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1st Workshop on

Structural Integrity of Additively Manufactured Materials

Polytechnic University of Timisoara (UPT)

Timisoara, Romania, 25th-26th February 2021
& online

Book of Abstracts

Workshop organized by:

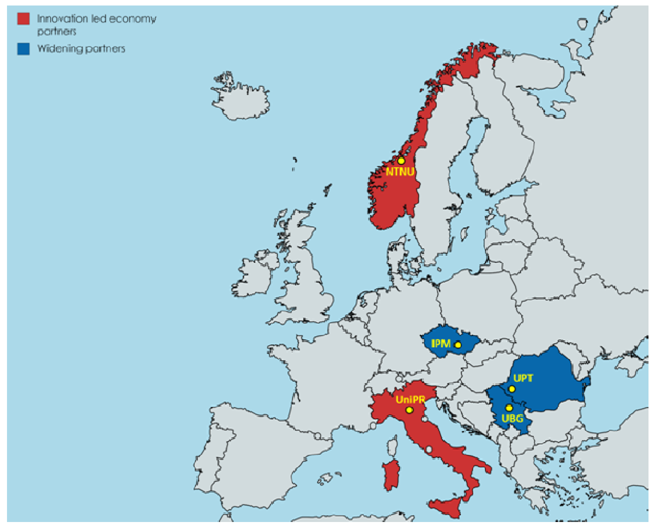
Polytechnic University of Timisoara,
ROMANIA

University of Belgrade,
SERBIA

Institute of Physics of Materials, Brno,
CZECH REP.

University of Parma,
ITALY

Norwegian Univ. of Science and Technology,
NORWAY



Participating institutions in SIRAMM project

Please connect to the Workshop by using
Zoom Meeting at this link:

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Meeting ID: **916 7786 9713**
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Workshop Program

(Central Europe Time (CET) - Rome, Paris, Berlin)

Thursday
25th February 2021

8:30-9:30	Registration of participants (UPT library, Timisoara, Romania)
9:30-10:00	Opening of the Workshop and presentation of the SIRAMM project (UPT library & online) Prof. Liviu Marsavina
10:00-10:30	**1st Keynote lecture** (online) Chairman: Prof. Andrea Spagnoli ***Manufacturing and printing of super soft materials for mechanical tissue-mimicking applications*** Antonio Elia Forte (Harvard University, USA & Polytechnic of Milan, Italy)
10:30-11:00	*Coffee break* (UPT library)
11:00-12:45	**1st Session** (UPT library & online) (12 min presentation + 3 min Qs&As) Chairman: Prof. Aleksandar Sedmak <u>*Characterization of AM materials*</u>
11:00-11:15	*Experimental assessment of printing parameter impact on eligibility of plain-strain facture toughness measurement* Isaak Trajkovic, Aleksa Milovanovic, Milos Milosevic, Snezana Kirin, Goran Mladenovic, Aleksandar Sedmak, Liviu Marsavina
11:15-11:30	*Fatigue behavior of additively manufactured Ti6Al4V alloy under different loading conditions* Danilo A. Renzo, Emanuele Sgambitterra, Carmine Maletta, Franco Furgiuele, Carlo A. Biffi, Jacopo Fiocchi, Ausonio Tuissi
11:30-11:45	*Energy Release as a parameter for fatigue design of AM metals* Dario Santonocito, Andrea Gatto, Giacomo Risitano
11:45-12:00	*Effect of the microstructure on the fatigue damage in highly anisotropic stainless steel fabricated by selective laser melting* Miroslav Šmíd, Stanislav Fintová, Ivo Kuběna, Michal Jambor, Tomáš Vojtek, Pavel Pokorný
12:00-12:15	*High cycle fatigue life estimation of SLMed lattice components using the Finite Cell Method* N. Korshunova, G. Alaimo, M. Carraturo, A. Reali, E. Rank, S. Kollmannsberger, F. Auricchio
12:15-12:30	*As-built surface quality and fatigue resistance of Inconel 718 obtained by additive manufacturing* Federico Uriati, Gianni Nicoletto, Adrian H.A. Lutey
12:30-12:45	*Bending behaviour of 3D printed sandwich beams with different types of core geometry* Andrei Ioan Indreș, Dan Mihai Constantinescu, Oana Alexandra Mocian

12:45-14:30 *Lunch break* (UPT library)

14:30-15:00 **2nd Keynote lecture** (online)
Chairman: Prof. Dan Serban
A seedcoat-inspired damage-tolerant architectured material
Chao Gao (NTNU, Trondheim, Norway)

15:00-15:15 *Coffee break* (UPT library)

15:15-17:30 **2nd Session** (UPT library & online) (12 min presentation + 3 min Qs&As)
Chairman: Prof. Roberto Brighenti

AM technologies advancements

15:15-15:30 *Additive Manufacturing in Construction: a review on technologies, processes, materials and their applications of 3D and 4D printing*
Gerardo Arcangelo Pacillo, Mario Fagone, Giovanna Ranocchiai, Federica Loccarini

15:30-15:45 *Printing and characterization of 3D high-loaded nanocomposites structures*
Corrado Sciancalepore, Federica Bondioli, Massimo Messori, Daniel Milanese

15:45-16:00 *Curved layer fused deposition modelling method*
Anni Cao, Filippo Berto, Chao Gao

16:00-16:15 *Post-processing technologies of copper - PLA composites obtained by 3D printing FDM method*
Sebastian Ambrus, Roxana Muntean, Norbert Kazamer, Cosmin Codrean

16:15-16:30 *EBM process for lattice structure manufacturing: bending test results*
Costanzo Bellini, Rosario Borrelli, Vittorio Di Cocco, Stefania Franchitti, Larisa Patricia Mocanu, Luca Sorrentino

16:30-16:45 *Design and optimisation of 3D fast printed cellular structures*
Chiara Ursini, Luca Collini, Ajeet Kumar

16:45-17:00 *The use of the impression guide in the classical impression techniques*
A.C. Cojocariu, C.S. Neagu, S. Chebici, M. Romînu, M.L. Negruțiu, C. Sinescu

17:00-17:15 *A designed six-in-lobed shaft of AlSi10Mg additively manufactured: the torque capacity assessment by linear and nonlinear buckling*
Marius Nicolae Baba, Călin Husar

17:15-17:30 *Residual Stress simulation in additive manufacturing: A Data-Driven Framework*
Osama Aljarrah, Jun Li, Wenzhen Huang, Alfa Heryudono, Jing Bi

