H2020-WIDESPREAD-2018-03
Project No. 857124

International conference

East Europe Conference on AM materials

Faculty of Mechanical Engineering
University of Belgrade, Serbia
& Online

2nd-4th September 2021

Conference Programme & Book of Abstracts

Conference organized by:

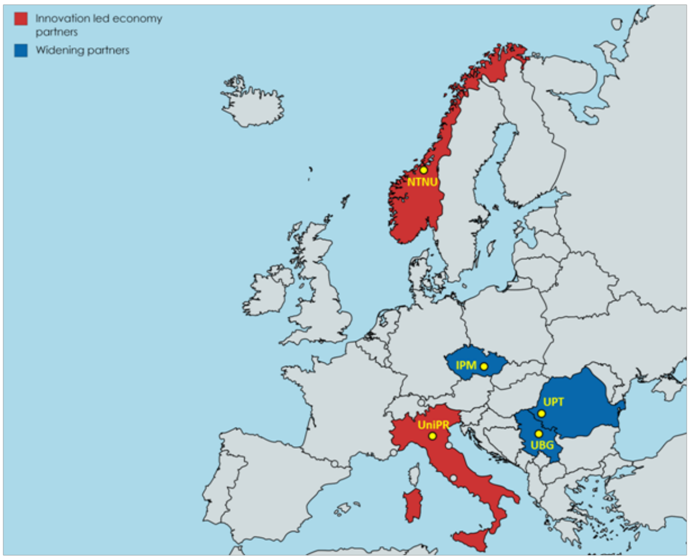
Polytechnic University of Timisoara,
ROMANIA

University of Belgrade,
SERBIA

Institute of Physics of Materials, Brno,
CZECH REP.

University of Parma,
ITALY

Norwegian Univ. of Science and Technology,
NORWAY



Participating institutions in SIRAMM project

To join the conference online,
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https://zoom.us/j/99530434470?pwd=S3Z6Y3pCSWtRZVZxdGNOYVZoUmdwZz09

Meeting ID: 995 3043 4470

Passcode: 395628

Conference Programme

(Central European Time - Paris, Rome, Belgrade)

● in presence & online
● online

Thursday, 2nd September 2021

8:00-9:15	Registration of participants Faculty of Mech. Eng. (FME), Univ. of Belgrade, Serbia
9:15-9:45 ●	Opening of the Conference and presentation of the SIRAMM project (FME & online) Prof. Liviu Marsavina
9:45-10:15 ●	**1st Keynote lecture** (FME & online) Chairman Prof. Liviu Marsavina ***Mechanical Properties and geometric aspects in Selective Laser Sintering*** Dr. Dan Stoia (Politehnica University Timisoara, Romania)
10:15-10:45	*Coffee break* (FME)
10:45-12:45	**1st Session** (FME & online) (12 min presentation + 3 min Qs&As) Chairman: Milos Milosevic ***Characterization of AM materials***
10:45-11:00 ●	*The strength of additive manufactured screws* Andrei Morariu, Estera Valean, Monica Buzdugan, Liviu Marsavina
11:00-11:15 ●	*Mechanical properties of polymeric elements obtained through Digital Light Processing* Roberto Brighenti, Liviu Marsavina, Mihai Marghitas
11:15-11:30 ●	*A green building technique: thermal transmittance value of the different materials used in 3D printed houses* Milica Ivanović, Aleksandar Simonović, Toni Ivanov, Aleksandar Kovačević, Dragoljub Tanović
11:30-11:45 ●	*Mechanical properties of FDM printed objects as a function of the printing parameters* Corrado Sciancalepore, Daniel Milanese
11:45-12:00 ●	*Application of additive manufacturing in jigs and fixture based manufacturing* Rohit Mishra
12:00-12:15 ●	*How does build orientation influences the torsional capacity of hollow shaft* Marius Nicolae Baba
12:15-12:30 ●	*Hardness analysis of additively manufactured metallic specimens* Miloš Milošević, Ivana Jevtić, Isaak Trajković, Žarko Mišković, Tihomir Ćuzović, Aleksa Milovanović, Milan Travica
12:30-12.45 ●	*Load-rate effects of Additively Manufactured metallic honeycomb structures under compression* Solomon O. Obadimu, Kyriakos I. Kourousis

12:45-14:15 *Lunch break* (FME)

14:15-14:45 • **2nd Keynote lecture** (online)
Chairman: Roberto Brighenti
Gender in Science and Technology
Dr. Roxana Ghita (Politehnica University Timisoara, Romania)

14:45-16:30 **2nd Session** (FME & online) (12 min presentation + 3 min Qs&As)
Chairman: Roberto Brighenti
AM technologies advancements & new experiences

14:45-15:00 • *The use of 3D printing for studying the influence of ionizing radiation on electronic components*
Stefan Ilić, Miloš Vorkapić, Toni Ivanov, Jelena Svorcan

15:00-15:15 • *CAD development of parts adapted to Additive Manufacturing production*
Goran Mladenovic, Ivana Jevtic, Milos Milosevic, Isaak Trajkovic

15:15-15:30 • *The first bridge - prototype development through Fused Deposition Welding Modeling (FDM)*
Anamaria Ioana Feier, Felicia Veronica Banciu, Mihai Brîndușoiu, Radu Băncilă

15:30-15:45 • *Additive Manufacturing of Removable Complete Dentures*
Christa Serban, Florin Ionel Topala, Meda Lavinia Negrutiu, Virgil Florin Duma, Liviu Marsavina, Cosmin Sinescu, Adrian Gh. Podoleanu

15:45-16:00 • *Mechanical properties of polymer matrix composite materials produced by additive manufacturing through the finite element method*
Israel David Mantilla Bravo, Octavio Andrés González Estrada, Oscar Rodolfo Bohórquez Becerra, Sebastián Casas Parra

16:00-16:15 • *KnowHub entrepreneurial projects based on Rapid Prototyping Technology: Montenegro in focus*
Jelena Šaković Jovanović, Janko Jovanović, Aleksandar Vujović

16:15-16:30 • *Experiences in 3D printing applied in education*
Petar Jakovljević, Đorđe Dihovični, Ivan Bijelić, Dragan Kreculj, Nada Ratković Kovačević

16:30-17:30 • **Practical session** (FME & online)
Demo from 3DRepublica company
Visit to testing and DIC Lab

Presentation of the project 5825 'Device for simultaneous measurement of thermo-mechanical properties of dental composites' funded by the Innovation Fund of the Republic of Serbia

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Friday, 3rd September 2021

9:00-9:30 •	**3rd Keynote lecture** (FME & online) Chairman: Prof. Aleksandar Sedmak ***Horizon Europe – new EU framework program*** Biljana Glišić (Horizon NCP, Serbia)
9:30-11:00	**3rd Session** (FME & online) (12 min presentation + 3 min Qs&As) Chairman: Prof. Aleksandar Sedmak ***Simulation of AM processes***
9:30-9:45 •	*Machine learning applications in additive manufacturing: an assessment of the state-of-the-art and future prospects* Lipika Mohapatra, Bikash Chandra Behera
9:45-10:00 •	*Link between reverse engineering and additive technology on the example of a model without technical documentation* Miloš Vorkapić, Ivana Mladenović, Aleksandar Kovačević, Marija Baltić
10:00-10:15 •	*Machine Learning Module for Predicting Tensile Response of SLMed Ti-6Al-4V* Mainak Banerjee, Ankan Banerjee, Dipayan Mukherjee, Anil K Singla, Jagtar Singh
10:15-10:30 •	*Modeling Selective Laser Sintering AM: an overview* Roberto Brighenti, Andrea Spagnoli, Michele Terzano, Mattia P. Cosma
10:30-10:45 •	*The importance of machine learning and generative design in AM* Aleksandra Joksimović, Ivana Medojević , Mladen Regodić
10:45-11:00 •	*Making a 3D Printer of Delta Configuration Using Open-Source Project* Miroslav Aleksandrović, Nada Ratković Kovačević, Dragan Kreculj, Đorđe Dihovični, Petar Jakovljević
11:00-11:30	*Coffee break* (FME)
11:30-12:00 •	**4th Keynote lecture** (FME & online) Chairman: Prof. Aleksandar Grbovic ***Numerical modeling of AM processes*** Roberto Brighenti (Univ. of Parma, Italy)
12:00-13:15	**4th Session** (FME & online) (12 min presentation + 3 min Qs&As) Chairman: Prof. Lubos Nahlik ***Fatigue of AM materials***
12:00-12:15 •	*Low cycle fatigue behavior of 316L steel manufactured by selective laser melting* Jiří Man, Ivo Šulák, Ivo Kuběna, Alice Chlupová, Lukáš Douša, Jaroslav Polák
12:15-12:30 •	*Numerical simulation of crack propagation in a component produced by additive manufacturing* L. Trávníček, F. Arbeiter, P. Dlhý, M. Spoerk, L. Náhlík, P. Hutař
12:30-12:45 •	*Correlation between fatigue behaviour and surface roughness of Inconel718 produced by additive manufacturing* Federico Uriati, Gianni Nicoletto
12:45-13:00 •	*Comparison of cyclic behaviour of SLM- and conventionally-processed 304L* Miroslav Šmíd, Michal Jambor, Daniel Koutný, Stanislav Fintová, Ivo Kuběna
13:00-13:15 •	*A_MADAM project - fatigue behaviour of steels produced by DMLS* Snežana Ćirić-Kostić, Nebojša Bogojević, Dario Croccolo, Giorgio Olmi, Zlatan Šoškić

13:15-14:30	*Lunch break* (FME)
14:30-15:00 •	**5th Keynote lecture** (FME & online) Chairman: Prof. Aleksandar Grbovic ***Additive Manufacturing in Aerospace Industry: Present and Future*** Ognjen M. Peković (Faculty of Mech. Eng. – Univ. of Belgrade, Serbia)

Organized city tour

15:15 – 16:30	**Museum Nikola Tesla**
16:45 – 17:45	**Saint Sava church**
18:00 – 22:00	**River cruise & Conference dinner**

Saturday, 4th September 2021

9:00-9:30 • **6th Keynote lecture** (online)
Chairman: Andrea Spagnoli
Design advanced interlocked structures via machine learning approach
Chao Gao (NTNU, Norway)

9:30-10:30 **5th Session** (FME & online) (12 min presentation + 3 min Qs&As)
Chairman: Andrea Spagnoli
Structural Integrity of AM materials

9:30-9:45 • *Monitoring of crack growth in additive manufactured pipe ring specimens by digital image correlation*
Isaak Trajković , Miloš Milošević , Bojan Međo , Marko Rakin , Aleksandar Sedmak

9:45-10:00 • *Estimating damping values of 3D printed ABS test specimens using the half-power method*
Ionuț Ailinei, Sergiu-Valentin Galațanu, Liviu Marșavina

10:00-10:15 • *Damage mechanisms of SLM-printed 316L steel subjected to thermomechanical fatigue*
Tomáš Babinský, Ivo Šulák, Adam Weiser, Lukas Englert, Stefan Guth

10:15-10:30 • *Microstructural characteristics lying behind the instability of additively manufactured Co-28Cr-6Mo alloy*
Michaela Roudnicka, Orsolya Molnarova, Jan Drahokoupil, Jiri Kubasek, Jiri Bigas, Vit Sreibr, Libor Pantelejev, David Palousek, Dalibor Vojtech

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10:30-11:00 *Coffee break* (FME)

11:00-12:15 **6th Session** (FME & online) (12 min presentation + 3 min Qs&As)
Chairman: Aleksa Milovanovic
Properties and models of AM materials

11:00-11:15 • *Printing parameter effect on tensile properties of FDM polypropylene material*
Aleksa Milovanović, Zorana Golubović, Ivana Jevtić, Aleksandar Sedmak, Miloš Milošević

11:15-11:30 • *Model development by FDM technique of additive production using dual extrusion - advantages and disadvantages*
Tijana Lukić

Replaced by the following paper

11:15-11:30 • *Influence of cordierite and zeolite on improvement of cavitation resistance of talc-based ceramics*
Marko Pavlović, Marina Dojčinović, Ljiljana Trumbulović, Drjan Todorović

11:30-11:45 • *In-process monitoring of the 3D-printing and its use in the development of special cutting tools*
Miloslav Kepka, Miroslav Zetek, Pavel Hanzl, Matěj Rott, Ivana Zetková, Martin Bureš

11:45-12:00 • *Implementation of additive manufacturing for solutions in agriculture*
Tihomir Cuzovic, Dusanka Colakovic

12:00-12:15 • *Development and additive manufacturing of bladeless thruster*
Janko Jovanović, Jelena Šaković Jovanović, Aleksandar Vujović

12:15-12:30 • *Experimental design in the quality control of the additive manufacturing process for carbon fiber-reinforced plastics*
Irina Gadolina, Sergey Smelov, Igor Maidanov

12:30-12:45 •	Closing of the Conference and presentation of future SIRAMM events (FME & online) Prof. Liviu Marsavina
12:45-14:00	*Lunch break* (FME)

Post Conference tour

14:00 – 15:30	**Neolitic pre-historic site Vinča**
16:45 – 19:00	**Viminacium - Roman settlement**

List of Keynote lectures & Abstracts

Keynote lectures

Keynote lecture

Mechanical Properties and geometric aspects in Selective Laser Sintering

Dr. Dan Stoia

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ABSTRACT

The additive manufacturing (AM) was integrated in all industry branches due to limitless geometrical possibilities of the products and to relative reduced production time [1-3]. Independently on the type of AM process, the accuracy and mechanical properties of the parts represents a challenging research issue. One of the AM technologies, Selective Laser Sintering (SLS), uses a laser beam to selectively bound the powder particles together. The inconsistencies in shape, size and mechanical properties are not avoiding this technology, a relation between technological parameters and mechanical and geometrical properties being studied by many authors [4-7]. Knowledge to the field was added by conducting extensive mechanical tests, for fully characterizing the properties of samples obtained by SLS. Also, in what extend the obtained properties belong to the material or to the technology used for fabrication represents a major concern [8-11].

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5. Griessbach, S.; Lach, R.; Grellmann, W. Structure–property correlations of laser sintered nylon 12 for dynamic dye testing of plastic parts. Polym. Test. 2010, 29, 1026-1030.
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8. D.I. Stoia, Liviu Marsavina, Emanoil Linul, Correlations between Process Parameters and Outcome Properties of Laser-Sintered Polyamide, Polymers, 2019 – in review process
9. Dan Ioan Stoia, Linul Emanoil, Liviu Marsavina Influence of Manufacturing Parameters on Mechanical Properties of Porous Materials, in Selective Laser Sintering, MDPI – Materials 12(7), 2019
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Keynote lecture

Gender in Science and Technology

Dr. Roxana Gita

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ABSTRACT

The aim of this lecture is to explore gender gaps leading to a career in science and engineering, from the decision to enrol in a degree, to the scientific fields that both genders pursue and the sectors in which they work. Moreover, the lecture sets out to outline the combination of factors which leads to the emergence of this gender imbalance at each stage of a scientific career: the graduate-level environment, performance evaluation criteria, the lack of recognition, lack of support for leadership skills development and conscious or unconscious gender bias.

