignificant yield strength.



(a) (b) (c) (d)

Figure 2 (a,b) Pressure testing; (c,d) shear testing of lattice structure

Conclusions

- Under the pressure loading the BCC lattice structures obtain the higher maximum standard force of 3511 N vs. 2682 N, but lower elastic modulus for lattice structure of 55.36 MPa vs. 79.40 MPa.
- Consideration of deformation characteristic is needed for design of parts using lattice structure for specific applications.

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Bio-inspired core-shell architectured filament with tunable damage tolerance

Li Liang[1], Filippo Berto[1], Chao Gao[1*]

[1] Norwegian University of Science and Technology (NTNU), Richard Birkelands vei 2b, 7491, Trondheim, Norway

Email: chao.gao@ntnu.no

ABSTRACT

Architectured materials, materials that manipulate the spatial configurations of two or more material phases, have recently received numerical attentions because of their unprecedented material properties (e.g., strength-to-lightweight, negative Poisson's ratio). Inspired by the structure of spider's silk in Nature, a new type of architectured filament was designed and fabricated by multimaterial Fused deposition modelling (FDM) printer (A4V4). The architectured filament has a stiff PolyLactic Acid (PLA) core surrounded by a soft Thermoplastic polyurethane (TPU) shell. Uniaxial tensile tests were performed at quasi-static loading condition in order to quantify the damage tolerance and failure modes of architectured filaments. The mechanical model of this core-shell architectured filament was developed to better understand the synergistic effect of filament's morphology and combinations of different material phases. The experimental results were quantitatively consistent with the numerical predictions.

Keywords: Architectured materials, Fused deposition modelling, Mechanical testing

5th Session

5. Applications & advancements in AM materials and structures

Effect of voids and inclusions on the wrinkling pattern of tensile thin sheets: an experimental and numerical study

Andrea Spagnoli[1*], Riccardo Alberini[1], Roberto Brighenti[1], Matteo Montanari[1]

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

Email: spagnoli@unipr.it

ABSTRACT

Thin structures are vulnerable to instabilities when pressure, force or traction lead to geometric, material and force non-linearities. In bidimensional structures, like membranes and sheets, this phenomenon is also known as wrinkling, and the control of its pattern is crucial in many application fields. For instance, in skin plastic surgery [2], wrinkles represent aesthetic blemishes to be reduced. On the other hand, wrinkle pattern could be induced to achieve specific configuration for stretchable electronics [3, 8], making suitable plates for cell culture [4], or deploy adaptive aerodynamic drag control surfaces [6]. Numerical tools, like the finite element method, has been extensively used to simulate thin walled structures, and recent studies demonstrated how the arrangement of voids in a continuum membrane can be used to tailor prescribed wrinkle patterns [7]. In the present work, we extend this concept by considering both voids and rigid inclusions in uniaxially stretched membranes (see Figure 1). The numerical analysis is carried out using a newly developed algorithm [1], capable to model membranes containing multiple cavities and inclusions with complex shape.