Friday
26th February 2021

9:00-9:30	**3rd Keynote lecture** (online) Chairman: Prof. Liviu Marsavina ***In-situ monitoring for digital twins and accelerated qualification in additive manufacturing*** Paul Hooper (Imperial College London, UK)
9:30-11:15	**3rd Session** (UPT library & online) (12 min presentation + 3 min Qs&As) Chairman: Prof. Filippo Berto *Modeling of AM processes and materials*
9:30-9:45	*A Review on Machine Learning Applications In Additive Manufacturing* Abhishek Pandey, V. Ramesh
9:45-10:00	*Photopolymerized AM materials: modelling of the printing process, mechanical behavior and sensitivity analysis* Mattia Pancrazio Cosma, Roberto Brighenti, Andrea Spagnoli, Michele Terzano, Riccardo Alberini
10:00-10:15	*Modelisation of the selective laser sintering of polyamide 12* Hanane Yaagoubi, Hamid Abouchadi
10:15-10:30	*From μ-CT images to mechanical properties using the Finite Cell Method* N. Korshunova, M. Carraturo, G. Alaimo, A. Reali, E. Rank, S. Kollmannsberger, F. Auricchio
10:30-10:45	*Models for process simulation of additively manufactured polymers based on SLS technique* Riccardo Alberini, Roberto Brighenti, Mattia Pancrazio Cosma, Andrea Spagnoli, Michele Terzano
10:45-11:00	*Numerical evaluation of fatigue life of AM robot's head with initial crack* Aleksandar Grbović, Gordana Kastratović, Aleksandar Sedmak, Nenad Vidanović
11:00-11:15	*The benefits of Immediate dentin sealing (IDS)* Sergiu Chebici, Andreea Codruța Cojocariu, Cosmin Sinescu, Mihai Romînu, Meda-Lavinia Negruțiu
11:15-11:30	*Coffee break* (UPT library)
11:30-13:15	**4th Session** (UPT library & online) (12 min presentation + 3 min Qs&As) Chairman: Prof. Lubos Nahlik *Quality and control of AM materials*
11:30-11:45	*About Photogrammetry Applied in Mechanical field* Dorian Nedelcu
11:45-12:00	*Influence of Printing Parameters on Plain-Strain Fracture Toughness Results for PLA Polymer* Aleksa Milovanovic, Aleksandar Sedmak, Aleksandar Grbovic, Isaak Trajkovic, Tamara Mijatovic, Zorana Golubovic, Milos Milosevic
12:00-12:15	*Defects and quality controls in SLS industrial 3D printing* Francesco Soncini
12:15-12:30	*Design for additive manufacturing and post processing of cellular lattice structure* Ajeet Kumar, Luca Collini, Jeng-Ywan Jeng
12:30-12:45	*Experimental testing of two short-fiber reinforced composites: PPA-GF33 and PPS-GF40* Dan Micota, Alexandru Isaincu, Liviu Marşavina

12:45-13:00 *Fatigue life evaluation of an additively manufactured SAE 316L steel shaft under rotational bending: FEA versus DIN 743*
Marius Nicolae Baba, Aurel Andrei Paraschiv

13:00-13:15 *Experimental study regarding the optimization of metamaterial structures with Kelvin cells*
Dan-Andrei Șerban, Alexandru-Viorel Coșa, Radu Negru, Liviu Marșavina

13:15-14:30 *Lunch break*
(UPT library)

14:30-15:00 **4th Keynote lecture** (online)
Chairman: Prof. Aleksandar Grbovic
Geometry dependent mechanical properties of AM components
S.M. Javad Razavi (NTNU, Trondheim, Norway)

15:00-15:15 *Coffee break* (UPT library)

15:15-18:00 **5th Session** (UPT library & online) (12 min presentation + 3 min Qs&As)
Chairman: Dr. Milos Milosevic
Mechanics and damage of AM materials

15:15-15:30 *Numerical analysis of interlaminar tensile strength in fibre-reinforced AM composites*
A C Paredes, Juan León-Becerra, O. A. González-Estrada, O. Bohórquez, A. Pertuz

15:30-15:45 *Progressive damage in pipes of composite material through finite elements*
Sergio Augusto Peña Serrano, J. León Becerra, Oscar Rodolfo Bohorquez, Octavio Andres Gonzalez-Estrada, Alberto Pertuz

15:45-16:00 *Fracture behaviour of PLA and advanced PLA-X material*
Aleksa Milovanović, Aleksandar Sedmak, Isaak Trajković, Zorana Golubović, Miloš Milošević

16:00-16:15 *Mechanical properties comparison between new and recycled PETG obtained from FDM waste*
L.Bergonzi, M.Vettori, A.Severini

16:15-16:30 *Fracture toughness in additive manufacturing by selective laser sintering. An overview*
Liviu Marșavina, Dan Ioan Stoia, Linul Emanoil

16:30-16:45 *Charpy impact properties and numerical modelling of polycarbonate composites*
Tamas Krausz, Iulian-Ionut Ailinei, Sergiu Galatanu, Liviu Marsavina

16:45-17:00 *Simulation of the behavior of lattice structured impact absorbers manufactured by additive manufacturing*
Vinícius Veloso

17:00-17:15 *The effects of layers orientation on impact energy evaluation of FDM printed specimens*
Iulian-Ionuț Ailinei, Sergiu-Valentin Galațanu, Liviu Marșavina

17:15-17:30 *Additive manufacturing in dentistry*
Carina Neagu, Andreea Cojocariu, Sergiu Chebici, Cosmin Sinescu

17:30-17:45 *Modern Techniques in the Detection of Dental Caries*
Christa Serban, Carina Neagu, Andreea Codruta Cojocariu , Laura Cirligeru , Meda Lavinia Negrutiu, Cosmin Sinescu

17:45-18:00 Closing of the Workshop and presentation of future SIRAMM events (UPT library & online)
Prof. Liviu Marsavina

List of Abstracts

Keynote lectures

Keynote lecture

Manufacturing and printing of super soft materials for mechanical tissue-mimicking applications

Antonio Elia Forte[1,2]