The lecture focuses on a comparative analysis of gender imbalance in science and engineering in Romania and Italy. Participants are encouraged to bring their own input on this topic, based on both their personal and cultural experience.

The final part of the lecture aims to discuss policies for gender equality that have already been created and their efficacy, as well as other approaches that can be taken in order to ensure an equitable and diverse work environment in science and engineering.

Keynote lecture

Horizon Europe – new EU framework program

Biljana Glišić

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Horizon Europe National Contact Point, Serbia

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ABSTRACT

The Horizon Europe is an ambitious EU framework program for research and innovation. The goal of the program is to strengthen the scientific and technological basis of the EU and the European Research Area (ERA). Through this framework, EC trying to increase Europe's innovation capacity and competitiveness and jobs to meet the priorities of citizens and maintain socio-economic model and values. Added value through Horizon Europe is benefits for Europe strengthened and European R&I landscape, to create new market opportunities, to increase visibility for leading research and innovation and many more. Commission proposal for budget is €100 billion for period 2021-2027.

Keynote lecture

Numerical modeling of AM processes

Roberto Brighenti

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ABSTRACT

Additive manufacturing (AM) processes are based on a variety of technologies harnessing physical and/or chemical phenomena to produce the final printed part [1].
AM allows producing parts from a digital file by using a huge variety of materials, and multi-material printing has been also possible with the latest 3D printers, enabling the production of elements at very different scales.
Modeling AM is required for efficiently printing parts capable of guarantee the necessary quality and mechanical properties
In the lecture, the three most diffused AM processes are considered from the computational simulation viewpoint: 1) 3D printing based on powder melting & solidification [2]; 2) Liquid solidification [3],[4]and 3) material deposition [5].
For each class of additive manufacturing process, irrespectively of the specific technology they are employed in, the main governing equations are illustrated and the computational implementation aspects are explained.
Typically, the finite element (FE) is adopted for such a purpose, but other numerical technologies, such as the discrete element method, can be also conveniently employed to simulate some AM process.
Advantages, disadvantagies, computational cost, and opportunities offered by the simulation of AM processes through numerical techniques are finally discussed.

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[3] Brighenti, R., Cosma, M. P., Marsavina, L., Spagnoli, A., & Terzano, M. (2021). Multiphysics modelling of the mechanical properties in polymers obtained via photo-induced polymerization. The International Journal of Advanced Manufacturing Technology, 1-19.
[4] Brighenti, R., & Cosma, M. P. (2021). Mechanical behavior of photopolymerized materials. Journal of the Mechanics and Physics of Solids, 153, 104456.
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Keynote lecture

Additive Manufacturing in Aerospace Industry: Present and Future

Ognjen M. Peković

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ABSTRACT

Additive Manufacturing (AM) technologies have a profound impact on the aviation industry, they are continuously expanding their share in the aerospace supply chain, providing better revenues, turnaround times, and lower CO2 emissions. Despite the huge expansion that has taken place over the last decades, it seems that the aerospace industry has barely scratched the surface of the enormous potential AM has to offer.

At the beginning of their use in the aerospace industry, additive technologies were used for nonfunctional parts (e.g. rapid prototyping), rapid tooling (e.g. molds), and non-critical parts such as assembly jigs, testing equipment, fixtures and accessories in the airplanes. Now, AM is used for the fabrication of some of the most critical aircraft components with high structural demand such as jet engine turbine blades and combustion chambers, wings and fuselages of Unmanned Aerial Vehicles (UAV), etc. As the aviation industry continues to embrace AM, the technologies are used in a variety of ways that were unthinkable just a few years ago, and new uses that could not have been imagined before are appearing almost daily.

As the safe operation of aerospace products is of utmost importance, standards and regulations have a critical role in the aerospace industry. AM technologies, while still in its infancy, made such a fast and extensive impact on the aerospace industry that the aviation authorities were not been able to provide adequate standards infrastructure and recommended practices for the design, build, and safe operation of AM parts in such a short period. This is one of the biggest challenges for wider use of the AM, and a large amount of research and effort is invested so that standardization of AM for aerospace progresses at the right pace.

This keynote, will present the current status of AM technologies in the aerospace industry, give an overview of different AM technologies in use and point out their advantages and disadvantages. Additionally, it will discuss problems with the developments of standards and recommendations for this application.

Keynote lecture

Design advanced interlocked structures via machine learning approach

Chao Gao

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ABSTRACT

The remarkable wavy interlocking features of biological materials (e.g., turtle shell, beak of woodpecker and ammonite shell) have received great interest from scientists and engineers over past decade and have been demonstrated as an effective strategy to improve mechanical properties of biological materials. As an example, the seedcoat-inspired additive manufactured parts have been verified to exhibit enhanced stiffness, strength and toughness as well as auxetic effect numerically and experimentally. However, the current design approaches, which are based on relatively simple interlocking features, provide limited design space of interlocked structures with custom properties. More recently, machine learning techniques have shown vast potential to improve the state-of-the-art of a range of fields such as protein structure prediction and drug discovery. As a preliminary study, we exploited machine learning approach to enlarge the design space of 2D interlocked structures. Accurate and fast assessments of mechanical properties of interlocked structures, which are generated through a cellular automation-like method, can be achieved using a convolutional neural network trained by a limited number of finite element results. The preliminary results show that pre-trained machine learning model can accurately predict mechanical properties of interlocked structures in a larger design space, thereby demonstrating the great potential to efficiently design advanced interlocked structures with cutting-edge properties via machine learning approach.

Abstracts

International Conference
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H2020-WIDESPREAD-2018-03
Project No. 857124

The strength of additive manufactured screws

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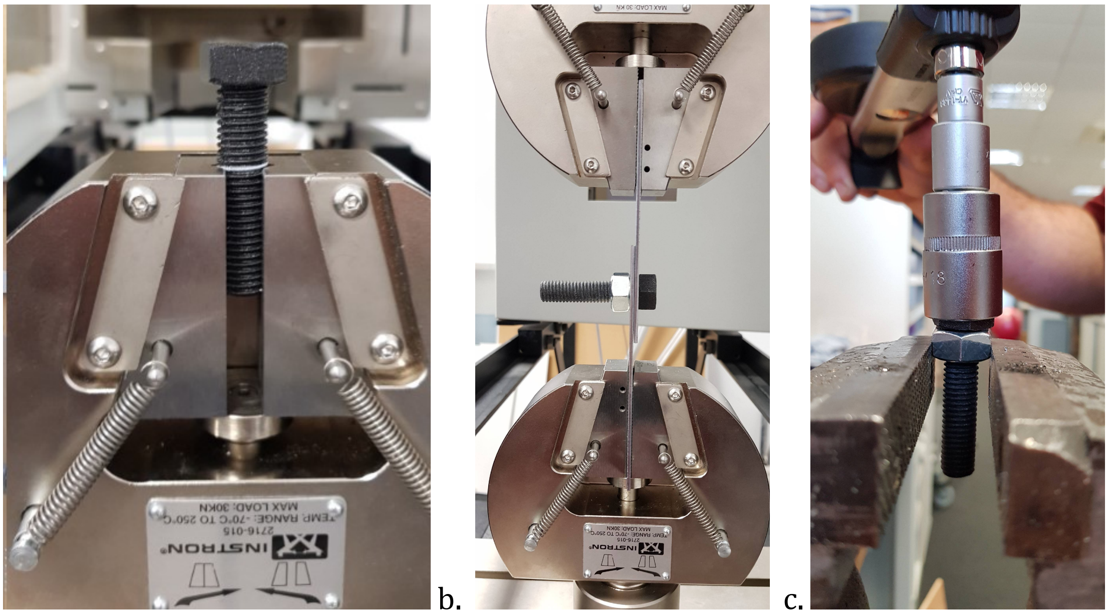
ABSTRACT

Additive manufacturing (AM) is increasingly being used in automotive industry. Fused Deposition Modelling (FDM) is one of the most used AM techniques all over the world, due to its cost-effective way of printing and the ease of building components [1]. The manufacturing parameters (orientation, layer thickness, …) plays a major role on the mechanical properties of the resulted parts.



a. b. c.

Figure 1. *Mechanical testing of AM screws (a. tensile, b. shear, c. torsion)*

The present paper presents the evaluation of strength of screws obtained by FDM. Tensile (Fig. 1.a), shear (Fig. 1.b) and torsion (Fig. 1.c) tests were applied to screws made of PLA.
The strength results are compared with the tensile strength results obtained on dog-bone specimens [2].

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Mechanical properties of polymeric elements obtained through Digital Light Processing

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ABSTRACT

The photopolymerization process is nowadays widely used in the production of polymeric elements through Additive Manufacturing (AM). Different technologies based on the same chemical-physical principle are available to date, such as: the Stereolithography (SLA), the Digital Light Processing (DLP), and the newest Projection Micro-Stereolithography, and Microstereolithograpy [1]. Photopolymerization allows creating polymeric components without limits in terms of geometry and dimensional scale; it operates starting from a liquid monomer whose polymerization is induced by light of a proper wavelength, typically falling within the UV range [2].

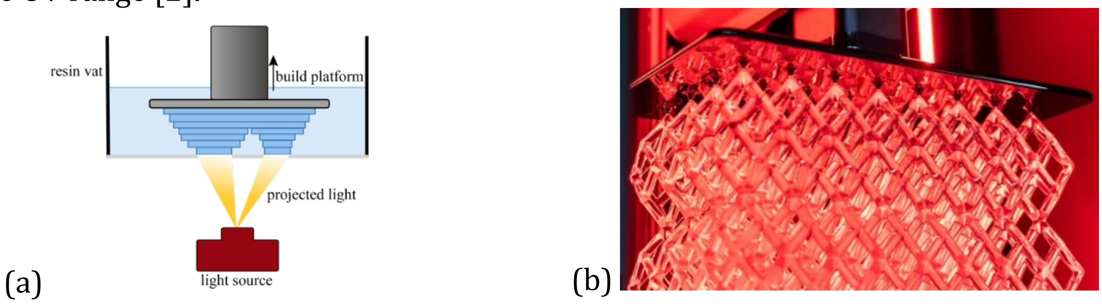

Figure 1. *Scheme of the DLP AM process (a) and real example of a photopolymerized cell structure obtained with DLP (b).*

In the present paper, we investigate the influence of the photopolymerization process parameters on the main mechanical properties [3] (i.e. the tensile strength, the elastic modulus and the elongation at failure), namely the UV exposure time and the printing orientation. It is shown that there exist an optimum exposure time which provides the best mechanical performances of the material, while the printing orientation seems to be not so relevant on the final mechanical properties being the material roughly isotropic irrespectively of the way of adding material is performed.

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A green building technique: thermal transmittance value of the different materials used in 3D printed houses

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ABSTRACT

In the terms of cost reduction, design flexibility, time and environmentally friendly process, additive manufacturing is gaining acceptance as an innovative technology in construction industry. The energy demand estimation, as one of the primary part of building industry nowadays, imposed a need for constant development of the existing materials. Taking in consideration stresses in a material and thermal transmittance value, several mixes that have adequate consistency and workability are described. The common is concrete base consisting of cement, sand and additives. Other elements include geopolymers, fibers, soil, clay, gravel, sulphur. Considering standards and regulations for the maximum thermal transmittance value (U-value), in the countries of Eastern Europe specifically, all considered mixes had greater U-value. The various wall configuration with different cavities inside (empty or filled with sand) enable better thermal properties of the wall that can obtain U-value less than legislation prescribes.

Mechanical properties evaluation of FDM printed objects as a function of the printing parameters

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ABSTRACT

Fused deposition modeling (FDM) three-dimensional (3D) printing is one of the most widespread technologies in the field of additive manufacturing to fabricate objects, prototypes or products starting from a virtual 3D model created by CAD software[1][2]. This printing technique allows to create a 3D object by adding extruded thermoplastic material layer by layer. The obtained products are characterized by an anisotropic behaviour[3]. Compared to those obtained through conventional production techniques, FDM 3D objects are generally less performing from the point of view of mechanical properties[4]. For this reason, they are mostly used as prototyping products and not as structural materials. In this work, the experimental activity was aimed at understanding the influence of printing parameters on the mechanical properties of samples made with FDM technology. The variation of the printing parameters was investigated to obtain an improvement of the mechanical properties of the samples. In fact, the effect of the optimization of the printing parameters on the mechanical properties allows to extend the field of applicability of the objects obtained, making the objects suitable for both functional and structural purposes.

The 3D specimens were obtained using a commercial BQ Hephestos 2 3D printer. The samples have a dumbbell shape and were designed using the Solidworks software, according to the standard geometry reported by the UNI EN ISO 527-2 standard for plastics. The selected thermoplastic material is the lactic acid polymer (PLA). The height of a layer was set at 100 μm and the diameter of the extrusion nozzle was 0.4 mm. The G-code containing all the operating instructions for 3D printing of the models was obtained using the Ultimaker Cura slicing software. The samples were printed with 2 different filling percentage (50 and 100%) and for each filling value the following printing parameters were modified: 4 different extrusion temperatures (200, 215, 230, 245°C), 4 different printing base temperatures (50, 60, 75, 90°C) and 3 different extruder rate (30, 45, 60 mm/s).
Once obtained, specimens were tested in the laboratory with a dynamometer for the uniaxial tensile test. The deformation rate was set at 1 mm/min.

The filling percentage of the sample has the greatest influence on the mechanical properties: as a result of the increase in the filling percentage, there is an increase in the elastic modulus (E) from 1400 MPa for the samples at 50% filling to 2000 MPa for infill of 100%. The tensile strength (σ) also increases, from 26 MPa for 50% infill up to 50 MPa for 100% infill samples. Lower percentages of filling determine a decrease in the area of resistant section and consequently a decrease in mechanical properties.

No particular influence was found on σ as the extrusion temperature varies in the range 200-245 °C, while E appears to increase linearly with temperature (Fig. 1a). The printing base temperature seems to determine an increase in σ and E, increasing from 50 to 90 °C (Fig. 1b).