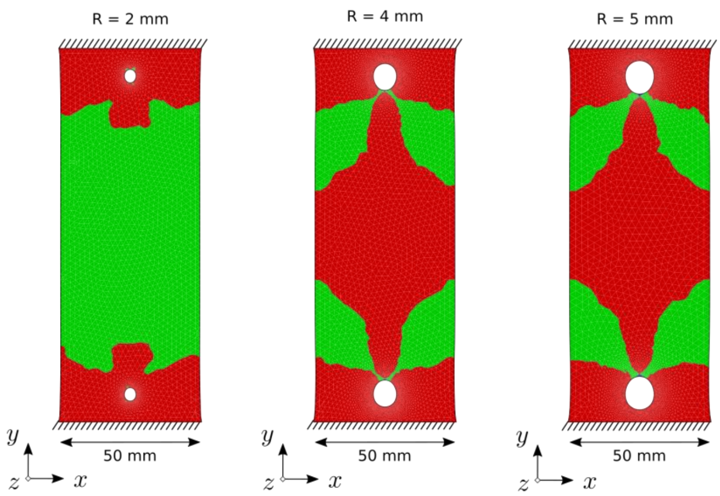
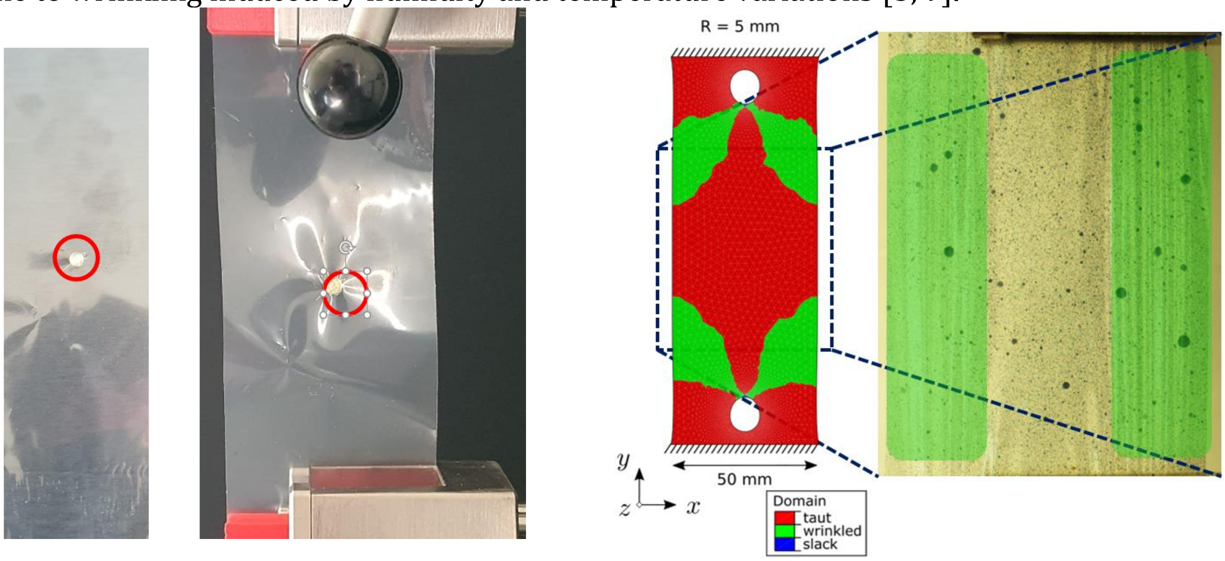


Figure 1. FE results of uniaxial test of membranes with increasing circular holes size. Contour plot show the regions of wrinkling in green.

Results are validated using Mylar® sheets specimens, upon which adherent polymeric islands are 3D printed to mimic rigid inclusions (Figure 2). The present work, conducted within the framework of the H2020 SIRAMM Project (GA No. 857124), might extend knowledge in the area of cultural heritage, in which several artworks painted upon natural membranes, such as organic canvas, parchment, and leather, are susceptible to the environment condition, and prone to wrinkling induced by humidity and temperature variations [5, 9].



(a) (b)

Figure 2. (a) View of a Mylar® sheet with a 3D printed TPU inclusion; (b) wrinkling pattern in a Mylar® sheet with holes in FE simulations and experiments.

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Center for Rapid Prototyping - Challenges in Additive Manufacturing and testing of materials

Milos Milosevic[1]

[1] Innovation Center of the Faculty of Mechanical Engineering, Kraljice Marije 16, 11100, Beograd, Serbia.

Email: mmilosevic@mas.bg.ac.rs

ABSTRACT

During the implementation of the Siramm project (H2020-WIDESPREAD-2018, SIRAMM under grant agreement No 857124.), one of the laboratories where the samples were prepared and tested was the Center for Rapid Development of Prototypes, within the Innovation Center of the Faculty of Mechanical Engineering in Belgrade. In this presentation, the equipment will be shown with a special review of the possibilities of use, as well as projects and tests that were carried out in the previous period.

Acknowledgments
The author would like to thank the support from European Union's Horizon 2020 programme (H2020-WIDESPREAD-2018, SIRAMM) under grant agreement No 857124.

Development and design of a two-armed robot from the aspect of mechatronics

Uros Ilic[1], Aleksandra Joksimovic[1], Marko Djurovic[1], Emil Veg[1], Isaak Trajkovic[2]

[1] University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11120, Belgrade, Serbia.
[2] Innovation Center of the Faculty of Mechanical Engineering, Kraljice Marije 16, 11100, Belgrade, Serbia.