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ABSTRACT

In the past three decades, 3D bioprinting has become one of the leading techniques for the replication of real tissue geometries, with the potential to mimic the soft tissue microstructure. Hence, bioprinting is currently the focus of several rapidly developing research fields. Recent applications include printing full human organs to contribute towards the shortage of organ donors. With the development of new soft tissue materials that can be used as printing inks, the field of biological 3D printing has grown exponentially, giving rise to the extrusion of living cells suspended in the printing ink.
It has been shown that the stiffness of the majority of human tissues lies within the order of a few kPa. Furthermore, in specific cases, cell differentiation and regeneration is promoted in tissue scaffolds that exhibit mechanical properties similar to those of the real tissue.
Therefore, a 3D printing technique that is able to produce geometrically and mechanically accurate scaffolds could hold enormous potential in regenerative medicine and biomimetics. To the best of our knowledge, there is a lack of studies focusing on bioprinting very soft materials with stiffness O(1) kPa. One of the causes of this is the inability of extremely soft materials to withstand their own weight: the printed structure is usually too soft to hold its shape or allow further layers to be built on top of it.
Therefore, the talk will be about the fabrication of mechanically accurate 3D printed composite hydrogels that mimic the stiffness of super soft tissues through the use of a novel printing setup based on cryogenic theory. Solid carbon dioxide (dry ice) and an isopropanol thermal conductive bath was used to achieve the cyrogenic stage, which is a safer alternative to liquid nitrogen. The ink used in this work is a composite hydrogel of poly(vinyl) alcohol (PVA) and Phytagel, which has been presented in [1,2,3,4] to mimic soft tissues, such as brain, with stiffness of O(1) kPa.

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[2] Tan Z., Parisi C., Di Silvio L., Dini D., Forte A. E., Sci Rep (2017)
[3] Tan Z., Rodriguez y Baena F., Dini D., Forte A. E., Sci Rep (2018)
[4] Dine A., Bentley E., Poulmarck L.A., Dini D., Forte A. E, Tan Z., HardwareX (2021)

ACKNOWLEDGEMENTS

A. E. Forte acknowledges that this project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 798244.

Keynote lecture

A seedcoat-inspired damage-tolerant architectured material

Chao Gao[1]

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ABSTRACT

Through millions of years of natural selection and convergent evolution, seedcoat (testa) in different seed plants has been developed as biological armor to protect inside embryos from various environmental threats such as bacterial infection, dehydration, freezing, and mechanical damage. The complex morphology and multifunction of these biological armors have received growing interest from scientists and engineers in many fields. Of particular interest are seedcoats of succulents and grasses, in which star-shaped epidermal cells articulate, forming a compact, tessellated exterior to protect the seed inside. We have employed an integrated analytical, computational and experimental methodology to quantify the mechanical efficiency of load transmission between building blocks, and demonstrated a seedcoat-inspired strategy to simultaneously improve stiffness, strength and toughness of architectured material.

<u>Keynote lecture</u>

In-situ monitoring for digital twins and accelerated qualification in additive manufacturing

Dr Paul A Hooper[1]

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ABSTRACT

Additive manufacturing (AM) processes build up components on a point-by-point, layer-by-layer basis. This gives engineers unprecedented levels of design freedom. However, with this approach comes defects. Process parameters, part geometry, scan strategy and material quality all influence the fusion of material on that same point-by-point basis. In-situ process monitoring tools can give insight into how these factors influence component quality and provide opportunities for improved process control. Inspection for quality control and certification can also be performed at the same time as the part is being built, giving a detailed picture of the material's initial condition, and reducing the need for costly post-build inspections. This talk will detail the development of a high-speed monitoring systems for laser powder bed fusion and discuss opportunities and challenges for in-situ monitoring of AM processes and its role in structural integrity assessments.

Keynote lecture

Geometry dependent mechanical properties of AM components

Seyed Mohammad Javad Razavi

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ABSTRACT

The knowledge and prediction of the overall mechanical performance of Additively Manufactured (AM) parts still encounter scrutiny and will depend on various factors such as the microstructure of printed material, surface condition, and statistics of the internal defects. These factors are thought to be dependent on the input geometry of the part. In the design of complex industrial and biomedical components, the presence of non-uniform section thickness and geometrical discontinuities such as notches are unavoidable. The geometry and material properties of AM parts are closely related in a way that every change in geometry of the part will change the underlying manufacturing strategy, which, in turn, affects the microstructure and consequently, the mechanical behaviour of material. Consequently, the AM parts typically have a gradient of different microstructural features, surface roughness, and internal defects. To the best of author's knowledge, the effect of geometry and size on the fatigue behaviour of EBM has yet to be studied. Hence, in this presentation, the preliminary results of our research on the build thickness and geometry effect on microstructural features, surface morphology and mechanical performance of EBM Ti-6Al-4V specimens under static and fatigue loading conditions will be presented and discussed.

Abstracts

Experimental assessment of printing parameter impact on eligibility of plain-strain facture toughness measurement

Isaak Trajkovic[1], Aleksa Milovanovic[1], Milos Milosevic[1], Snezana Kirin[1], Goran Mladenovic[2] , Aleksandar Sedmak[2], Liviu Marsavina[3]

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[2] Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade 11000, Serbia.

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ABSTRACT

In this paper the printing parameter impact on SENB (Single Edge Notched Bend) specimens used for plain-strain fracture toughness measurement will be shown. Main concern for the eligibility of plain-strain fracture toughness measurement is the direction of crack propagation during the performed test. As suggested in the standard ASTM D5045-14, SENB specimens are recommended for plain-strain fracture toughness tests on three-point bending test equipment. All prepared SENB specimens meet the plain-strain requirement for fracture toughness test i.e., thickness of the specimen is B=10mm, height is W=20mm and the length between the supports is 80mm. Notch is directly printed not milled, as suggested in the paper [1]. Pre-cracking of the specimen was performed by tapping on a blade to defined dimension. According to ASTM D5045-14 standard pre-crack must be at least twice the length of the notch width, which was done accordingly.

Main issue with the fracture toughness tests was the delocalization of the crack from the expected crack propagation path (Fig.1). In FDM (Fused Deposition Modeling) technology parts are fabricated with included outlines, which are printed on the edges of each performed layer. Our experimental finding shows that if the pre-crack is shorter than the thickness of outlines i.e., if pre-crack does not breach the printed outlines, the crack will initiate and propagate from the delamination site with the highest stress concentration state between outlines, from where the crack will find another part usually with an angulation from the predicted crack path. Hence, the crack may propagate even without the influence of the pre-crack. In our case, pre-crack is 2.5mm long and if three outlines are printed (which are approx. 3mm long) the delocalization of crack from predefined path is expected. In the next iteration number of outlines was shortened to only two (approx. 2mm long), with which the crack propagated along the expected path (Fig. 2).