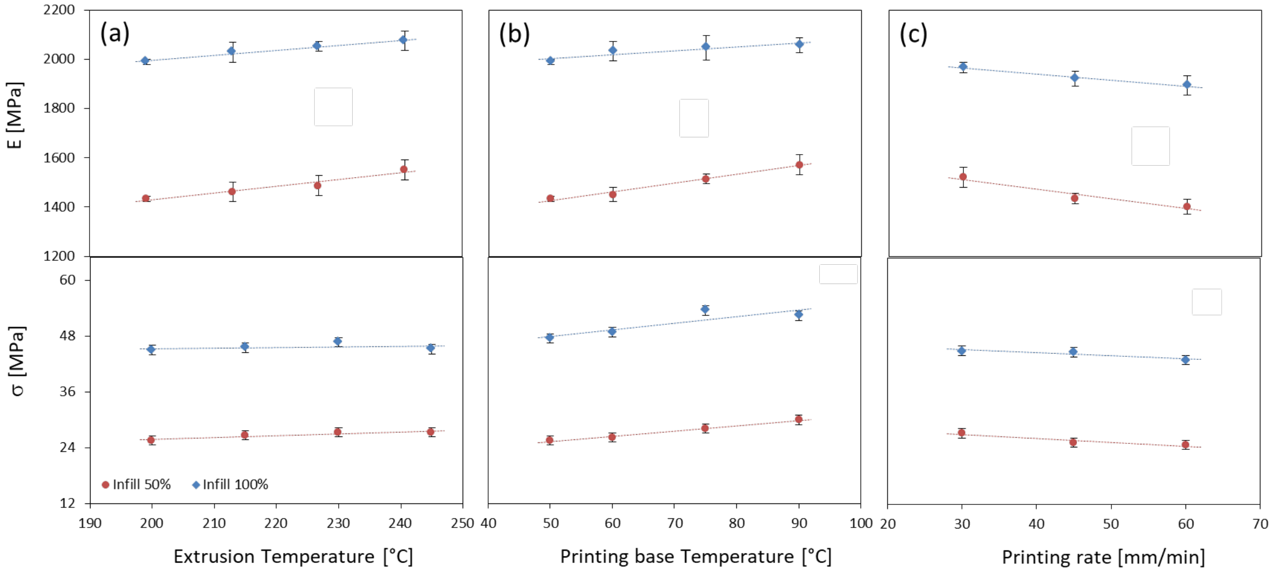

Figure 1 – E and s trends for different filling percentages as a function of the extrusion temperature (a), the printing base (b) and the printing rate (c) respectively.

The printing speed also produce a variation of the mechanical properties: a decrease from 60 to 30 mm/s determines an increase in σ and E (Fig. 1c).
Based on the results obtained from the experimental analysis, it was possible to identify the values of the parameters that can lead to improvements in the mechanical properties of the 3D printed samples, by setting the different printing parameters in the correct way.
In FDM printing technology it is possible to obtain products whose mechanical properties can vary more or less considerably as the set parameters vary. Knowing how to exploit this information can help to obtain parts with higher and more reliable mechanical characteristics for the same filling percentage. Many experimental implications of 3D printing technologies have not yet been fully clarified and through an experimental research process of the most influential printing parameters and how these can be modified, it is possible to achieve better results and increase mechanical reliability in additive manufacturing technology.

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Application of additive manufacturing in jigs and fixture based manufacturing

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ABSTRACT

Tools, like jigs and fixtures are an integral part of manufacturing technology that help maintain quality as well as production efficiency. Jigs and fixtures are generally used to hold, align and assemble various components and sub-assemblies throughout the manufacturing process. Their importance is practically invisible while the production is running smoothly but becomes much more evident when problems occur. To steer clear of production defects or halts, manufacturing tools must be constantly evolved and developed through rapid prototyping, manufacturing and deployment. In this innovation report, we have presented how we designed and used 3D printed jigs and fixtures to improve the manufacturing of probably the most important part of the ATV (All-Terrain Vehicle), i.e. the suspension arms.

How does build orientation influences the torsional capacity of AlSi10Mg thin-walled hollow shafts designed for additive manufacturing?

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ABSTRACT

With the advent of additive manufacturing techniques in line with the advanced CAD/CAE software, the use of AlSi10Mg thin-walled hollow shafts in the near future is expected to widely extend toward numerous highly specialized engineering fields. It is well-known that AM-produced parts have anisotropic properties varying with sample orientation relative to the building direction [1], [2], [3]. Figure 1 shows a longitudinal section of the FE-model, highlighting the material directions corresponding to typical horizontal and vertical orientations relative to geometry and loading direction.

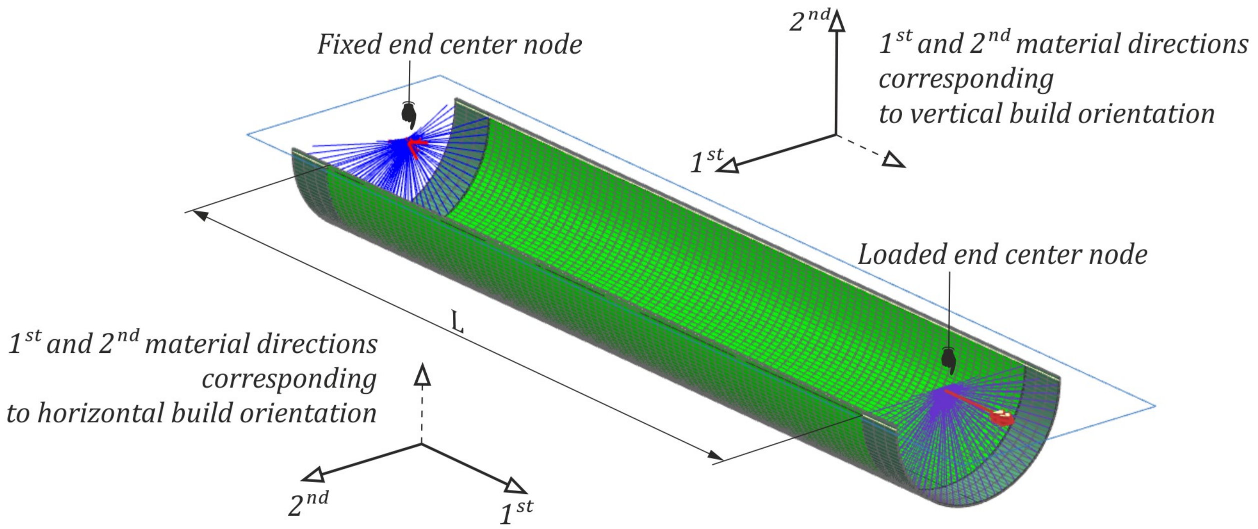

Figure 1

Torsion is the main loading that these shafts carry, and most of the analytical methods available at present do not cover the particular build orientations specific to actual additively manufacturing processes.
The paper aims to investigate how the build orientation influences the torsional capacity of AlSi10Mg thin-walled hollow shafts designed for additive manufacturing. The parametric FEA results are referenced to the experimental data reported in paper [3] for a thin-walled hollow shaft with the same geometry and made of the associated wrought material (i.e., Al6061). The comparison is quite reasonable since, at the moment, the only aluminum available for commercial DMLS production is AlSi10Mg [4].

Materials and methods

The mechanical properties for the material in question (i.e., AM-produced AlSi10Mg) are taken from Mower et al. [4]. Their study measured elastic moduli in bending, and stress-strain characteristics were measured by a tensile test under the deformation control. The commercial software Simcenter 3D was used to perform the FEA parametric study. The elastoplastic material properties and large deflections are considered. Pure torsion is applied at one end of the shaft in question through the MPC elements, while a fixed boundary condition is considered at the opposite end, as shown in Figure 1.

Research outcomes

The conclusion drawn from this parametric FE study can be helpful for the design engineers because the effects of different geometric ratios on the buckling capacity of thin-walled hollow shafts made of AlSi10Mg additively manufactured can be easily assessed.

Moreover, the calculation methodology presented in the paper offers significant advantages over the existing approaches available at the moment in literature, as it can effectively provide an accurate estimation of the torsional buckling capacity for AM thin-walled hollow shafts. It also offers a compelling cost advantage relative to the experimental tests for new AM shaft designs as a validation procedure.

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Hardness analysis of additively manufactured metallic specimens

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ABSTRACT

The subject of this research is the hardness analysis of different metallic specimens, obtained using additive technology. All specimens were printed on ''Metal X'' 3D printer (Markforged, Watertown, MA, USA). Selected device can manufacture components from many mettalic materials, such as stainless steels and copper. Of all the available mettalic materials, the following are most frequently used: 17-4 PH stainless steel, H13 tool steel, A2 and D2 tool steels and Inconel 625. In this case, 17-4 PH stainless steel was used to make specimens for this research. The hardness measurements of all specimens were performed on both the mobile and regular hardness measuring device. Mobile device is used to measure hardness with Vickers (HV) method, and on regular device Rockwell C (HRC) method is applied. The range of hardness measurements are 30-70 for HRC, and 278-1210 for HV. Measurements are conducted on components support, raft and directly on the component. One of the conclusions of conducted hardness measurements is that more relevant results are obtained when the back surfaces are measured, because of the sufrace smoothness. Also, more accurate measurements are obtained on the components raft or support, due to larger thickness on particular areas. By hardness measurements on raft and directly on the component, mobile device showed 3 times higher values when measurements were conducted directly on the component than on the component's raft. Comparing the mean HRC and HV values of the raft and support results, measured hardness on rafts tend to have 10% higher values than obtained values on the support.

Load-rate effects of Additively Manufactured metallic honeycomb structures under compression

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ABSTRACT

Introduction
Metallic honeycomb structures can exhibit high relative stiffness and efficient energy absorption when operated under compressive loading. The emergence of additive manufacturing (AM) has offered the opportunity to enhance the compressive performance of honeycomb structures. Nevertheless, there is currently limited research on the load-rate effects of AM honeycomb structures under compressive loading. This presentation reports preliminary results from the evaluation of the in-plane compressive performance of metallic honeycomb structures produced via fused filament fabrication (FFF) and laser powder bed fusion (LPBF).

Methodology
The FFF and LPBF AM methods were employed to fabricate Steel 316L honeycomb structures. The BASF Ultrafuse Steel 316L filament was used for the production of FFF honeycombs with varying cell sizes of 6, 6.5 and 7 mm, printed with a Prusa i3 MK3 printer. While the Steel 316L LPBF honeycombs of 2.45 mm cell size were fabricated with a GE Concept Laser Mlab cusing R system. The in-plane compressive mechanical behaviour of the honeycomb structures was investigated via testing performed under uniaxial compression at loading rates varying between 0.5 mm/min and 600 mm/min using a 100kN ZwickRoell universal testing machine.

Results
The obtained results indicate that the investigated AM honeycomb structures are load-rate sensitive. In particular, yield stress and compressive stress were found to increase with increasing load for both FFF and LPBF structures. The 6 mm cell size FFF-fabricated structures exhibited higher compressive strength than their 6.5 mm and 7 mm counterparts. Additionally, as expected, the failure mode of both FFF and LPBF honeycomb structures is cell wall bending, plastic buckling, cell wall collapse, and folding.
Conclusions: AM metallic honeycomb structures are load-rate sensitive. As the rate of loading increased, the compressive properties of the honeycomb structures increased. Additionally, variation of the cell size can optimise the in-plane compressive performance of honeycomb structures.

The use of 3D printing for studying the influence of ionizing radiation on electronic components

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ABSTRACT

The application of additive technology gives a designer more freedom in designing and defining the optimal product design. Also, it is possible to make a model with different materials that have different mechanical properties in order to meet different requirements in different places inside and outside of the part. In this paper, a 3D printer Wanhao Duplicator, type i3 plus, made in the People's Republic of China, was used for the realization of the elements of a mechanical mounting system. It is a desktop 3D printer with a maximum printable area of 200 x 200 x 180 mm3, nozzle diameter of 0.1-0.4 mm, and printing speed of 10-100 mm/s (see Figure 3). For the realization of the model, the chosen material was ABS (Acrylonitrile Butadiene Styrene) in the form of a filament (diameter 1.75 mm, manufacturer Wanhao). ABS is an amorphous polymer with the following features: excellent mechanical properties, resistance to elevated temperatures, and resistance to shocks. On the Wanhao printer, the prescribed distance between the nozzle and the plate is 0.1 mm. This is the minimum thickness of a single printed layer in the xy plane. The diameter of the melted thread is 0.1 mm, which is very thin, allowing for a very dense construction of the print along the z axis. All these parameters are essential for the quality of the print. 3D printing technology enabled the custom design and fabrication of a mechanical system intended to be placed in an irradiation room, in order to hold the component whose electric characteristics are being examined. The irradiation room may contain one or more sources of ionizing radiation. Each irradiation room may have a different way of mounting the component under test. Since it is necessary to study a specific electronic component with different ionizing radiation sources (gamma and X-ray), at different dose rates, and located in different irradiation rooms, designing a custom mounting system for each irradiation room is necessary. The cost of making a mechanical mounting system using 3D printing technology is significantly lower compared to other production methods. Thus, the creation of a system for each irradiation room individually becomes more economical. Creating such a system for each irradiation room allows much easier and more accurate positioning of the component, which reduces the error in calculating the dose that the component receives during irradiation. Each mechanical system should allow the installation of printed circuit boards of different sizes, on which the tested electronic components are located. Also, the material from which the mounting system is made must not affect the component during the experiment. Materials

used in 3D printing have a negligible effect on the reflection or scattering of high-energy photons because they do not contain atoms with heavy nuclei.

ACKNOWLEDGEMENT

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CAD development of parts adapted to Additive Manufacturing production

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ABSTRACT

In this paper is presented procedure for CAD development of parts which are predicted to be produced by additive manufacturing technology by PLA materials [1]. Generally, recently usage of additive production technology is in rising. In that way it is needed to adjust CAD models in design phase to be possible to produce such parts with additive production technologies. It is known that stress state of the part can be calculated by FEA (*Finite Element Method*) based on developed CAD model. By contrast, in cases where parts are produced by additive technologies stress state is different that one obtained by FEA. This is caused because many approximations are needed to be made on part in additive technology production such shape and size of the filling etc. Also, parameters of additive production process are also affected on rigidity of the part. In that way it was designed CAD models as it should be after additive production with all approximation. For these purposes many researches have been done with specimens for experimental determination of fracture mechanics parameters [2]. Based on developed CAD models which was designed by approximation it was performed FEA in order to obtain stress state. Also, FEA was performed on same part which was designed without approximations and was noticed differences in stress and deformation state. In next state it is predicted to experimentally determine stress and deformation state on designed models in order to verify conducted FEA.

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The first bridge - prototype development through Fused Deposition Welding Modeling (FDM)

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ABSTRACT

The theme of the paper was chosen from the desire to participate in the Virtual Exhibition "Art in Welding" within the conference "Welding 2021" organized in April 2021 in Resita and further to the Exhibition of Welded Art in the 74th General Assembly of IIW from Genoa. The model of the first welded bridge in Romania was made according to the technical project made at the last expertise of the structure. Thus, the 3D model that was used for the expertise was imported into a 3D program to adjust the structure and ready for 3D printing.. Only the main elements were preserved on the structure: upper sole, lower sole, struts, side members, lattice beams. Secondary elements such as parapet, sidewalk consoles have been removed from the 3D structure to make the layout of the model easier. The paper will present the process of making the 3D model of the First Welded Bridge in Romania through the FDM process. The model was made of PET from 4 distinct segments which were then joined together. In order to obtain the components, it was necessary a remodeling in FEM of the construction dimensions of the bridge as well as an adjustment of these dimensions to a scale of 1/25, the resulting model had a size of 1.25 m. The paper will contain from the printing parameters of the model to the examination of some components from the model.