Email: ilicuros01@gmail.com, ajoksimovic@mas.bg.ac.rs

ABSTRACT

In this paper, the development of a two-handed manipulator from the aspect of mechatronics will be shown, with a focus on the possible problems during this process. The goal of this robot is to be able to connect and assemble simple parts, even if the parts are scattered on the work surface or if they are approaching the robot's workspace on the conveyor. Although there are already interchangeable grippers for different types of operations, this paper will show the development of designing a machine (robot) for a specific task, from the aspect of mechatronics. When the selected industrial parts are in the working range of the robot, the robot will recognize them using a sensor system - a smart camera. It processes the information it receives from the sensor system according to the already set assembly instructions, and thus knows exactly which parts are connected to each other and how. The entire model was created in the SolidWorks environment, in order to create an animation that shows the possible movement of the robot during the assembly process. This robot is capable of actually working independently, but it can be modified to work with an operator, which is the direction of further development.

Acknowledgment
This research was supported by the Serbian Ministry of Science and Technological Development – projects "Research and development of equipment and systems for industrial production, storage and processing of fruits and vegetables" (Project no. TR 35043).

Significance of designing the filling of an open rapid sand filter when removing impurities from water

Marko Djurovic[1], Aleksandra Joksimovic[1], Uros Ilic[1], Emil Veg[1], Isaak Trajkovic[2]

[1] University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, 11120, Belgrade, Serbia.
[2] Innovation Center of the Faculty of Mechanical Engineering, Kraljice Marije 16, 11100, Belgrade, Serbia.

Email: markodjurovic9717@gmail.com, ajoksimovic@mas.bg.ac.rs

ABSTRACT

Filtration is a mechanical process of squeezing, during which the passage of liquid occurs, in this paper, specifically water, through a porous layer of material. During that flow, the impurities are retained within that layer, which is called the filter, and the water is desired quality comes out of the filtering device. The goal of this work is to demonstrate the importance of dimensioning the filter itself, so reliably that during the actual filling of the filter, almost all impurities remain in that layer. There are different types of filters, and also different dimensions for each type. Which type will be specifically used depends on several factors such as the desired quality of the water coming out of the filter, the initial state of the water (pollution) coming into the filter, the amount of water reaching the filter, the speed of the filtration process itself, etc. In this paper, the importance of dimensioning sand filters, as well as the selection of the filter filling method, is highlighted.

Acknowledgment
This research was supported by the Serbian Ministry of Science and Technological Development – projects “Research and development of equipment and systems for industrial production, storage and processing of fruits and vegetables” (Project no. TR 35043).

Strategy for wire arc additive manufacturing of thin walls

Jakub Slavíček[1], Jakub Hurník[2], Daniel Koutný[3]

[1,2,3] Brno University of Technology, Faculty of Mechanical Engineering, Institute of Machine and Industrial Design, Technicka 2896/2, 616 69 Brno, Czech Republic

Email: Jakub.Slavicek1@vut.cz[1], Jakub.Hurnik@vut.cz[2], Daniel.Koutny@vut.cz[3]

ABSTRACT

Introduction
Additive manufacturing (AM), also called 3D printing, has become an alternative to conventional subtractive manufacturing methods in recent decades [1]. Wire arc additive manufacturing (WAAM) is a type of AM that is based on arc welding (GMAW or GTAW) and depositing material layer by layer. The main advantages of this technology include the low cost of filler material, high deposition rates, good structural integrity, and low equipment cost [2]. Shrinkage occurs during the solidification of liquid metal. It causes the formation of plastic and elastic deformations, especially in the longitudinal direction of material deposition [3]. One of the possibilities, to influence the creation of deformations, is to divide the object and manufacture it part by part. While a new part is deposited, the previous one cools down. It should ensure more effective heat management and fewer deformations. In this paper, the influence of thin-walled parts manufacturing strategies on deformations will be observed.

Materials and methods
Production of specimens was carried out at a workplace equipped with a robotic arm KUKA KR60 HA and welding power source Fronius TPS 3200 CMT. A S235JR steel base plate (150x150x30 mm) was used as the substrate and G3Si1 filler wire with a diameter of 0,8 mm was used as the feedstock material. The welding took place in a protective atmosphere of CORGON (82 % Ar, 18 % CO_2) with a flow rate of 15 $l{\cdot}min^{-1}$. Three types of experiments were conducted. The first experiment was focused on searching for suitable process parameters. Four different WFR (wire feed rate) settings in the range of 2.5 - 10 $m{\cdot}min^{-1}$ in combination with 7 different TS (torch speeds) in the range of 0.15 - 1.05 $m{\cdot}min^{-1}$ were tested. The second experiment dealt with searching for suitable offsets in weld beads joints in the range from -1 to 1 mm. The last experiment was focused on producing thin walls using 5 different printing strategies. Examples of 3 of these strategies are shown in Figure 1. The control of the dimensional accuracy of the specimens was carried out using the Atos III Triple Scan device.