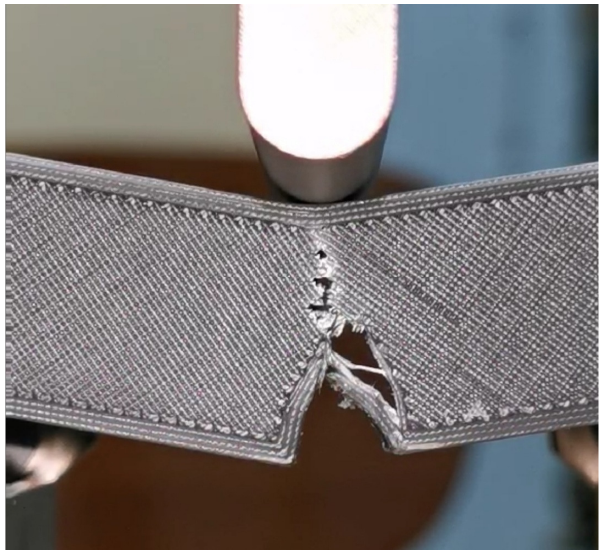

Fig. 1. SENB specimen with three outlines, shown during the fracture toughness test

Fig. 2. Batch of SENB specimens with two outlines

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ACKNOWLEDGEMENTS

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Multiaxial fatigue of additive manufactured Ti6Al4V specimens

Danilo Antonello Renzo[1], Emanuele Sgambitterra[1], Carmine Maletta[1], Franco Furgiuele[1], Carlo Alberto Biffi[2], Jacopo Fiocchi[2], Ausonio Tuissi[2]

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ABSTRACT

Making components with complex geometry and optimal mechanical response represents an ever-increasing engineering need in modern industry, that is encouraging the continuous development and widespread application of additive manufacturing (AM) technologies such as the Selective Laser Melting (SLM). However, the use of AM in high demanding engineering applications is currently hindered by the limited mechanical properties of AM parts. This is of major concern especially when dealing with multiaxial fatigue conditions, arising from service loads and/or complex geometries, mainly due to the precence of AM-induced microstructural defect. In fact, multiaxial stresses are responsible for complex crack initiation and propagation mechanism and multiaxial fatigue of AM parts represents a challenging research field.
In this work, multiaxial fatigue behavior of Ti6Al4V samples, made by SLM process, was analyzed. Fatigue tests were carried out under different fatigue loading conditions: i) tensile, ii) torsion, and iii) combined proportional axial-torsional loads. A modified damage model, based on the Sines' criterion [1,2], is proposed and it was used to analyze fatigue data. Full-field measurements, by Digital image correlation (DIC) and infrared thermography (IR), were simultaneously carried out to capture both local strain and temperature within the samples. Higher temperature increases were observed during combined axial-torsional loading due to the increased equivalent strain with respect to pure tensile and torsional loads, even under the same equivalent von Mises stress [3,4]. In fact, DIC results showed that the combined effect of the normal and shear stress, generated by axial-torsional loading, produces a higher level of equivalent mean strain with respect to the other loading conditions and evident irreversibility occurred during the loading history. Fatigue strength curves, in terms of both stress and strain amplitudes, were obtained and cyclic fatigue properties were analyzed. Fatigue results highlighted different failure modes among the three loading conditions as also demonstrated by the analysis of fracture surfaces carried out by Scanning Electron Microscopy (SEM).

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Energy Release as a parameter for fatigue design of AM metals

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ABSTRACT

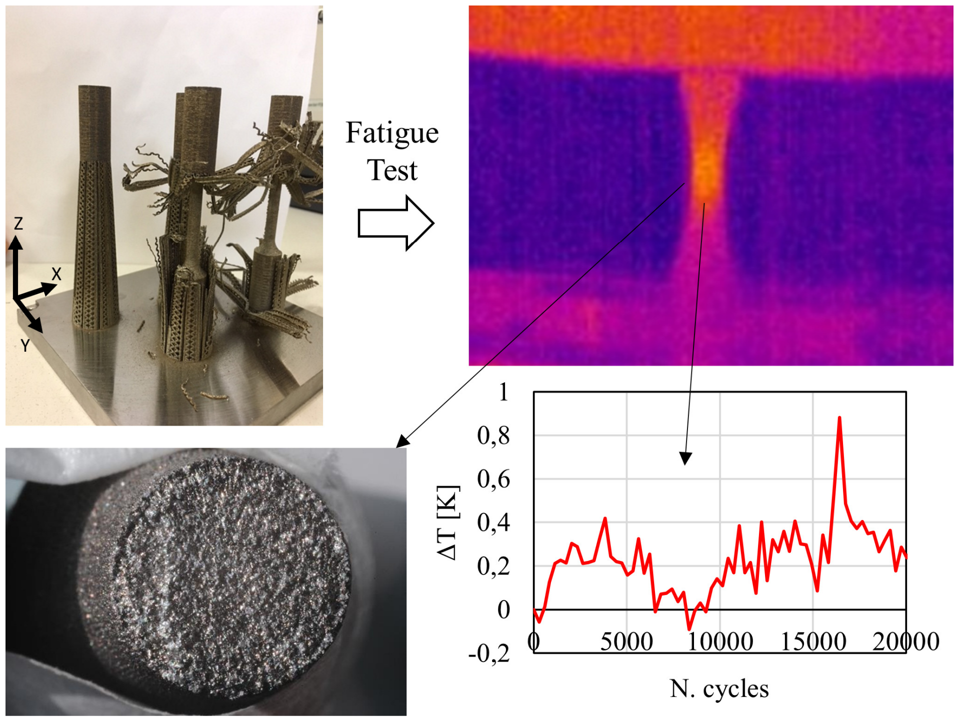
Additive manufacturing (AM) is spreading in a wide range of industrial fields. At first, it was adopted as a rapid prototyping technique but, in the recent years, the demand for real components has been increasing due to their low-weight and low material consumption compared to traditional manufacturing techniques. As the design opportunities increase, on the other hand, also the process parameters to consider when dealing with AM increase. Their influence on the mechanical performance is still an open issue among researchers.
It is of fundamental importance to guarantee mechanical reliability in such components, particularly when dealing with fatigue loads, which can lead to an unexpected failure.

Classical fatigue tests require a large amount of time and materials to be consumed, which is incompatible to a rapid time-to-market for real components. The uncertainty of the AM process parameters, in addition to long test time, may represent a serious economic investment for companies.

Within the traditional material fatigue assessment, the Thermographic Method (TM) [1,2] is able to derive in a very rapid and reliable way, the Wöhler curve and fatigue limit of the material monitoring its energetic release during a fatigue test [3]. This is possible adopting a very limited number of specimens and a rapid test procedure.
Recently, the superficial temperature during static tensile test on AM polymer has been monitored to derive information regarding the damage evolution within the material, applying the Static Thermographic Method (STM) [4].