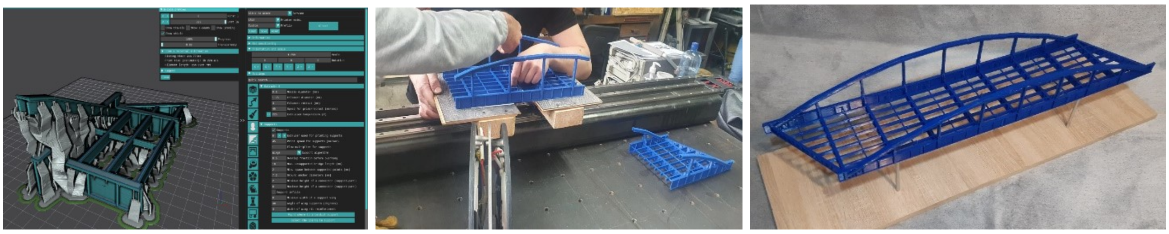

Figure 1. Steps in the process of obtaining the model

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Additive Manufacturing of removable complete dentures

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ABSTRACT

Introduction
Removable complete dentures are commonly made out of polymethyl methacrylate (PMMA) to replace missing teeth and bone structure for an entire dental arch. Fractures of complete dentures are an unresolved issue due to defects that may occur in stress-bearing areas of the denture. Additive manufacturing (AM) is an alternative technique for complete denture fabrication. The aim of this study is to evaluate and present the potential applications of AM in the fabrication of complete dentures.

Materials and Methods
Three types of AM methods were considered: selective laser sintering (SLS), sterolithography (SLA), and fused deposition modelling (FMD). The mechanism of AM fabrication is presented, along with advantages, disadvantages, and applications.

Results and Conclusions
The use of AM in complete denture fabrication had the potential to modernize traditional denture fabrication techniques, reduce costs and efficiency. More research on these techniques is required to increase their applications in removable prosthodontics.

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Mechanical properties of polymer matrix composite materials produced by additive manufacturing through the finite element method

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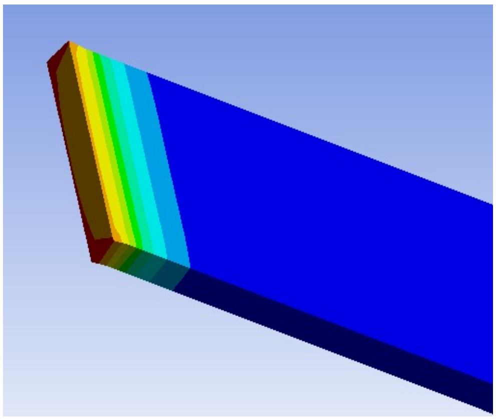
ABSTRACT

The development, innovation, and application of new materials bring with them production through additive manufacturing (AM), it is well known that this is a process that changes the paradigms in design, overcoming limitations such as complex geometries, which in turn optimized and strengthened the production of important parts for various fields of application such as aerospace engineering, medicine, among others. Previous research has shown that it is possible to model the properties of these materials using finite element method (FEM) and thus predict the behavior of the material with some proximity to that obtained in an experimental model. Consequently, the results of tests applied on specimens of a polymeric matrix reinforced with continuous fiber and delimited by American and European standards were analyzed. These specimens were used as a basis for the configuration of a numerical model that allowed to obtain the properties and characteristics of these materials. The objective of this modeling process is to contrast the results achieved by the finite element method in the normalized stress test applied to a composite material with reference to the experimental tensile test applied to the same material assembled by additive manufacturing in accordance with the same regulations. Furthermore, a numerical modeling tool was used to define the geometry of the specimens, their meshing, and their structure in the stacking of the composite material. On the other hand, the normalized tension test was configured to a certain extent that the required properties were achieved. The results obtained allowed to establish the similarities between numerical modeling and the measurements of experimental development.

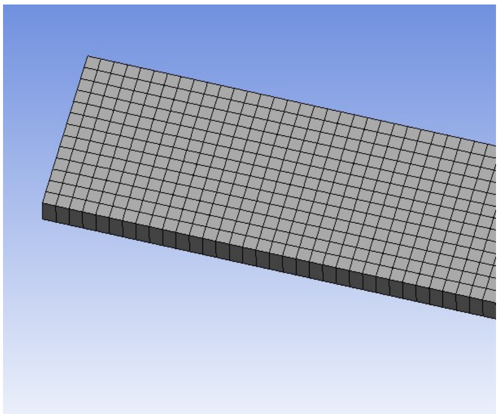
Keywords: Additive manufacturing, composite material, numerical modelling, contrast.

Figures

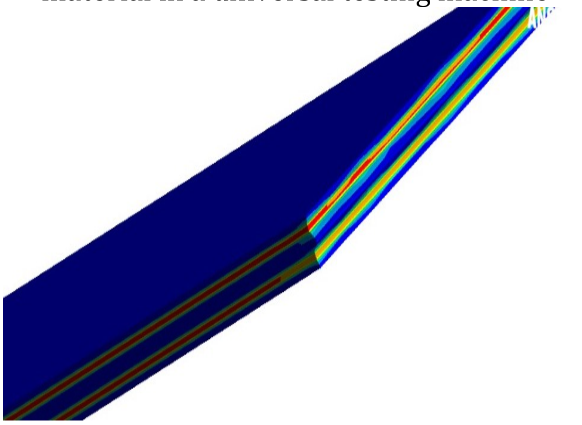


Stress on a Nylon matrix layer

Tensile test of the specimen made of composite material in a universal testing machine



Specimen meshing



Distribution of stresses on the specimen

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KnowHub entrepreneurial projects based on Rapid Prototyping Technology: Montenegro in focus

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ABSTRACT

The international project KnowHub, in which the University of Montenegro participates, aims to develop Coomercialization hubs at Western Balkan universities, as interfaces between higher education institutions and enterprises, which should attract enterprises, to the universities because of the knowledge and skills of professors and students as well as the valuable technology that they purchased [1].
The initial research on cooperation between the University of Montenegro and the economy, conducted through a survey, showed that it is necessary to continuously strengthen cooperation between universities and the economy, and encourage the development of entrepreneurial competencies of students [2]. Actually, it is shown that students need support and infrastructure to commercialize innovative ideas; academic staff need support and infrastructure to commercialize the results of applied research, and manufacturing companies need knowledge and infrastructure to innovatively develop products.
In this direction, in order to strengthen the cooperation between students, teaching staff and companies, through the KnowHub project will be innovated some ECTS catalogs at the study program Mechanical Engineering in accordance with the requirements of the economy, in order to provide conditions for developing entrepreneurial competencies of students which are in relation with application of Rapid Prototyping Technology. Through the project is also provided the equipment for the application of this technology. In accordance with that, activities have started on the development of 3 project solutions that will be valorized by the company, as follows:

- Project 1: Development of mechanisms for kitchen elements
- Project 2: Development of a universal device for calibration of rollers for controlling the braking force of motor vehicles and a dynamometer for controlling the force on the brake pedal
- Project 3: Development of a new type of drone propulsion

The paper will present the course of project implementation as well as the results of design and development of functional prototypes of these devices. Design of prototypes will be realized in SolidWorks Premium and ANSYS software packages while realisation of prototypes will be realized on FFF 3D printers Sindoh 3D WOX 7X and Sindoh 3D WOX 2X and SLA 3D printer Formlabs Form 3 with Wash and Cure postprocessing devices. Materials used to build prototypes are ABS and Flexible filament for FFF 3D printers, as well as, Rigid and Tough resin for SLA 3D printer. At the very end of the paper, the multiple benefits of such cooperation will be pointed out.

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Experiences in 3D printing applied in education

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ABSTRACT

3D printing is technology at the core of Additive Manufacturing. Applications of 3D printing are numerous; in mechanical engineering - for rapid prototyping or additive manufacturing of finished products; in architecture, civil engineering and masonry - to make scaled physical models; in dentistry - to produce dental implants; in medicine - to manufacture medicines and its packaging, to make implants or prosthetic devices, or even artificial tissues and organs; in art and design - for 3D printing of clothing, objects of art or home appliances and aesthetic utensils, and so on. Wherever there is an application of 3D printing in some area, there is or can be an implementation of the same (3D printing) in education in that area.
Rapid development of 3D printing technology has introduced new solutions (some new problems arise too) in industry, as well as in areas of applied science (including mechanical engineering, aerospace, robotics, electrical engineering, etc.). As new opportunities are emerging, the need for improvement is rising to achieve desired goals. There is a variety of important uses for applying the 3D printing in education, in primary and secondary schools, as well as in universities, libraries and technical colleges [1], [2]. Application of 3D printing in education has several goals [2], [3]: teaching students about 3D printing, teaching educators about 3D printing, supporting technology in teaching, making artefacts that aid learning, creating assistive technologies, and supporting the outreach activities. 3D printing technologies contribute to the improved learning, skills development and increased student and teacher engagement with the teaching subject [1]. Five major benefits of 3D printing in education are [1]: it creates excitement, complements the curriculum, gives access to knowledge previously unavailable, opens new possibilities for learning, promotes problem-solving skills. Application of 3D printing in education is based on two questions [2], [3]: Where is it used and how is it used in educational system? [1] - [4]
3D printing technologies enable practical, hands-on knowledge for the understanding of scientific and engineering concepts [5]. Modern educational institutions need robust 3D printers built for the classroom demands, that are relatively easy to assemble, affordable and user-friendly, for fabricating 3D models using different materials. Additive manufacturing provides many opportunities to aid visual and practical learning over many areas of the science, engineering and art, while 3D-printed components are often used as test models for specific scientific experiments [1]. [1], [5], [6]

Undergraduate mechanical engineering courses can be radically transformed and gain enhanced pedagogies when utilizing 3D printing [6]. To give an example of application of 3D printing in education the 3D printer based on FDM (Fused Deposition Material) technology was used [7] - [9]. 3D priner supports .STL files which are obtained in any 3D modeling program. In this application SolidWorks was used as modeling program.

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Machine learning applications in additive manufacturing: an assessment of the state-of-the-art and future prospects

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ABSTRACT

In Additive manufacturing (AM) technique numerous trial-and-error experiments or computationally intensive simulations are often needed for property prediction and process optimization. Machine learning (ML), on the other hand, has the potential to expedite the adoption of innovative printing technologies. Since its inception, machine learning (ML) has sparked considerable interest in the area of artificial intelligence (AI) owing to its superior performance on data-intensive tasks such as classification, regression, and clustering. This article provides an in-depth analysis of the current state of the art in machine learning applications across a wide range of application domains. These applications, which include parameter optimization and anomaly detection, are subdivided into several kinds of machine learning tasks, which include regression, classification, and clustering, among others. Different machine learning algorithms are tested and compared to see how well they perform in different kinds of AM. The authors conclude by suggesting a number of possible future study paths. In addition to the optimization of process parameters, modern machine learning techniques may also be used to investigate powder dispersion and fault identification during the production process, among other applications. After that, the most significant findings from the literature are summarised, together with insights into some of the most intriguing applications of machine learning in the area of AM.

Key words: Additive manufacturing; Machine learning; Regression; classification; clustering

Link between reverse engineering and additive technology on the example of a model without technical documentation

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ABSTRACT

Reverse engineering (RE) is a process that integrates additive technologies, while enabling finishing or modifications of an existing model, as well as the application of new ideas in design improvement. This approach leads to the reduction (or elimination) of certain steps of the product development process, and faster model digitization, with further improvements and optimization of parameters. The biggest challenge in the application of RE is the high-quality physical part reproduction with the best possible characteristics, while keeping the realization costs as low as possible. Especially in this segment additive technologies become increasingly important. In this work, RE is applied in order to fabricate a protective cover of a machine used in semiconductor production, based on the existing (damaged) physical sample. The protective cover is a part of a silicon wafer dicing saw (Micro Automation, Model 602M), and it is made of plastic. Due to the age and the long exploitation of the machine, the sample part was broken at one of its supports. Unfortunately, since the machine has become obsolete a long time ago, the spare parts cannot be found. In such cases, RE has an important role, and the fabrication of a new part would be almost unthinkable without the application of additive technology. The CAD model of the protective cover was defined based on the measured dimensions of the damaged part. The procedure is very convenient in cases when only a physical part (or a finished product) exists without technical documentation, or when the existing technical documentation is not in a digital form. We performed model optimization and load simulation on the supports for different materials. After digitization, the model manufacturing process started. The model was made of the thermoplastic polymer ABS on the 3D printer Wanhao Duplicator, type i3 plus, made in the People's Republic of China. In this paper, we intended to illustrate the significance of the symbiosis of RE and the additive technology in the process of realization of parts/assemblies of an obsolete product with no spare parts available.

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Machine Learning Module for Predicting Tensile Response of SLMed Ti-6Al-4V

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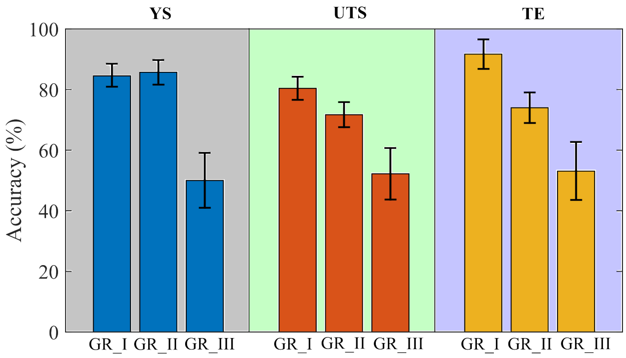
ABSTRACT

Titanium Ti-6Al-4V alloy, possessing an exclusive combination of strength-to-weight ratio and biocompatibility, is fast evolving as a potential alloy for biomedical and aviation industries. Being a cost-effective technique in additive manufacturing (AM), selective laser melting (SLM) of titanium Ti-6Al-4Valloys is regarded as one of the most challenging areas; where suitable tensile properties are obtained via varying different AM correlation parameters. Among the several process parameters involved, the four most influencing parameters are found from the prolonged experimental observations to be laser power (P), scan speed (v), hatch spacing (h), and layer thickness (t) [1]. In addition, two energy densities, namely, the volumetric (E_V) and the linear energy density (E_L) are defined in terms of four aforementioned parameters [2] are observed to play pivotal role in controlling various properties (mechanical, thermal) of the fabricated material. Involving the aforementioned most influencing parameters, along with two well-established energy function relationships, this work provides a rigorous methodology for developing machine learning (ML)-based classifier models involving the printing parameters to predict the yield strength (YS), ultimate tensile strength (UTS), and total elongation (TE) of the SLM as-built samples. A complete account of the comparison of the trained model accuracy of different support vector machine (SVM) classifiers has been carried out using MATLAB R2015a involving different input and output parameters as well as for the



(a)

Variable group ID	Variable(s) involved
GR_I	Laser power, scan speed, hatch spacing, and layer thickness
GR_II	Linear energy density, hatch spacing, and layer thickness
GR_III	Volumetric energy density

(b)

Fig. 1: (a) Accuracy variations during model training involving (b) different variable groups

cross-fold variations. For this statistical analysis, mean values have been considered and respective deviations in the accuracy has been studied (Fig. 1(a)) for each variable group (Fig. 1(b)). The trained YS, UTS, and TE models have attained the average maximum accuracies of 85.7% (Fig. 2(a)), 80.4% (Fig. 2(b)), and 91.7% (Fig. 2(c)), respectively, indicating a high precision for the predictive capabilities. Finally, the exported models have been validated and the corresponding correctness accuracy percentages are shown in Table 1.