Results and discussion
The best combinations of process parameters to achieve continuous weld beads were: WFR 5 $m{\cdot}min^{-1}$ combined with TS 0.3 and 0.45 $m{\cdot}min^{-1}$ and WFR 7.5 $m{\cdot}min^{-1}$ combined with TS 0.6 and 0.45 $m{\cdot}min^{-1}$. These four combinations of process parameters were further tested in the second experiment focused on welding beads joining. This experiment has shown that the best results are achieved by the usage of a positive offset (material added) with weld beads fabricated towards each other and by a negative offset (material reduction) with weld beads fabricated back-to-back. TS 0.3 $m{\cdot}min^{-1}$, WFR 5 $m{\cdot}min^{-1}$ and offset 1 mm were selected as the

best parameters for the third experiment. Using these parameters, several thin-walled samples were fabricated by five different fabrication strategies. Fabricated thin-walled specimens are shown in Figure 2c.

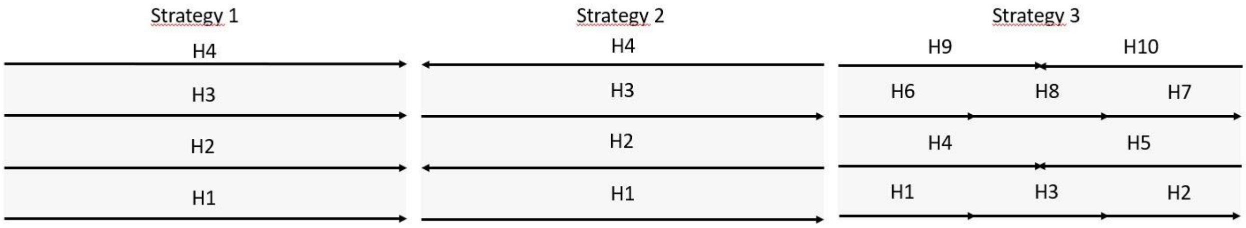

Figure 1. Fabrication strategies

These strategies have been observed to have different effects on dimensional accuracy and the development of residual stress. The reason for the appearance of dimensional inaccuracies is an accumulation of errors caused by local under-extrusion or over-extrusion.

(a) (b) (c)

Figure 2. (a) Process parameters test; (b) weld beads joining test; (c) walls fabricated with different strategies

Conclusion

- Suitable process parameters to produce thin-walled objects were found.
- Differences between the deformations of thin walls, fabricated by different strategies, were observed as well as differences in geometric accuracy.

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Additive manufacturing of nanometre alignment mechanisms for Croatian National laboratory for length

Marko Horvatek[1]

[1] Faculty of mechanical engineering and naval infrastructure, University of Zagreb

Email: mhorvatek@fsb.hr [1]

ABSTRACT

Introduction
Compliant mechanisms are often used in micro and nano positioning as they can provide highly precise linear and rotational motions. These mechanisms gain their motion from relative flexibility of its sections. This differs from mechanisms with joints that are traditionally used in mechanical engineering (Fig. 1). Although compliant mechanisms provide many benefits such as no backlash, no maintenance, as well as low friction and noise, they still haven't managed to live up to their great application potential. Main reasons are complex design process and production limitations using traditional manufacturing methods.

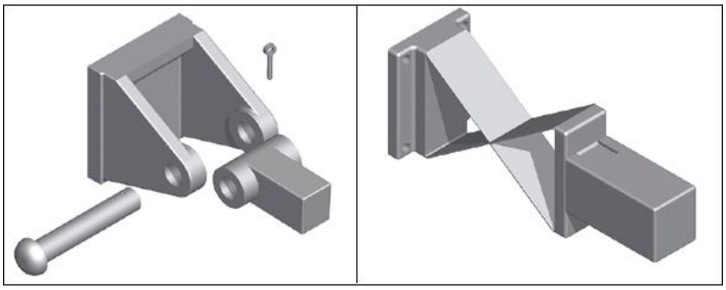

Fig. 1 Examples of rigid body mechanism and compliant mechanism alternative

Compliant mechanisms are often used for providing highly linear motion required for metrology and sample manipulation applications.