In this work, for the first time, the TM is applied to specimens made of AISI316L, obtained by SLM technique and printed along Z direction. The specimens were tested at two different load frequencies, with a positive stress ratio of 0.1, while the superficial temperature was monitored by means of an infrared camera.

Compared to literature data for the same AM material, the specimens show premature failure, even at low stress levels, with very brittle fracture surfaces. The internal microstructure seems to be strictly related to the energetic release of the material.



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Effect of the microstructure on the fatigue damage in highly anisotropic stainless steel fabricated by selective laser melting

Miroslav Šmíd, Stanislav Fintová, Ivo Kuběna, Michal Jambor, Tomáš Vojtek, Pavel Pokorný

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ABSTRACT

The title presents the main topic of recent research project which is under investigation at Institute of Physics of Materials (Brno, Czech Republic). The workshop contribution briefly introduces the main topics which will be pursued. The focus on selective laser melting (SLM) processed materials is recently under a high attention of industry and academia since this technique is capable to produce components with very complex geometries but also with tailored microstructure. Moreover, a certain optimization of the SLM processing parameters bring an intriguing chance to produce the materials possessing directionally dependent mechanical properties. In combination with materials susceptible to the so-called transformation-induced plasticity and its undeniable dependency on crystallography (Figure 1), the project aims to produce structures possessing enhanced work-hardening capability depending on local loading requirements of a printed component. The fatigue behaviour, alongside with active deformation mechanisms and induced martensitic transformation, will be studied in detail by combination of experimental techniques.

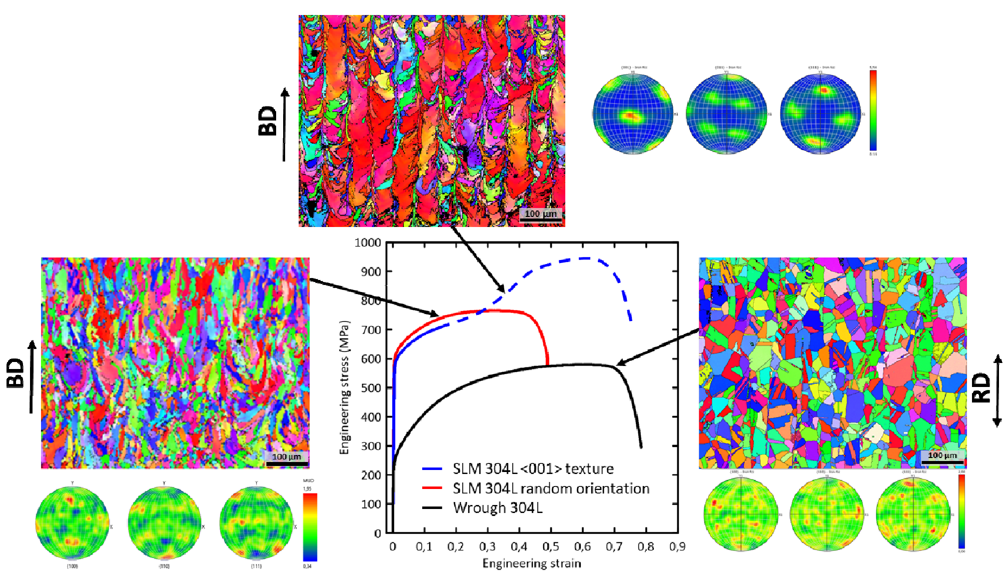

Figure 1. The effect of crystallography on mechanical response of SLM-processed metastable 304L austenitic steel.

Fatigue life prediction of SLMed parts using the Finite Cell Method

N. Korshunova[1], G. Alaimo[2*], M. Carraturo[2], A. Reali[2], E. Rank[3], S. Kollmannsberger[1], F. Auricchio[2]

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ABSTRACT

Lattice components manufactured by Selective Laser Melting (SLM) processes are increasingly employed for producing high performing lightweight parts to be used in several industrial applications such as aerospace, automotive and biomedical. However, the geometry at a submillimeter scale of the final lattice can exhibit not negligible differences with respect to the nominal design due to the high complexity of the multi-physical phenomena involved in the manufacturing process. Accordingly, the mechanical behavior of lattices structures, including the fatigue life, is strongly influenced by such manufacturing process-induced geometrical defects. On the other hand, numerical analyses represent an effective tool to estimate fatigue life. However, numerical analysis on the as-designed geometry might result in unacceptable result which are very different from experimental evidence. Therefore, in order to obtain sufficiently accurate numerical simulations, the as-build geometry, as acquired for instance by means of micro computed tomography (μ-CT), should be considered.
In this work, we present the results of numerical investigation directly performed on several as- manufactured lattice beam geometries. The aim of the work is the estimation of high cycle fatigue life in simple three points bending configuration. An immersed boundary method, namely the Finite Cell Method (FCM), is used to directly perform numerical analyses on μ-CT images.

Keywords: Additive manufacturing, selective laser melting, high cycle fatigue, finite cell method, micro-CT, stainless steel 316L

As-built surface quality and fatigue resistance of Inconel 718 obtained by additive manufacturing

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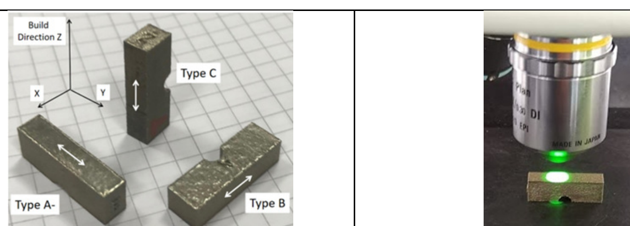
ABSTRACT

The realization of metal parts through additive manufacturing has proved very promising in many industrial sectors. Components with complex geometries can be easily produced using L-PBF (Laser-Powder Bed Fusion). The relationship between process parameters, material microstructure and mechanical properties has been extensively discussed [1]. It has been recognized that parts produced with surfaces in the "as-built" state, exhibit reduced fatigue properties. On the other hand, post-process surface finishing is expensive and often unfeasible due to the complexity of parts. Therefore, surface quality parameters must be considered when designing ab-built parts for structural applications.
This work presents the mechanical characteristics and as-built surface topography of Inconel 718 samples produced via L-PBF with three different systems (SLM280HL, EOSM290, RENISHAW AM250)and the respective fatigue behavior evaluated experimentally. The aim of the research is the identification of a link between th fatigue response of L-PBF IN718 alloy without post fabrication finishing and surface roughness parameters.



a) b)

Fig.1 - a) Miniature specimen denomination, orientation and applied stress direction; b) Flat specimen surface under investigation using Taylor Hobson CCI optical profiler

This study adopts a testing method based on the use of prismatic directional miniature specimens [2] of the prismatic shape shown in Fig. 1a. The specimens are tested under plane cyclic bending loading with a load ratio of R=0. This innovative test methodology drastically reduces material and production costs that typically characterize AM technology and materials that hinder extensive fatigue testing campaigns. The main areal roughness parameters of as-built surfaces are determined using Taylor Hobson CCI optical profiler, Fig.1b (Table 1). Here only Type C specimen orientation (i.e. vertical) in Fig. 1a is considered.