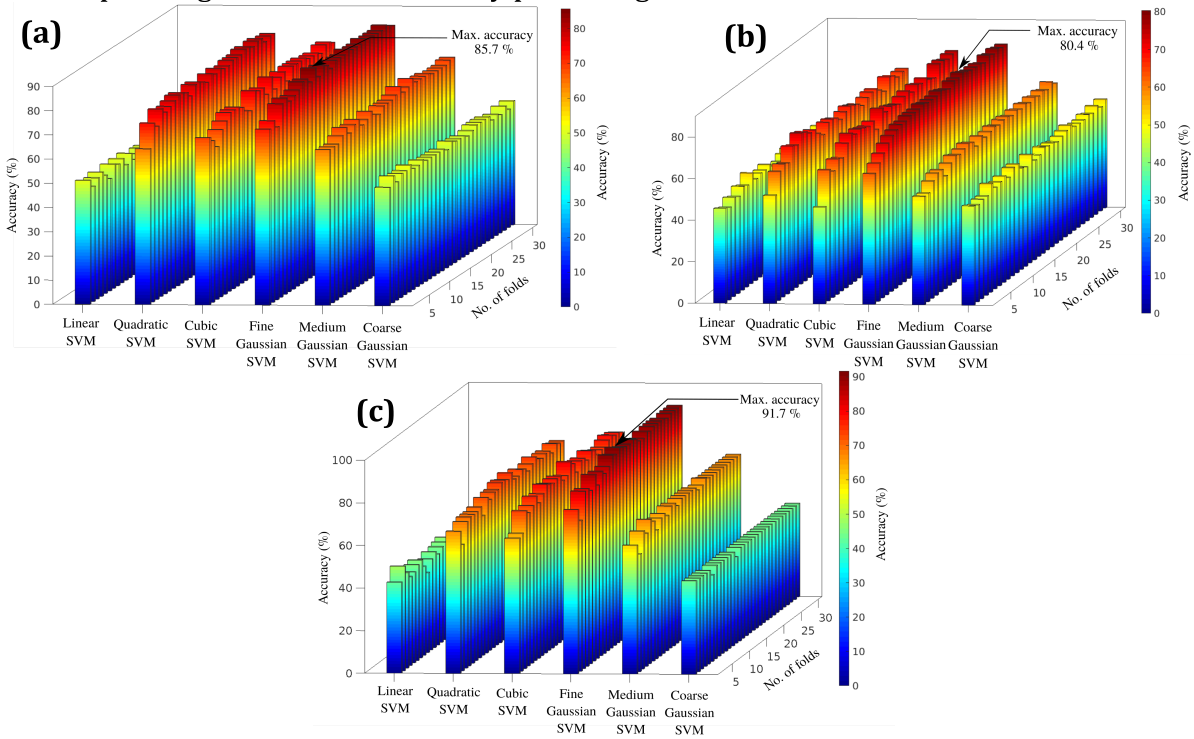


Fig. 2: 3D-plot for maximum predictive model accuracy of (a) YS (GR_II), (b) UTS (GR_I), and (c) TE (GR_I) during model development using different SVM classifiers

Table 1: Prediction correctness of trained models during validation

Variable group	**YS model (%)**	**UTS model (%)**	**TE model (%)**
GR_I	81.25	85.71	93.33
GR_II	87.50	71.43	80
GR_III	62.5	57.14	46.67

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Modeling Selective Laser Sintering Technique in the Additive Manufacturing of Polymers: an overview

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ABSTRACT

In Additive Manufacturing (AM) of polymeric materials, Selective Laser Sintering (SLS) allows complex three-dimensional parts to be built by melting successive layers of powdered material: a thin layer of powder, previously heated to a specific temperature, is deposited on a platform, where it is selectively targeted by a high-power heating source, causing partial melting and densification of the particles (Figure 1).
Typically, SLS applies for printing semi-crystalline thermoplastics polymers such as polyamides (PA), polyethylene (PE), polypropylene (PP), polycaprolactone (PCL) as well as thermoplastic elastomers such as polyurethane (TPU), polyetherketone (PEK) and polyetheretherketone (PEEK). Amorphous polymers, such as polycarbonate (PC), poly(methylmethacrylate) (PMMA) and polystyrene (PS) can be also processed with SLS [1], [2].

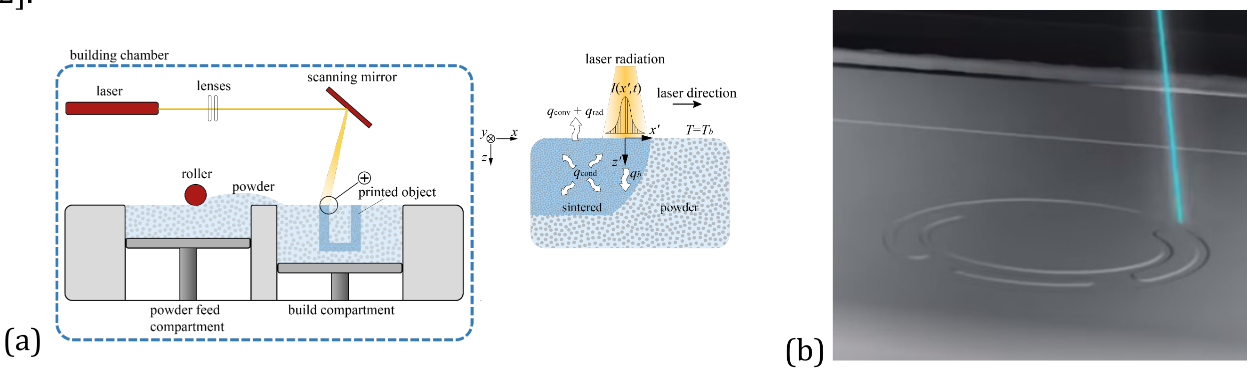

Figure 1. *Scheme of the SLS AM process (a); printing of a selectively laser sintered polymer part (b).*

SLS technology is controllable through several printing parameters such as laser power and beam diameter, scan velocity and spacing, build orientation, pre-heating temperature, etc., all of them affecting the characteristics of the printed parts.
SLS is a multi-physics process involving several phenomena such as heat transfer, melting/solidification, flow of complex rheological fluids, crystallization, diffusion, etc.
In order to obtain good material mechanical properties of the final printed part, the powder particles need to form a homogeneous melt during the fabrication process [3]-[6]. This results can be achieved by a full description of the various coupled phenomena involved in SLS that need to be modelled by a detailed mathematical framework.

In the present paper we describe the governing equations involved in the multi-physics phenomena characterizing the SLS process and discuss the main parameters affecting the final physical and mechanical properties of the AM component.

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The importance of machine learning and generative design in AM

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ABSTRACT

The importance of machine learning and generative design in Additive manufacturing (AM), also known as 3D printing, is a transformative approach to industrial production that enables the creation of lighter, stronger parts and systems. 3D printing has had the greatest application in the production of prototypes, but today, in this way it is possible to produce almost any part, and from different materials. That is why the importance of additive production in the industry is at a very high level. Higher-level can be achieved in combination with generative design and machine learning. As described in this study [1], an automated 3D modelling pipeline are created using a machine learning technique. The automated 3D modelling pipeline developed in this study has demonstrated a working idea of application of machine learning approach in a 3D modelling work. Generative design refers to a design process that utilizes a computer algorithm, with the formulation of parametric algorithms, design results can be automatically generated by computers, which can help in automatization parts at the design process [2][3]. DzAIℕ is based on an algorithmic architecture that combines topology optimization and deep learning methods [4]. The proposed methodology is based on the form-finding abilities of DBNs in combination with SIMP and the the effect that mesh density has on the final result of topology optimization.
Topology optimization algorithms typically start with a pre-existing design and remove the material from it to reduce part's weight. When used with 3D printing, the benefits can be further expanded to include decreased manufacturing costs and increased productivity, lightweighting and part consolidation. This paper presents a group of examples in which AM is significantly improved by applying machine learning and/ or generative design. The biggest benefit of combination AM with machine learning and generative design is finding the ideal part from the existing ones in the database, which satisfies all defined parameters, and yet is a unique solution in a series of similar ones.

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Making a 3D Printer of Delta Configuration Using Open-Source Project

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ABSTRACT

The term 3D printing was often used as a synonim for Additive Manufacturing or Rapid Prototyping. 3D printing is the technology at the core of Additive Manufacturing, and with rapid development, 3D printers can also be used to make final products. 3D printing is based on conversion of the digital model of the product into physical, three-dimensional object, in a layer-after-layer manner. The process of 3D printing does not require custom designed tools, while it produces custom designed products, building the object layer by layer, often directly making it on a working platform.
Here the building of a 3D printer is described, following an open-source project for the device Rostock MAX 3D printer, as in [1]. Components like various joints and rods and essential parts of the 3D printer have to be printed on another 3D printer. Both the printer that was made and the one used for its making have delta configuration [2]. Rostock MAX 3D printer [3] is one of the derivations of Rostock 3D printer, which is a linear delta robot prototype [4], built in 2012 by Johann C. Rocholl in Seattle, USA, and named perhaps after his town of birth. The Rostock MAX 3D printer is chosen for this project since it has delta configuration, stable construction, fixed base surface, lightweight end effector with hot end, adjustable print surface (heated glass) and adjustable height of the print (therefore adjustable build volume too). End – effector in delta configuration is lighter - it has reduced inertia by the end of the movement; this is why it is able to respond quickly while retaining it's accuracy. With simpler construction this reduces maintenance and costs. Rostock printer [5] is considered to be relatively easy to make and assemble, having in mind it consists of less than 200 parts in total.
A variety of designs and suggestions for the items to 3D print, including the parts for building the Rostock MAX 3D printer, can be found on the web, e. g. [6]. The dimensions of the plates that make up the printer housing can be either determined by the user or a CAD document downloaded, containing blueprints with the required dimensions. The housing should be made of solid materials such as metal, wood panels or PVC. Here the wood panels were chosen because they are affordable, easy to obtain and to process and meet the specified criteria [1]. Depending on the thickness of the wood plate and the budget available, panels can be cut on a CNC machine or by hand, where precision is very important. Some of the parts can be purchased in stores for hobbyists, like rods made out of stainless steel and carbon tubes for the robot's hands.

Electronic components for the Rostock 3D printer can be bought separately, but the most cost-effective choice is to buy the electronics in a set from many available online stores ([7] - [13], etc.). The data sheets and mounting instruction can be found on-line too. The heat bed is an optional 3D printer module, however it is strongly suggested that it should be added. The heat bed provides better printing results by making cooling process of 3D printed materials controlled. The heat bed also prevents problems such as poor adhesion to the working platform, poor adhesion between layers of the printed object, heat loss during printing, and bending of the final product. After assembling the 3D printer, the calibration is performed. This can be either software or mechanical calibration. Both have to be done and both can be complex and time consuming. Software calibration can be cumbersome process for someone who is not skillful in programming. However, open-source programs can be found on the Internet ([13] - [16], etc.) which allow the most relevant data to be pre-configured and changed by entering the parameters of the printer that is being built. Upon successful calibration, the 3D printer should be tested by printing a cube [1].

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Low cycle fatigue behavior of 316L steel manufactured by selective laser melting

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ABSTRACT

Additive manufacturing (AM), familiarly called also 3D printing, of metallic materials represents undoubtedly a revolution in production technology and presently attracts considerable interest of numerous research groups both in academia and industry. Among the metal AM techniques the most common and frequently utilized technology is selective laser melting (SLM) (also termed laser powder bed fusion (L-PBF)) which enables direct manufacturing of 3D complex shape parts with an internal architecture from numerous metallic materials, especially Ti- and Al-alloys, stainless steels and nickel-based superalloys. At present, austenitic stainless 316L steel represents one of the most intensively studied SLM materials due to its perspective utilization in demanding sectors as nuclear and biomedical industry.

The structure of SLM 316L steel is due to the "welding" nature of SLM process completely different from its wrought counterpart with typical polyhedral grains and annealing twins. High temperature gradients and solidification rates together with repeated cooling/heating cycles during SLM process result also in austenitic structure but with columnar grains comprising sub-grains with a characteristic fine dislocation solidification cellular structure and nano-oxide particles (for the most recent review on this topic see [1]). This specific complex hierarchical but non-equilibrium structure of SLM 316L results in yield strength considerably higher than their conventionally produced counterparts without a reduced ductility [2].

Majority of fatigue studies on AM 316L steel has been performed under load controlled (high-cycle fatigue (HCF)) conditions (axial loading, rotating bending or flexural bending) with the primary aim to establish fatigue life curves or simply fatigue limit for various post-processing and post-heat treatment states. However, these studies are generally accompanied only by fractographic analysis to reveal crack initiation sites while no attempt is devoted to study fatigue damage mechanisms and possible microstructure changes in the bulk of fatigued SLM material.

Contrary to numerous HCF studies there are only three papers on low-cycle fatigue (LCF) behavior of SLMed 316L steel – two of them coming from Shamsaei's fatigue group. In the first paper [3] the authors studied the effect of building direction (vertical, horizontal and diagonal) on fatigue performance of net-shape samples in the as-built conditions and samples machined from pre-printed cylinders. This study indicated the presence of cyclic softening. The second paper [4] highlights the usefulness of the building platform preheating for considerable suppression of porosity and thus ductility and fatigue strength improvement of

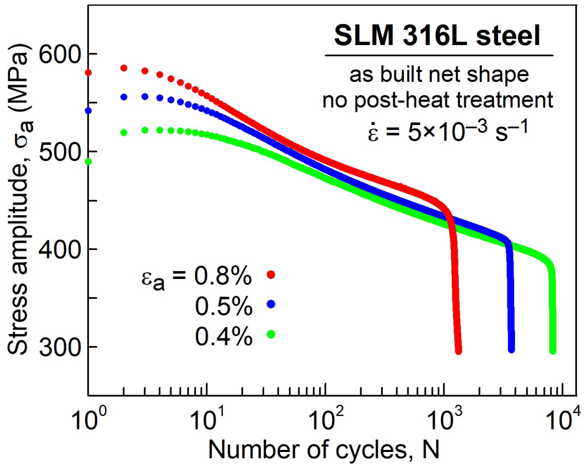

Fig. 1 Cyclic hardening/softening curves of SLMed 316L steel fatigued with various constant strain amplitudes ε_a at room temperature.