Traditional compliant mechanisms manufacturing methods
Traditionally used manufacturing methods for production of compliant mechanisms are machining, stamping, as well as laser, water and EDM cutting. Stamping and cutting technologies are most commonly used but they are generally limited to two-dimensional geometry designs. More complex mechanisms can theoretically be produced using multi-axis machining, but deformation of the stock during thin wall machining creates problems in production and limits accuracy.
In contrast to traditionally used technologies, additive manufacturing allows simple production of the complex geometries. This does not only allow production of currently unfeasible geometries but also speed up the design process. In addition, testing phase can be shortened significantly as prototypes can be made in days rather than weeks. Another advantage of additive manufacturing includes easy customization and possibility to produce parts just in time, without need for large stock.

Application of 3D printed compliant mechanisms in Croatian National laboratory for length (FSB-LPMD)

In the measurement of linear scales in Croatian national laboratory for length, one axis optical measurement system is used. Consequently, sample parallelism with the measurement axis is crucial and it is necessary to fine adjust pitch and jaw angles of the measured scale (Fig. 2).
For this purpose, we have constructed two compliant mechanisms that provide each one DOF, generating consequently needed pitch and jaw movements (Fig. 2).

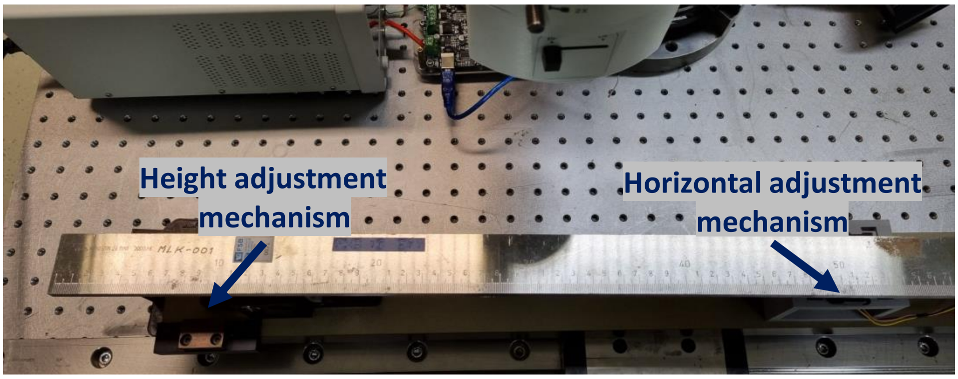

Fig. 2 Height and pitch (horizontal rotation) adjustment mechanisms

Design of hybrid compliant mechanisms for sample alignment

Compliant mechanisms for scales manipulation were designed with required displacement ranges as main objectives and additive manufacturing as production technology. 1st compliant mechanism (Fig. 3) provides the vertical alignment (height adjustment as noted on Fig. 2) while 2nd compliant mechanism provides rotational adjustment in horizontal plane (horizontal alignment as noted on Fig. 2). Stepper motor with reductor was used for displacement generation of 100 µm in vertical and 350 µm in horizontal stage.

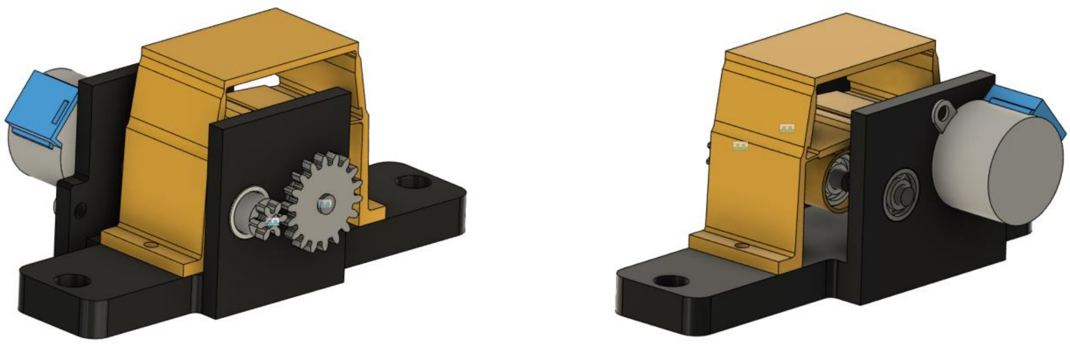

Fig. 3 Front and back isometric view of height adjustment mechanism CAD model

Laboratory testing and conclustion

Mechanisms were manufactured with FDM and SLA technologies using Plastika Trček PET-G and Formlabs Grey materials. Mechanisms displacements were measured with Mahr Millimar P2004 inductive probe. Testing was conducted in laboratory conditions (temperature of 20°C) on vibration dampened Thorlabs optical workbench.
In horizontal direction displacement of 338,7 µm was achieved and in vertical displacement total displacement of 105,2 µm. Through whole range of motion, displacement resolution of under 100 nm was achieved. The results confirm feasibility of using additive manufacturing for production of complex alignment mechanisms in field of metrology.