SLM280 – C	EOS290 - C	RENISHAW AM250 - C

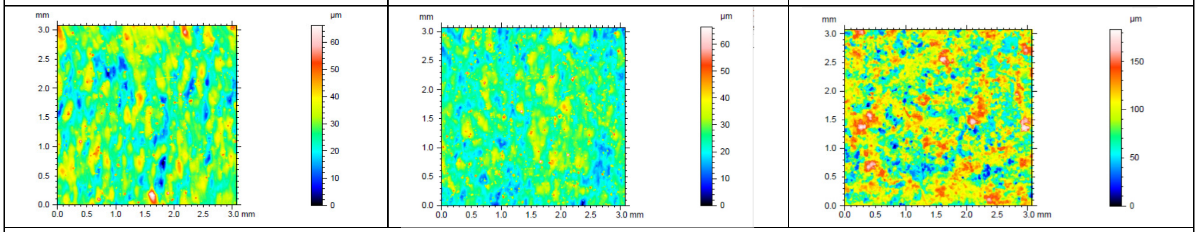


Fig. 2 - Surface Topography of C oriented as-built IN718 specimen

Table 1.- Miniature specimen areal roughness surface parameters (ISO 25718) and layer thickness

	Sa[μm]	Sq[μm]	Sv[μm]	Ssk	Sku	Layer thickness [μm]
SLM280 - C	5.22	6.82	27.8	0.338	4.30	50
EOS290 - C	4.52	5.9	25.7	0.695	5.14	40
RENISHAW AM250 - C	22.4	27.6	90.1	-0.104	2.67	30

The fatigue data for L-PBF IN718 specimen produced with the three different systems are plotted in Fig. 3. The results of the present Type C specimens are compared with the vertically built standard specimens tested by D. Wells [3]. Inspection of Fig. 3 reveals complex interplay between fatigue behavior and surface roughness that will be discussed in the contribution.

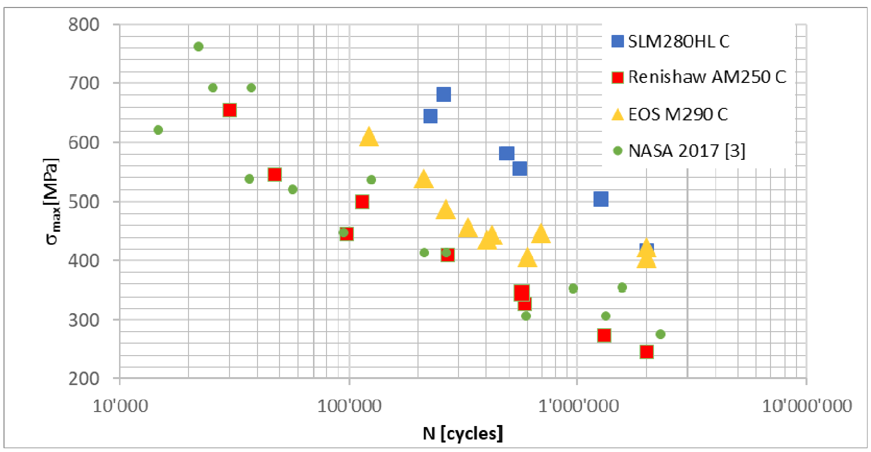


Fig. 3 - Fatigue behaviour of as-built IN718 produced with three different L-PBF systems

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Bending behaviour of 3D printed sandwich beams with different types of core geometry

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Sandwich composite structures are widely used in automotive, naval, sporting and aerospace applications due to their high stiffness/weight ratio, high strength/weight ratio, and energy absorption capacity. Lightweight-architected cores have been introduced as an advanced alternative to improve the overall performance of sandwich structures. In this study programmed sandwich structures containing 3D printed core materials with conventional honeycomb, chiral and re-entrant honeycomb topologies were used [1-3]. The sandwich beams were manufactured by fused deposition modelling (FDM) using the Ultimaker 3 Extended printer. The specimens were made from a polylactic acid polymer (PLA). The software used to create the 3D model was CATIA V5.

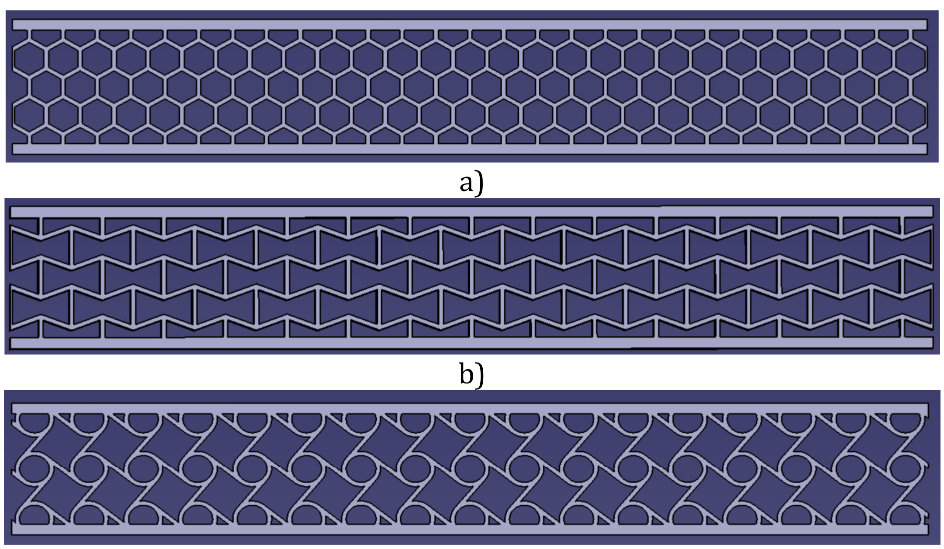

Fig. 1. Models of sandwich beams: a) honeycomb core, b) re-entrant honeycomb core, c) chiral core

Three-point bending tests were conducted on sandwich beams using a testing machine Instron 8872 following ASTM C393-00 [4] as to obtain the mechanical properties, including bending stiffness, strength, and energy absorption [5] of the sandwich beams for these three designed core materials. The quasi-static load was applied at a displacement velocity of 1 mm/min. The load was applied through a central roller of 10 mm diameter, the supports were two outer cylindrical rollers also having 10 mm diameter and the span length was 125 mm.