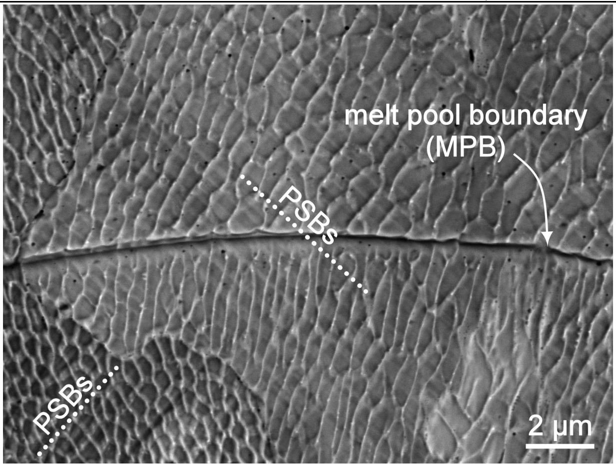

Fig. 2 Microstructure of SLMed 316L steel cyclically strained with ε_a=0.8% up to the end of fatigue life (SEM, special color etching).

SLM 316L steel. More systematic study on the cyclic stress-strain response accompanied by limited characterization of changes in fine dislocation cellular microstructure in 316L steel manufactured by SLM and fatigued under total strain control has been published only recently by Yu et al. [5].

The aim of the present work is to deepen our knowledge on cyclic plasticity and LCF behavior of SLMed 316L steel with emphasis to reveal deformation mechanisms and possible changes within unique cellular/columnar dislocation substructure during cyclic straining. For this purpose cylindrical net shape specimens were manufactured in vertical orientation with a relative density higher than 99.65% by SLM from AISI 316L steel recycled powder. Fatigue specimens in as-built state without any post-heat treatment were cyclically strained in symmetrical push-pull (R_ε = −1) with three different constant total strain amplitudes of 0.4%, 0.5% and 0.8% at room temperature. Except for a very short period of initial mild strain hardening the cyclic straining resulted in permanent cyclic softening up to the end of the fatigue life the intensity of which decreased with decreasing applied strain amplitude – see Fig. 1. The virgin, non-equilibrium microstructure with characteristic fine cellular/columnar subgrain morphology showed, generally, a high stability against cyclic straining. Nevertheless, the adoption of a special color etching technique has indicated the presence of straight parallel lamellae of different thickness running across cellular structure as observed in individual grains by scanning electron microscopy (SEM) – see Fig. 2. The nature of dislocation arrangement in distinct lamellae of localized cyclic slip following (111) slip plane – persistent slip bands (PSBs) – has been characterized in detail by high resolution transmission electron microscopy (TEM). The occurrence of cyclic strain localization into PSBs is confronted with the course of cyclic hardening/softening curves and characteristic changes of hysteresis loop shape during cyclic straining. Some implications of the present experimental findings for future fatigue studies on additively manufactured metals are highlighted.

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Numerical simulation of crack propagation in a component produced by additive manufacturing

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ABSTRACT

Introduction

Additive manufacturing is a layer-based manufacturing process which allows automatic fabrication of products of complex shape at optimized cost with reduced time. It has been widely believed that components produced by this method have lower mechanical properties in comparison with conventionally produced homogenous components, due to weak bonding of printed filaments [1]. However, recent studies proved, that this negative effect can be reduced by choosing appropriate printing parameters [2].
Fracture properties and crack growth kinetics of PLA (polylactic acid) were studied by Arbeiter [3] in a series of measurement on CT specimens with different line orientations. The results showed that regardless of the orientation of the lines, the cycles to fracture and to initiation as well as the crack initiation and propagation law appear to be almost identical. Based on these results, a Paris' crack propagation law was used for the crack propagation description, and the material constants were determined: $A = 10^{-3.78}$ and $m = 2.87$ [3]. The main aim of presented study is to verify the validity of the experimentally obtained material constants on a real mechanical component – a wrench – made of PLA material. It is done by creating a 3D numerical model containing a crack that will allow calculation of the stress intensity factor along the crack front which will be then used for the estimation of a residual fatigue lifetime of the modelled wrench. Finally, by the comparison between estimated fatigue lifetime value and experimentally obtained one, the material data can be validated.

Numerical modelling

The numerical modelling was chosen due to the complicated stress field near the crack front, that is influenced by contact stresses and by the stress concentration caused by sharp edge, where the crack initiated. However, the complexity of the conditions during the real experimental measurements resulted in a challenging task of creating the numerical model. To simulate a real crack front shape, the problem had to be modelled in 3D. The contact between wrench and bolt caused the nonlinearity of the calculations which extended the calculation time substantially. The contact friction analysis showed that the value of the coefficient of friction has influence on the spot where the crack starts to initiate. Keeping both parts in contact during the simulation was secured by COMBIN element (highlighted by purple colour) and by using contact elements between both parts (highlighted by blue colour), see Fig. 1.

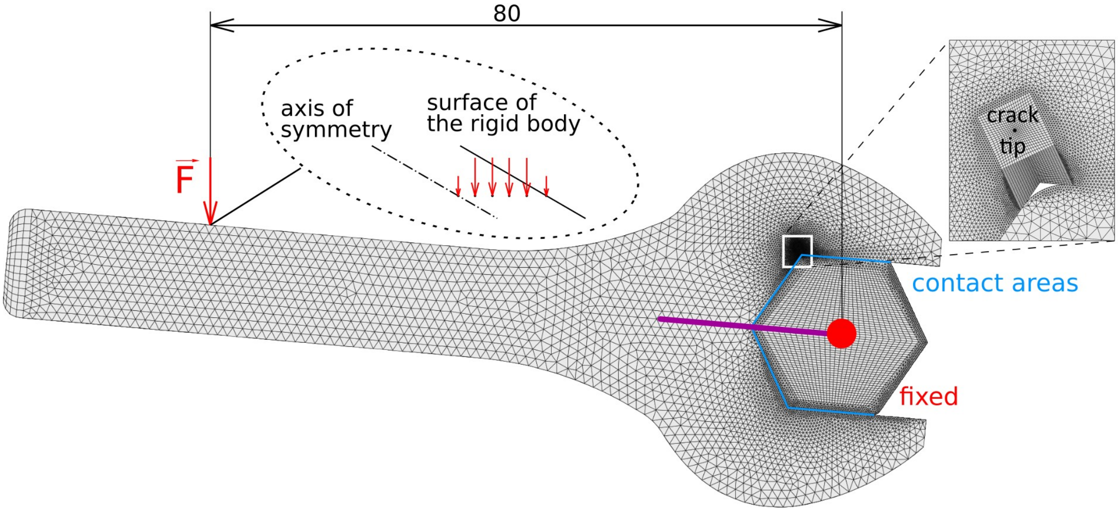

Figure 1: Finite element model with the detail of very fine mesh in the crack surroundings

Conclusion

This numerical model allows calculation of the stress intensity factor along the crack front, where the crack growth is simulated in steps and two models of cracks are considered. The obtained stress intensity factor values were used for numerical estimation of residual fatigue lifetime of the wrench. The comparison with experimental data was done and good agreement has been found – see the published paper in Additive Manufacturing journal [4].

Acknowledgements

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Correlation between fatigue behaviour and surface roughness of Inconel718 produced by additive manufacturing

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ABSTRACT

Additive manufacturing (AM) has implemented a revolutionary approach of metal part fabrication technology that has attracted the attention of many industrial sectors. Components of extremely complex geometry are readily obtained from powder by Laser-Powder Bed Fusion (L-PBF), the most successful metal AM technology. However, the mechanical properties of components realized with this technology depend on process parameters, material microstructure, internal defects and surface quality. An AM-aware designer must recognise and properly link together all these factors to obtain successful applications. In the development of structural components while exploiting the full technological potential, it is critically important to reduce post-processing such as surface finishing because very expensive and often unfeasible due to geometrical complexity. Therefore, the "as-built" surface quality has to be characterized and understood especially when fatigue properties are important such as in structural applications. It is well known that surface roughness and fatigue behaviour are strictly dependant.
This contribution is focussed on the systematic investigation of the fatigue behaviour of Inconel 718 specimens manufactured with three different L-PBF industrial systems (SLM 280HL, EOS M290, RENISHAW AM250) and of their as-built surface morphology.
An innovative fatigue test method based on the use of prismatic miniature specimens is adopted. It drastically reduces material and production costs that typically characterize L-PBF technology. Despite the small size of the specimens, valuable and original results are obtained by exploiting their versatility. Here specimens produced in different build directions are characterized in terms of surface roughness and corresponding high cycle fatigue behaviour. Roughness measurements are carried out on flat surfaces in terms of ISO 4287 parameters Ra; Rq; Rz; Rt using the roughness tester SA6220 (SAMA Tools, Italy). An empirical correlation between the experimental fatigue strength and the measured roughness parameters is sought. Implications of the measurements on roughness-based fatigue model development will also be discussed.

Comparison of cyclic behaviour of SLM- and conventionally-processed 304L

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ABSTRACT

Additive manufacturing (AM) offers unpreceded design freedom and a chance to tailor the inner structure of fabricated parts. Generally, the AM-processed components possess a combination of notably higher strength and lower ductility compared to their wrought counterparts. This difference is stemming from the characteristic nature of microstructure achieved by AM featured by higher volume fraction of grain boundaries, chemical microsegregation and high dislocation density. Thus, mechanical properties will inevitably differ. Monotonic properties have been studied by multiple studies where a pronounced increase of strength characteristics and decrease of ductility were observed. Unlike numerous papers dealing with monotonic loading, cyclic loading has not been studied so frequently. This contribution will focus to highlight the principal differences in cyclic behaviour of selective laser melting- (SLM) and conventionally-processed austenitic stainless steel 304L in low cycle fatigue (LCF) regime with respect to their specific microstructures.
The specimens were fabricated from gas atomized 304L powder (Sandvik Osprey, UK) in a form of horizontally printed blocks by an SLM 280 HL system equipped with a 400 Watt IPF fiber laser. The final specimen geometry was machined and the specimen surface underwent mechanical grinding and electrolytic polishing. The specimens were subjected to fully reversed cyclic loading ($R_\varepsilon = -1$) by an MTS 880 servo-hydraulic machine under constant total strain control regime.
The cyclic loading resulted in notably different cyclic behaviour. In general, wrought 304L steel exhibited a sequence consisting of initial cyclic hardening followed by mild softening and subsequent cyclic hardening whereas cyclic response of the SLM 304L steel was characterized by significantly higher stress amplitudes and continuous cyclic softening with subsequent saturation or mild cyclic hardening. The final hardening stage can be attributed to activated martensitic transformation for both material variants. This cyclic hardening is seemingly more intensive in the case of the wrought 304L steel although the chemical compositions is nearly identical with the SLM 304L steel. Therefore, martensitic transformation seems to be strongly influenced by inner structure. High dislocation density arranged into cellular structures significantly suppresses the susceptibility of the material to phase transformation due to its very fine character. The wrought variant, with notable chemical heterogeneity of Cr and Ni originating from rolling process, possesses highly metastable areas which easily undergo $\gamma \rightarrow \alpha'$ transformation. Different cyclic behaviour was complemented by scanning electron microscopy concentrated on specimen surface and cross-section observations. The

character of dislocation structures and developed surface relief correlates well with the specific cyclic behaviour of studied materials.

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A_MADAM project - fatigue behaviour of steels produced by DMLS

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ABSTRACT

Additive manufacturing (AM) comprises a set of different manufacturing technologies that use principle of joining of raw material to create a product. The principle enables manufacturing of objects with complex shapes, featuring curved surfaces and internal holes, which facilitates production of lightweight structures and products with shape-integrated functionalities. These features made AM technologies suitable for automotive and aerospace applications. However, the respective mechanical strength requirements substantially limit the choice of AM technologies that may be used for these applications. For AM production of metal components, the manufacturers of automotive and aerospace components almost exclusively use technology of direct metal laser sintering (DMLS) or melting (SLM). A particular feature of the automotive and aerospace applications is that the mechanical structures and components are exposed to dynamic loads, which makes fatigue resistance of the used materials a topic of research interest. The majority of research about fatigue properties of DMLS and SLM products until 2015 was focused to light metals, mainly aluminium and titanium, which motivated the authors of the paper to propose project that would represent a comprehensive and systematic study of fatigue behaviour of steels produced by DMLS. Entitled "Advanced design rules for optimal dynamic properties of additive manufacturing products", the ongoing project was approved and funded by European Commission in period 2017-2021, and it is realized by a consortium consisting of two academic and three industrial partners [1].

The initial research program is developed after process that consisted of study of the state-of-the-art of the research topic, identification of potential research direction and analysis of limitations of the consortium and the project. The main research direction of the investigations was application of the standard test methodologies to samples of standard shapes made by DMLS technology. The intended outcome was better understanding of the influence of some production conditions (orientation and position of the products during production process, and the combination of manufacturing technologies) and post-processing methods (heat treatment, surface treatment by micro-shot-peening /MSP/ and machining) to fatigue behaviour of producs of three kinds of steel manufactured by DMLS: maraging steel MS1 (equivalent DIN 1.2709), stainless steel PH1 (equivalent DIN 1.4540) and the maraging stainless steel EOS CX, specially developed for DMLS purposes. The experimental samples under the study were subjected to fatigue testing according to the ISO 1143 standard [2] which specifies the experimental method for fatigue testing of metallic materials using

bending of rotating bars. According to the experimental plan used in the project, the samples were divided in sample sets, such that the samples of each individual set were manufactured under the same production conditions and, after the production, treated by the same post-processing procedures.
The differences between the fatigue resistances of of different sets were attributed to different production conditions and post-processing procedures, and the ANOVA analysis, as well as some machine learning methodologies, enabled studies of the influence of the production conditions and the post-processing procedures to the fatigue behaviour of studied materials [3-5]. The first important result of the analyses is that different kinds of steel exhibit different dependencies of fatigue resistance on various production and post-production factors. The common point is that the post-processing by heat treatment, shot peening and machining increase the fatigue resistance of the materials, as it may be expected, as it was the case with the steels manufactured by traditional technologies. However, an important difference is that the order of the post-processing procedures does not have the same effect as in traditional techologies, as it was noted that the application of machining as the last post-processing step may reduce the fatigue resistance of the samples. Therefore, the highest fatigue resistance was observed when MSP was performed after the machining, which reduced the surface quality of the samples. The explanation is that the MSP reduces residual stresses and close pores in surface layer, and susequent machining removes the surface layer and the beneficial effects of MSP.
ANOVA method was not able to establish the dependence of fatigue resistance of maraging steel MS1 on building orientation, the position of samples in production chamber and the thickness of the allowance for machining. Further studies using machine learning indicated that only the the position of samples in production chamber may have some influence on fatigue resistance of the maraging steel MS1. On the other hand, ANOVA analyses have shown that the orientation of the samples and thickness of allowance affect fatigue resistance of the stainless steel PH1, with an unexpected outcome that the samples with horizontal and vertical buliding orientation had smaller fatigue resistance than the samples with slanted builiding orientation. The explanation was found in the high tensile residual stresses and specific microstructure of stainless steel PH1 produced by DMLS. The results of fatigue tests of maraging stainless steel CX are still under study, but the initial results indicate that it fatigue resistance resembles more that of maraging steel MS1 than that of stainless steel PH1, with fatigue resistance not depending on production conditions, but depending on post-processing procedures and their interaction.