Testing climatic stress component in vegetation via AM: challenges and new opportunities

Ozge Ogut[1,2], Ole Emil Herrmann[1], Nerantzia Julia Tzortzi[2], Chao Gao[1], Chiara Bertolin[1]

[1] Mechanical and Industrial Engineering, Norwegian University of Science and Technology
[2] Architecture, Built Environment and Construction Engineering, Politecnico di Milano

Email: ozge.ogut@ntnu.no, oleehe@stud.ntnu.no, chiara.bertolin@ntnu.no, julia.georgi@polimi.it, chao.gao@ntnu.no

ABSTRACT

Introduction: vertical green structure and plant selection

This study aims to develop a methodology to support decision making process during the plant selection stage in vertical green structure (VGS) design. These structures are used to increase the amount of green infrastructure in built environments optimizing space-related concerns caused by the lack of space in urban areas due to ongoing increase of volume compactness level. Within this framework, a VGS being a skin layer on building façades or a standing wall built in open public areas becomes a solution that without using horizontal space offers several benefits in a urban environment at district scale (e.g. air quality improvement, urban heat island reduction, potentiality for food production, enhancement of social wellbeing). Number and material of VGS's components vary based on complexity of the system. This study will focus on components of vegetation only. These are the constituting components which exists in all the VGS typologies.

At building scale, one of the possible benefits of a VGS is to act as a thermal insulation layer by changing microclimatic conditions [1, 2]. It helps to stabilize indoor temperature inside a building increasing it during cold seasons and decreasing it in warm seasons, correspondingly the amount of energy needs for cooling and heating is also reduced thus offering cost effectiveness. To optimize all these benefits, the vegetative component selection has to be done in an efficient way. Actually, the most concern is the aesthetical value provided by vegetation, however, as its main aim is to improve an efficient thermal behaviour, the aspect of reaction of vegetation to hygro-thermal variation has to be assessed as much as possible quantitatively.

Test preparation

Therefore this study aims to test the climatic stress on vegetation occurred after fluctuations of temperature (T) and Relative Humidity (RH). In the preparation stage of the test, four different vegetation species have been selected to be monitored by a thermal camera (FLIR A70, with 464 × 348 IR resolution and ±2°C accuracy; detector pitch=17 μm, FOV=29°x22° and f=14.3 mm; image frequency=30 Hz) when subjected to variations of environmental parameters (i.e., T and RH) in a climate chamber (Memmert HPP1060). Three different climates will be simulated during the test resembling the seasons average conditions in Trondheim/Norway (Dfc-Continental Subarctic Climate), Milan/Italy (Cfb-Marine West Coast Climate), and Nicossia/Cyprus (Bsh-Mid-Latitude Steppe and Desert Climate). The selected plant species are listed as follows:

- Silverstar (*Sedum Lineare*)
- Winter shine (*Pachysandra Terminalis*)
- Marmor alunrot, also known as palace purple (*Heuchera Villosa*)
- Barren Strawberry (*Ternata Waldsteinia*)

The plants differ from structural appearance that was one of the criteria to choose the plants as all the leaves have different dimensions and geometrical forms. In addition, other selection criteria have been based on water requirement and light requirement. In fact the test will be conducted during wintertime in the climate chamber located at the Fatigue Laboratory, Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology, so plants have both to require low amount of water to modify as little as possible T and RH conditions set inside the chamber; and low light conditions since they will be stabilized under light condition provided by LED growth lamps (Cosmorrow Light package Growth).

Additive manufacturing of the leaves

To analyse the thermal images of leaves precisely, reference objects are needed and under preparation per each of the four species. By observing the common features of different species and assuming leaves have a repeated design pattern, we simplified the complex leaves into simple geometrical unit shapes i.e., an ellipse. Number of ellipses varies as the complexity of leaves' shapes. Moreover, owing to the variety of original dimension, the reference leaves of three types of plants are scaled up with different factors, and projected in 2D accordingly. The simplified designs of reference objects will be fabricated by fused deposition modelling (FDM)—the most widely used additive manufacturing (AM) technology that deposits materials layer by layer on printing platform. Industrial FDM printer (3ntr A4V4) with temperature-controlled chamber will be utilized to produce high-quality FDM printed leaves by polyactide (PLA). The additive manufactured leaves will be used as reference objects in the climate chamber for thermal measurement.

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