The relative density of the core material was 0.15 for the first three samples and 0.25 for the next three samples. The wall thickness was 0.5 mm, respectively 0.8 mm. Fig. 2. shows on the left side the load-deflection response of the sandwich beams and on the right side are shown the specimens deformed after three-point bending testing.

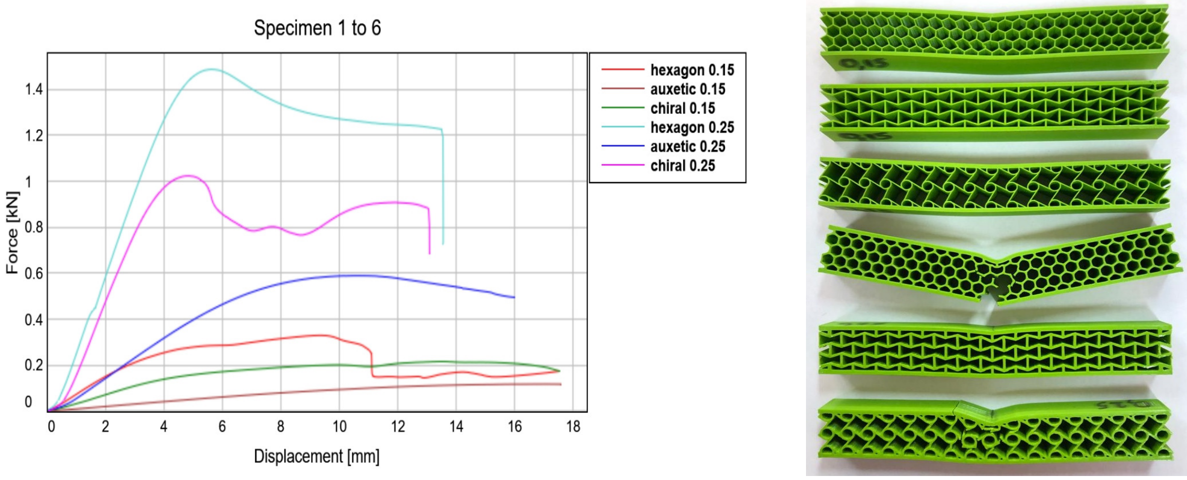

Fig. 2. Bending characteristic of sandwich beam specimens with different core structures

The maximum force of 1.49 kN was reached for the hexagonal core topology with a relative density of 0.25 and a wall thickness of 0.8 mm, giving a vertical displacement of 5.5 mm.

ACKNOWLEDGEMENTS

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Additive Manufacturing in Construction: a review on technologies, processes, materials and their applications of 3D and 4D printing

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ABSTRACT

Additive manufacturing (AM) is an advanced process of production that can produce complex shapes and geometries automatically through a 3D computer-aided design model without any tooling, dies and fixtures. Unlike subtractive manufacturing, as milling, which works with a subtraction process, addictive manufacturing creates the object adding material. The AM technologies have been used for years to build a physical prototype but are progressively coming into use for products ready to use in several fields, such as biomedical, aerospace, automotive, microelectronics (MEMS) and also fashion and design fields. This is possible because in these fields AM has significant benefits like the reduction of the build time, a less human intervention and minimal material waste[1][2]. AM is not always able to replace industrial mass production as the use of AM for mass production is not economically sustainable and advantageous; however, for fewer and customized quantities of products for final use or the combination of AM with conventional production, it is possible to have various advantages in terms of costs and benefits.

In the construction sector AM technology can offers advantages as permits the automation of the construction process reducing extra costs, building in-site and off-site, safety in construction workplaces, reduction of material waste with benefits for the environment and the possibility to design components or entire buildings with complex geometries and shapes combining also different materials during the construction process. Moreover, the AM can be developed as to produce structural and non-structural components functionally and topologically optimized, that would be otherwise too expensive with conventional techniques[1][3][4]. It is clear that AM can also be successfully applied to large-scale construction of components and structures, in fact research interest has increased exponentially in the past few years. However, there are still fundamental challenges to be faced and further studies, with interdisciplinary and transversal research, are necessary [3][4]. The most important challenges are: the transfer of AM technologies to large-scale construction[5], the need of new and diversified materials for AM technologies, the development of new constitutive models and computational processes, the implementation of AM in the design and construction process through new design and structural optimization techniques as well as new technology systems and innovative assembling method that the

construction field requires and that AM can satisfy[3][6]. In order to have AM accepted in the construction sector, it is necessary to study new job opportunities and new professional figures and to define specific technical regulations and standardized quality processes; the latter is fundamental importance.
This paper is a review of the state of art of AM in the construction fields; information collected was organized into:

- AM technologies: the processes and solutions of AM technologies will be described as well as their application into research projects and construction.
- Materials science: several materials (aggregate-based materials, metals, polymers, smart materials) will be illustrated by introducing the concept of 4D printing [7][8][9]. The 4D printing, an emerging field of AM, is the combining of AM technologies with programmable materials, like smart materials that have the capacity of changing and transforming their properties and shapes over in time depending on the external stimuli, like temperature variation, mechanical stress, magnetic and electric field, humidity and many other. Combining the advantages of AM with the properties of smart materials, it is possible to design dynamic and smart components and structures that can be used for myriad of applications.
- Design and manufacture: the advantages of AM to design and build components and buildings will be analysed and described, listing some completed projects[3][6].
- Markets relevant: these will be shown, comparing them with conventional markets to highlight the advantages and disadvantages[3][9].

Finally, the potential of AM to revolutionize the construction industry, the challenges and opportunities to face up and further research future will be described.
In conclusion, this study aims to offer a detailed overview of AM for the construction industry, trying to consolidate its use as a next generation production method, promoting its movement towards buildings, components and structures that are smart, functional, environmentally-friendly and easy to use.