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Monitoring of crack growth in additive manufactured pipe ring specimens by digital image correlation

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ABSTRACT

The application of models made by additive manufacturing has largely found its place in engineering practice. Models made in this way are temporary functional elements of an assembly, and more and more often replacement parts that perform their function as well. In addition to the mechanical parameters that the models made by additive manufacturing had to meet, it was necessary to examine the effect of fracture toughness. Frequent exposure of the model to mechanical contacts with other parts of the structure may lead to model damage, which affects their integrity, especially when they are under the action of radial load. Samples were tested using tools designed for pipe ring specimen tested on a universal Shimadzu AGS-X (100kN) machine with simultaneous use of the Aramis 6.0 Digital Image Correlation System (DIC). The samples were printed on a German Reprap x400 3D printer made of polylactide acid (PLA) material at 100% infil and number OUTLINES is 2. In this way, the criterion for achieving proper crack growth along the printed samples is met. The groove is formed in the longitudinal direction, while the force applied simulates the internal pressure, ie it acts in the radial direction. Using DIC, crack mouth opening displacement (CMOD) and crack type opening displacement (CTOD) were measured. Repeatable results indicate that pipe ring specimen obtained by additive manucaturing can be used to characterize the fracture of this material.

Estimating damping values of 3D printed ABS test specimens using the half-power method

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ABSTRACT

This paper discusses the vibrational behavior of Acrylonitrile Butadiene Styrene (ABS) test specimens, obtained by additive manufacturing (AM), having three different deposition directions, Figure 1.

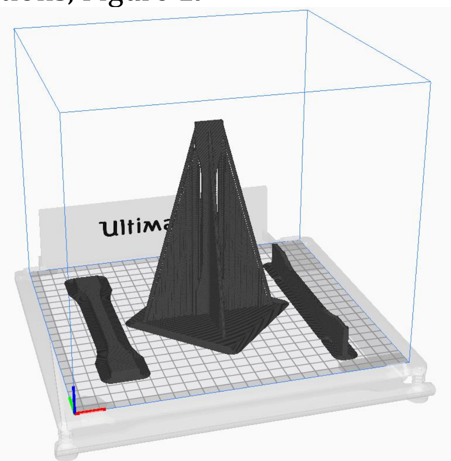

Figure 1 – Specimen orientation

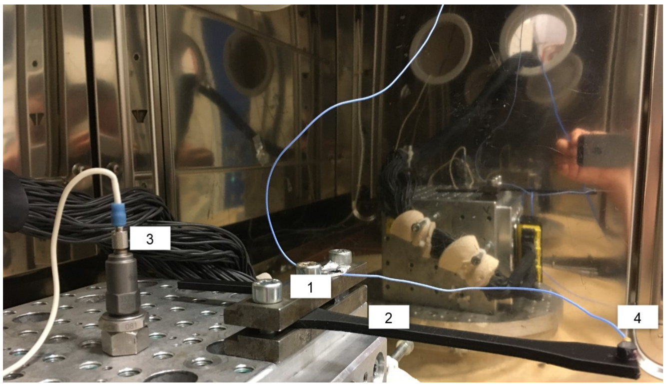

Figure 2 – Test setup

Test specimens were subjected to forced vibration on an electromechanical shaker and the frequency response amplitude was measured using accelerometers and half-power bandwidth method was used to compute structural damping. Natural frequency and Q-factors were discussed. The experiment showed that deposition direction generates a variability of the structural damping up to 30%. The parameters identified during experiments could be further used to develop Finite Element numerical models to virtually validate 3D printed structures generated with same process parameters as used for generating the test samples.

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Damage mechanisms of SLM-printed 316L steel subjected to thermomechanical fatigue

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ABSTRACT

The use of 3D printing in the manufacturing of metallic components brought fatigue as dominant failure mode into spotlight yet again. Though deeply researched for conventionally manufactured materials, the fatigue damage mechanisms in 3D-printed materials have still not been sufficiently examined. Real components are also subjected to variable temperature field, hence the thermomechanical fatigue simulating the conditions under which real components work is of high importance.

Present work deals with damage mechanisms occurring in austenitic steel subjected to thermomechanical fatigue. Both vertically and horizontally built specimens were tested. Cylindrical specimens were machined out of SLM-printed bars and were cycled in both in-phase and out-of-phase loading modes in the temperature range of 550–750 °C. Tests were controlled with mechanical strain amplitude of 0.2, 0.3 and 0,5 % (in-phase tests) and 0.3, 0.5 and 0.6 % (out-of-phase tests). The specimens were analyzed by means of visible light microscopy (VLM), computational tomography (CT), scanning electron microscopy (SEM) and transmission electron microscopy (TEM).

As revealed by VLM, the initial microstructure exhibited strong pattern corresponding to the building direction of the material. CT analysis revealed no big (> 5 μm) lack-of-fusion defects, however fine round defects of a micrometer scale were present. After cycling, the internal structure was composed of dislocation cells elongated in one direction as revealed by means of SEM and TEM. No slip bands were observed. Fine (up to ~500 nm), round oxides rich in Si and Mn were present.

Lifetime curves showed that the vertically built specimens exhibited better fatigue properties in in-phase loading conditions. High stresses at maximum temperatures led to the nucleation, growth and coalescence of cavities along grain boundaries as revealed by SEM. As a result, intergranular damage was dominant. On the other hand, the horizontally built specimens exhibited better fatigue properties in out-of-phase loading conditions. SEM analysis revealed the mechanism of oxidation-assisted crack initiation taking place. Numerous short, shallow cracks running approximately perpendicular to the surface were observed. As a result of absent or relatively low creep damage at high temperatures, the character of damage was transgranular and there were striations at the fracture surface. However, to fully understand all the aspects of thermomechanical fatigue damage in additively manufactured materials, more work needs to be conducted.

Microstructural characteristics lying behind the instability of additively manufactured Co-28Cr-6Mo alloy

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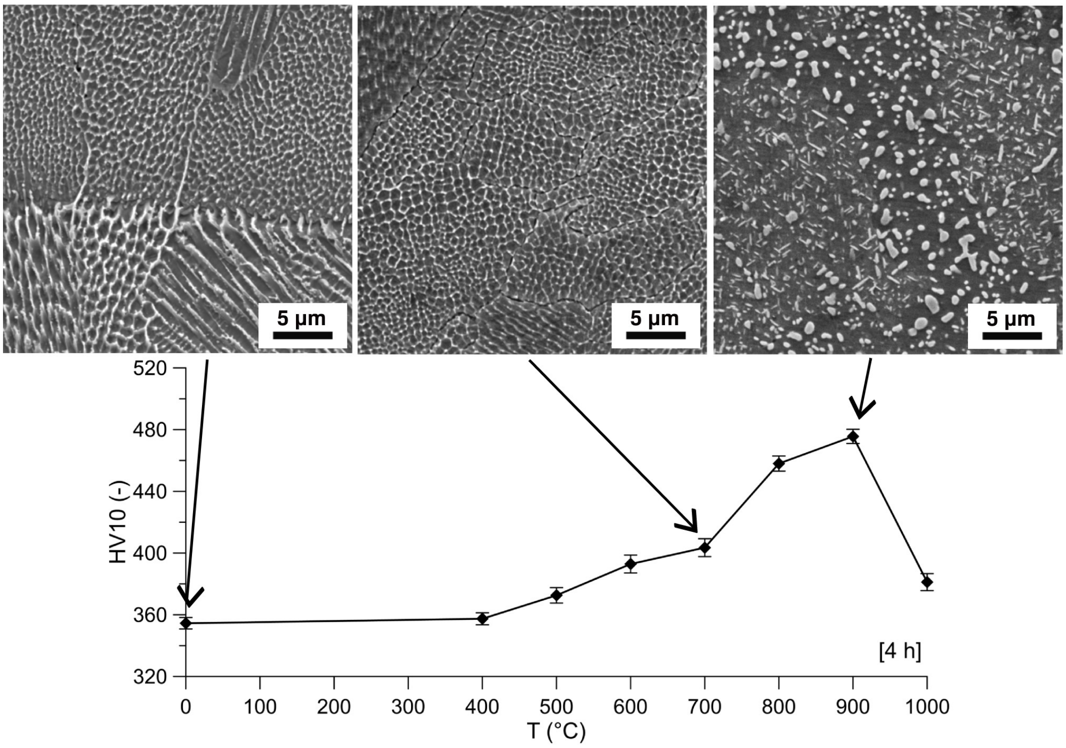
ABSTRACT

Research background
Specifics of additive manufacturing such as layer-by-layer production, high solidification rates, and repeated thermal effects significantly alter the material microstructure [1]. The non-equilibrium microstructure of laser powder-bed fused (L-PBF) Co-28Cr-6Mo alloy in the as-built state, comprising fine cellular microstructure with microsegregations, metastable phases, high content of crystal defects, internal stresses etc., may significantly influence the material stability [2]. It is thus important to study thoroughly the changes of microstructure and mechanical performance of this additively manufactured alloy as expositions to heat might occur in some applications (e.g. aerospace) and so operational safety might be jeopardized [3]. We are the first to focus closely on the material changes at increasing temperatures based on which necessary post-processing steps can be deduced.

Methodology
A batch of round tensile specimens oriented vertically was prepared using an SLM Solutions 280 HL machine working with a laser beam of 275 W in power and 800 mms^{-1} in speed. Layers of deposited gas-atomized powder of low-C Co-28Cr-6Mo alloy, 50 µm in thickness, were processed by stripe scanning strategy, with hatching distance of 0.12 mm and direction alternating by 45° each layer.
Samples were then subjected to annealing at temperatures of 400–1000 °C for 4h, followed by water-quenching. Vickers hardness was measured on metallographic cross-sections ground on SiC papers. Also, hardness evolution in time was measured for some selected temperatures. Microstructural changes were studied by scanning electron microscopy supplemented by EDS and EBSD, as well as by X-ray diffraction. Selected states were observed by transmission electron microscopy. Tensile tests were carried out.

Main outcomes
Above 400 °C, the L-PBF Co-28Cr-6Mo alloy shows microstructural instability associated with increasing hardness. First, these changes are attributed to isothermal fcc→hcp phase transformation. At about 800 °C, breakdown of the cellular microstructure occurs along with the precipitation of σ-phase rich in Mo. Detailed characterization of microstructural changes

at 900 °C revealed a rapid onset of massive transformation bringing grain refinement and conversion into almost fully hcp material. Such changes bring significant strengthening of the material but strongly limits its plasticity.



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Printing parameter effect on tensile properties of FDM polypropylene material

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ABSTRACT

FDM (Fused Deposition Modelling) additive manufacturing (AM) technology possesses many parameters that have to be defined before the actual additive process i.e., 3D printing. Those parameters have a substantial impact on mechanical properties of FDM materials. Most common FDM materials are PLA, ABS, PC, PET-G, PP, etc. For example, PolyPropylene (PP) material is a widely used plastic material due to its excellent chemical resistance, can be easily processed by many methods including injection moulding and extrusion. Because FDM is an extrusion-based technology[1], PP has a wide use in this technology. Nowadays, PP material is one of the most popular commodity plastics due to its low density, low cost and good mechanical properties. Most commonly this particular plastic is used in food and beverage industry for product packaging and also in biomedical industry- due to its sufficient biocompatibility. Because of PP material environment-friendly nature, today's research mostly focuses toward the creation of best combination of PP with other polymers, that originate from sustainable resources, in order to lower the dependence on petrochemical-based polymers. Concerning composite structures, PP material is mostly used as a matrix component due to its excellent ductility[2].

In FDM, PP materials have substantially higher elongation than any other FDM thermoplastics. In this research four specimen bathes were prepared for tensile testing. The batches differ in layer height, infill density and printing orientation. These three parameters are considered as the parameters that have the greatest influence on mechanical properties of FDM materials[3]. Tensile testing is conducted on Universal testing machine ''Shimadzu AGS-X'', with load cell capacity of 100 kN (Fig. 1), according to ISO 527-2 standard. All tested specimen batches show that PP is a ductile material, holding high toughness value and elongation. Highest measured toughness per batch is 181 J, which is an average value in the tested specimen batch with the best mechanical properties according to the three before-mentioned parameters. Lowest measured elongation per batch is 206% with some batches containing specimens that didn't break before reached maximal tensile machine stroke- which is 500 mm. Specimen length is 110 mm i.e., the vertical distance between the two supporting grips. Results show sufficient repeatability between specimens (Fig. 2).

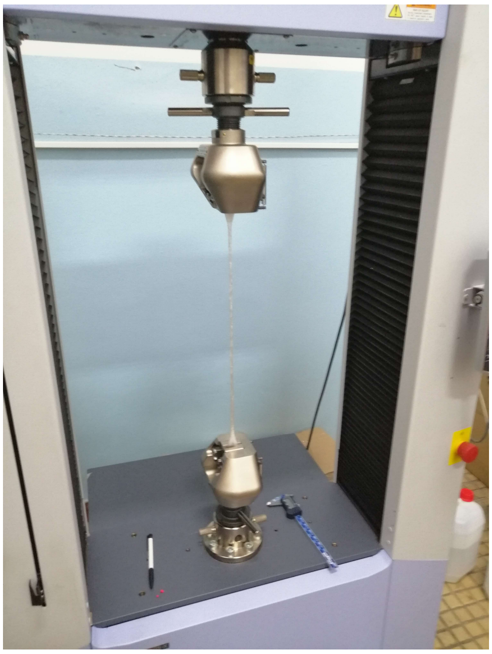

Figure 1: PP specimen on universal testing machine, during the tensile testing

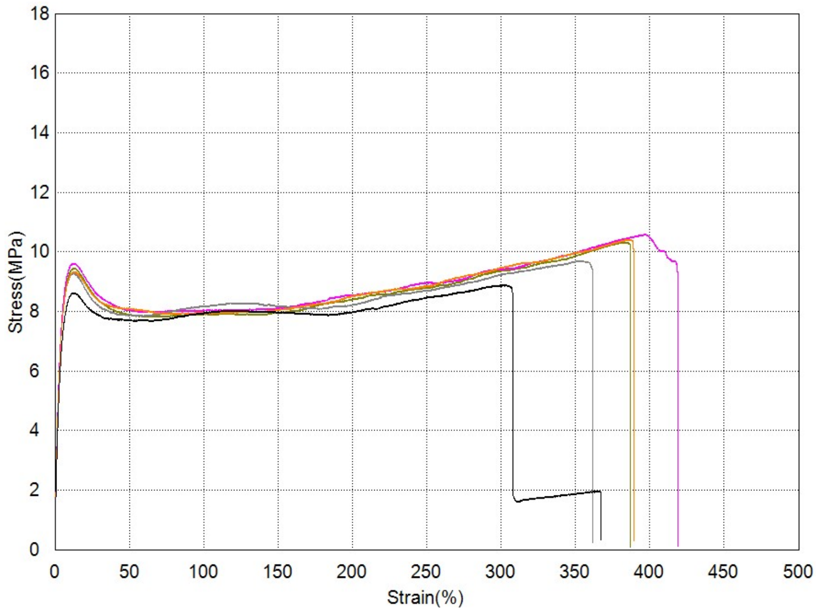

Figure 2: Stress-Strain diagrams of one particular PP specimen batch

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Model development by FDM technique of additive production using dual extrusion - advantages and disadvantages

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ABSTRACT

Additive production as an area of production of models from plastic, and now also from metal, is a part of production branches of various areas. With the development of additive technology techniques, in addition to the precision and capacity of the devices themselves, the possibilities of combining both techniques and materials within one technology are being improved. The technique that first started with the development of model making with a combination of materials is the FDM (Fused Deposition Modeling) technique. Bearing in mind that this technique is very widespread and that all its manufacturing mechanisms are well known, we see the importance of the possibility of combining two thermoplastic materials. This definitely guarantees the modification of the mechanical characteristics of the models made by the FDM technique in the desired direction. In addition to changes in mechanical characteristics, there have been opportunities to create complex model geometries that have so far only been possible with other techniques such as SLA (Stereolithography) or SLS (Selective laser sintering). This novelty was made possible by dual extrusion. This paper will present the biggest advantages and disadvantages of dual extrusion.

Influence of cordierite and zeolite on improvement of cavitation resistance of talc-based ceramics

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ABSTRACT

The paper examined three sintered samples based on talc, talc with the addition of cordierite and talc with the addition of zeolite. The resistance of these samples to the effect of cavitation was experimentally determined using the ultrasonic vibration method with a stationary sample according to the ASTM G32 standard. During the test, the change in the mass of the samples as a function of the time of cavitation action was monitored. Based on the values of cavitation velocity and morphology of surface damage, the effects of cordierite and zeolite on the improvement of cavitation resistance of the tested samples were determined.

Keywords: *talc based ceramic, cordierite, zeolite, cavitation resistance*

In-process monitoring of the 3D-printing and its use in the development of special cutting tools

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ABSTRACT

When developing a new product, which will be produced by 3D-printing technology, it is necessary to think about reliable and productive production. This also applies if the existing component or individual parts are to be replaced by one complex 3D-printed product. Special SW and HW tools help designers and technologists to find the final shape of parts and reduce their scrap. Simulation SW predicts deformations and stresses in the part during printing. It is also possible to simulate the effect of heat treatment, even the condition after cutting the printed parts from the platform. Thanks to this, it is possible to design suitable modifications of the shape, supporting structures, the position of the part during printing or the placement of several printed parts in the chamber. Nevertheless, it is sometimes necessary to additionally adjust the process parameters at critical points in the printed parts. These are areas where large energy gradients occur (overhanging ends, rapid changes in cross-section, connection of supporting structures, areas of lattice structures, generally parts with thin rods, etc.). Even printing that was without problems can show some problems when restarted. Therefore, it is important to control the printing process and have as much information as possible about its quality and the whole process. There are monitoring systems on the market today that make this possible. Some devices are already implemented in 3D printing machines. Most often it is an in-process measurement of the energy of the laser spot using one or two diodes. Using a thermal imaging camera, the work area is captured and the image is gradually assembled into one whole. The quality of the powder bed in the work area is often checked using an optical camera. These systems can be used for continuous control of print jobs and for subsequent optimization of process parameters.
When developing a new part, it is important to identify undesirable phenomena such as porosity or inclusions. However, this requires a high resolution. Recent publications of basic research results show that even smaller defects could be detected than current industrial systems can detect [1]. To optimize process parameters, teams of experts are trying to develop software that could simulate the printing process in detail. The publication [2] indicates which algorithms can be used. Monitoring systems are used to verify the results of simulations. All monitoring systems supplied with the EOS M290 are available at the RTI research center. To further refine the monitoring or verify the simulated values, a thermal imaging camera or other diode systems are often used, which are placed additionally on the device.

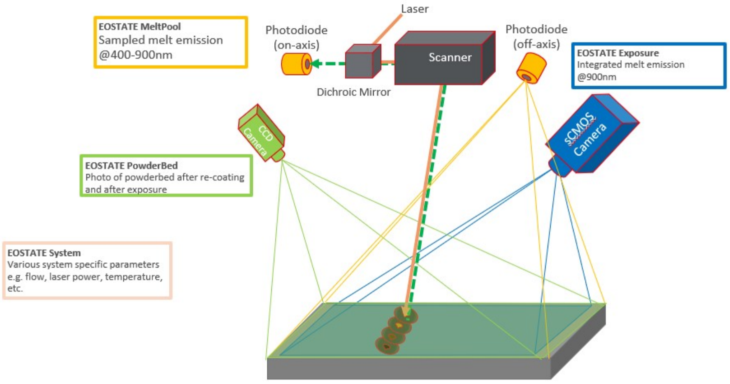

Fig. 1 Complete monitoring system for 3D printing using the PBF method in the RTI research center

Monitoring systems were also used in the development of special cutting tools - milling heads, which are characterized by a very light construction and special external and internal bionic shapes and lattice structures.

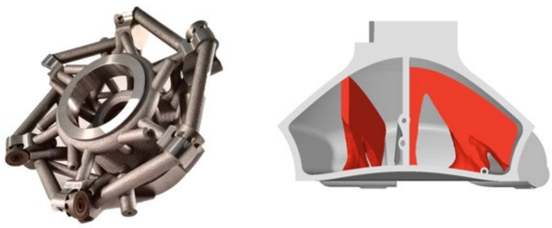

Fig. 2 New generation cutting tools produced by 3D printing technology (left Kraken, right Medusa)

Topological optimization was used to develop a tool with an internal "Medusa" structure. Computer simulations of the print followed. Necessary design modifications were made, setting of optimal process parameters. The printing process was monitored in detail, which made it possible to evaluate the effects of setting process parameters and further optimize the process. Part of the development was experimental measurement of the final mechanical properties of the component and the homogeneity of the material. By analysing all the obtained data, critical areas were identified and all input parameters were adjusted to achieve the most reliable printing.
Also, in the case of the "Kraken" tool, monitoring systems were used to monitor the quality of the printing process. A series of test samples of the tool were printed for a potential customer (mass manufacturer). Therefore, the emphasis was mainly on the homogeneity of print jobs. The monitoring results were satisfactory, but as a precaution, it was determined under which circumstances problem areas may arise at various points in the printed part. Detailed findings and conclusions of the research and development will be included in the presentation.

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Implementation of additive manufacturing for solutions in agriculture

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ABSTRACT

Most important implementation of additive manufacturing is production of functional prototypes, which can be used at many industrial branches, medical sector, science and research purposes. In our 1-year experience we employed FDM printing technology for executing several hundred projects, using different thermoplastic materials such as: PLA, ABS, PET G, PC-ABS, CARBON and TPU. This paper explains two projects we have executed for two innovators who had idea to implement smart solutions into the agriculture sector. Our activities were focused on partially modeling, optimization, preparation and production of parts which will be assembled into the functional prototypes. Parts had various geometries, dimensions and complexity, but at the end all of them were fabricated and assembled successfully. Prototypes are now being tested in order to get information about parts matching, material wearing and overall performance. Based on this information innovators will modify their ideas and turn them into the final product.

Keywords: Additive manufacturing, FDM technology, agriculture

Development and additive manufacturing of bladeless thruster

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ABSTRACT

Recent widespread of unmanned aerial vehicle (UAV), such as multi-copters arose many safety issues concerning propellers providing lift, propulsion and altitude control of conventional UAV. For instance, sudden breakdown and fall of UAV can produce rotating propeller induced injuries of random passersby. Such a safety issues require new approaches to development of UAV propulsion systems.
This paper deals with development and additive manufacturing of bladeless thruster as a new kind of UAV propulsion system which overcomes mentioned safety issue. Bladeless thruster is inspired by the Dyson bladeless fan [1].
Bladeless thruster is consisted of two parts, an electric ducted fan and a discharge frame. Electric ducted fan sucks the air from surroundings and directs it towards discharge frame which needs to accelerate incoming air flow. This process results in low-pressure area at the inlet of discharge frame and high-pressure area at the outlet of discharge frame which creates thrust from propulsion system.
A parametric model of geometry of discharge frame is established using FEA software ANSYS in order to investigate influence of geometric parameters, such us position of discharge frame inlet, shape of leading edges and shape and dimensions of discharge frame outlet upon thrust generated by propulsion system.
Methodology for additive manufacturing of discharge frame to be printed from ABS filament on FFF 3D printers is also established.
More detailed investigations of bladeless thruster regarding its geometry and additive manufacturing will be conducted in frame of ERASMUS+ project KnowHub and cooperation between local company and commercialization hub of the Faculty of Mechanical Engineering. Prototyping of bladeless thruster will be realized by FFF 3D printer Sindoh 3D WOX 7X.

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[2] Official web site of the project: https://knowhub.eu/

Experimental design in the quality control of the additive manufacturing process for carbon fiber-reinforced plastics

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ABSTRACT

Additive manufacturing (AM) and new 3D methods based not on the removal of material as in traditional mechanical processing, but on the layer-by-layer production according to a three-dimensional model obtained in a computer aided design. They add material in the form of plastic, ceramic, metal powders and their bonding by thermal, diffusion or glue method. However, advances in materials and equipment are needed to make polymer parts suitable for applications beyond prototyping or low-key applications. The limited number of polymers that can be used in 3D printers lack the mechanical and thermal properties required to withstand repeated loads or high temperatures. In this regard, the reinforcement of polymers with fibers with a higher strength and stiffness is required.
In production of critical parts from composites using 3D printing, it is important to ensure the quality of the composites, which is generally influenced not only by the technological process, but also by the quality of its constituent parts: fibres and matrix. Optimization parameters can be hardness, stiffness, strength, resistance to repeated loads (fatigue) and, in some cases, tribological properties - surface quality [1]. If it comes to operation with the sensors reading during production, the big data tools are inevitably should be employed. Many existing industrial quality control systems for AD products are not designed to correct the technological process because the control cycle with self-correction is significantly complicated by a large number of factors potentially leading to technological deviations and product rejects, as well as by high process dynamics.
Many factors influence on the quality of production process and on production itself. For creation of the optimal composition of factors, the design of experiment [2] is planned to be applied. As an optimizing parameter $\boldsymbol{y}$ it was proposed to choose microhardness. This parameter is easy to control and it is connected with strength. For the factor $\boldsymbol{x_i}$ the authors propose to use the followings from the list:

- Plastic's type. A study of the properties of plastics, sometimes used as a matrix, is contained in [3]. Two types of ABS plastics (Acrylonitrile Butadien Syrene), white and grey, were investigated, and differences in the mechanical properties of the resulting products were revealed. Also, in [3], some technological drawbacks of 3D technology were noted, which are very likely to adversely affect the quality of manufacturing of solid structural parts.
- Temperature. Due to their viscoelastic nature, polymers can undergo stress relaxation, which is desirable in large scale AM. Predicting the degree of stress relaxation allows optimizing the printing process and optimize the workflow. In Fig.1 the influence of the

temperatures on viscoelastic behavior of polymers [4] is schematically shown for some production variants. Tg here is a glass transition temperature and Tm is the melting temperature.

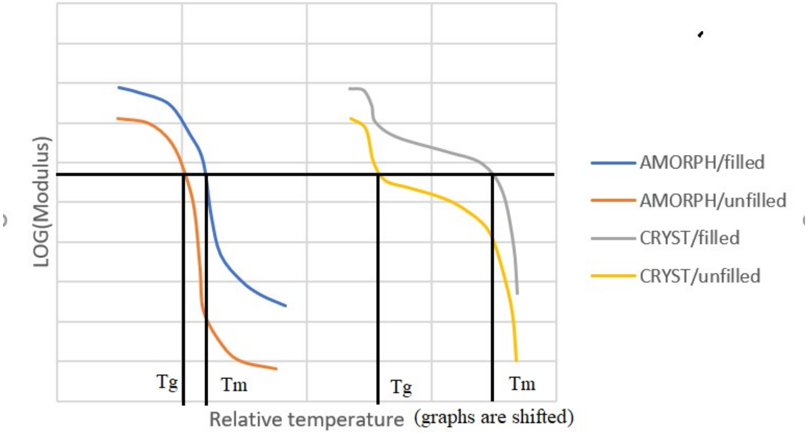

Fig.1. Effect of fillers on viscoelastic behavior of amorphous and crystaline polymer [4]

- The area around the Tg, known as the "leathery" area, is where the viscoelastic behavior is most noticeable. In this area, the temperature rises, which leads to an increase in free volume, which provides a greater mobility of the chain. It can be seen that in the presence of fillers, Tg shifts to the left, which provides better conditions for production. This analysis also stresses out the importance of the fillers.
- The layer thickness. It is set in the printer settings. This factor can vary depending on the part size. Here two levels (0.05… 0.3 and 0.1 … 0.5 mm) were chosen.

According to the aim of this study, the samples sized 10 mm x10 mm are supposed to print at printing machine for FDM (fused deposition modeling). The factor levels will be chosen according the Steepest Ascent plan (experiment design, [2]), which allows optimize the experiment. During experiment specimens will be been tested for the hardness which will allow to plan the further steps of factors attribution.

Conclusions

To guarantee the high-quality production of the additive manufacturing there is a need to optimize the parameters of printing. It is going to apply the Design of experiment for choosing the best modes of production process basing on the maximum specimen's hardness.

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