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Printing and characterization of 3D high-loaded nanocomposites structures

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ABSTRACT

Additive Manufacturing (AM) technologies are spreading rapidly both in academic research and industrial environments [1]. Nanomaterials have proven to provide new size-dependent properties compared to traditional bulk materials [2]. The integration of nanotechnology into AM opens new and interesting challenges in manufacturing advanced nanocomposite materials with custom-made properties and geometries [3]. Synergy between nanomaterials, such as metal and oxide nanoparticles, and AM can in fact result in improved functional and structural performance of manufactured devices, filling the gap between design and production of a specific tool. For instance, silica nanoparticles (SiO_2 NPs) are increasingly used as nanofillers, thanks to their excellent mechanical properties, to fabricate nanocomposites used in a wide range of applications [4]. Stereolithography (SLA) represents one of the most widespread AM technologies used to fabricate 3D engineered structures. The general procedure for building objects with SLA involves photo-polymerization of liquid monomer into solid resin by means of an ultraviolet (UV) laser, which creates targeted cross-linked regions where the light irradiates the matrix [5]. SLA AM of nanocomposites usually involves mixing of *ex situ* synthesized nanoparticles with commercially available acrylic monomers, followed by an optimized printing process. Stable dispersion of colloidal SiO_2 NPs in acrylate monomers or oligomers are commercially available, such as Nanocryl product family commercialized by Evonik. These products are traditionally used in adhesive and electronic applications, such as highly scratch-resistant coatings for fiber optic cables, conformal coatings, UV curing adhesives for printed circuit boards and can be successfully employed in AM of high-loaded nanocomposites. The produced 3D-printed specimens were employed to characterize the nanocomposites microstructure and thermo-mechanical properties respectively by means of scanning electron microscopy (SEM) and dynamic-mechanical analyses (DMA).

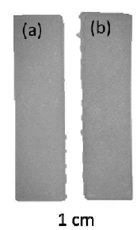

Figure 1. Photographs of printed samples: (a) filled and (b) unfilled resin.

Printable acrylate-based nanocomposites containing 45% of SiO_2 NPs were obtained by photo-curable hybrid formulation, based on a mixture of Evonik Nanocryl A215 (TPGDA - Tri Propylene Glycol Di Acrylate and SiO_2 NPs) 90 %, MAT3D 3DGlass (photocurable acrylic resin) 10 % and BASF Irgacure 819 (photo-initiator for SLA process) 2 phr.
Printed nanocomposites were compared with unfilled samples, consisting only of acrylate matrix (Allnex TPGDA – 90 %, MAT3D 3DGlass – 10 %, BASF Irgacure 819 – 2 phr) (Fig.1).

Printed samples microstructure was investigated by SEM analysis (Fig. 2). Compared to the reference unfilled sample, the presence of nanoparticles can be observed within the printed polymer matrix. Nanoparticles have approximately spherical shape and are well dispersed in the matrix with no significant aggregation after printing. The observed nanoparticles have diameters ranging between 10 and 50 nm and can be ascribed to the presence of silicon dioxide in the considered system, as confirmed by EDS spectra (Fig. 2(a)).

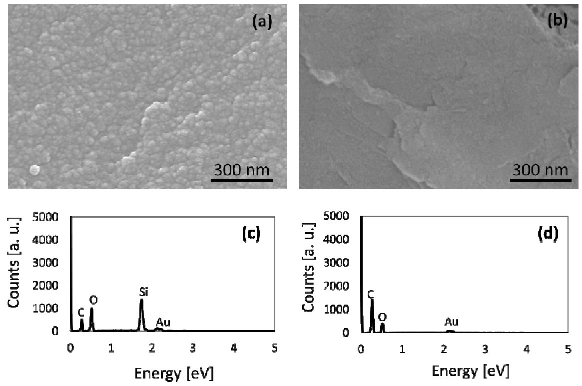

Figure 2. SEM micrographs and EDS spectra respectively of filled (a, c) and unfilled (b, d) resin.

DMA analysis was carried out on all printed specimens, giving information on the thermal and viscoelastic properties of the materials in a large temperature range. Storage modulus (E′) and damping factor (tan δ) curves, as a function of temperature, are shown in Fig. 3. From the DMA curves, a shift of about 15°C toward higher temperature of tan δ peak, associated to the glass transition temperature (T_g), was observed (Fig. 3b): T_g is detected respectively at 62 and 87°C for pristine and filled samples. The higher storage modulus of nanocomposite filled sample was evident in the whole analysed thermal domain and in particular beyond the T_g, expanding effectively the applicability range of nanocomposite (Fig. 3(a)). This behaviour can be attributed to the impediment, induced by the SiO_2 NPs in the polymer network, to the segmental motion of the polymeric chains . The increase in segmental motions constrains in the polymeric chains is mainly due to the uniform distribution of the silica nanoparticles which was also evidenced by SEM analysis.

This study shows the possibility to obtain SLA printed nanocomposite objects using the laser radiation of a commercial stereolithography printer to cure a hybrid formulation based on acrylic monomer and SiO_2 NPs. After the printing process, SiO_2 NPs are well dispersed and homogeneously distributed in the crosslinked matrix as evidenced by SEM analysis. The presence of the filler causes an increase in the physical and mechanical properties of the samples that become significantly stiffer and stronger than the pristine matrix. Thermo-mechanical tests provided promising results for the use of the developed formulation in the building of 3D polymeric structures with improved multistructural properties, providing further rapid prototyping option to research and development of new products.

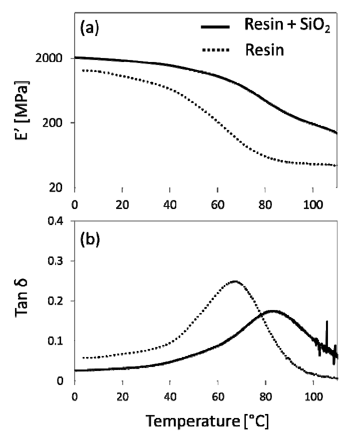

Figure 3. Storage modulus (a) and damping factor (b) curves of both filled and unfilled resin.

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Curved layer fused deposition modelling method

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ABSTRACT
Curved Layer Fused Deposition Modelling (CLFDM) is a novel additive manufacturing method that can fabricate complex geometrical configurations by directly generating curved extruding toolpath based on geometry. CLFDM technique has recently received much interest from scientists and engineers owing to not only its great potential to overcome several manufacturing limitations of traditional planar FDM such as "stair-case" effect and poor bonding strength of curved surfaces or shells, but also enhanced mechanical properties of CLFDM printed parts. However, the question that how to accurately evaluate the mechanical behaviors of CLFDM printed parts numerically and experimentally has still remained. This presentation will include an overview of the CLFDM process, research progress of evaluation methods on the mechanical properties of CLFDM printed parts, and challenges. Specifically, we will focus on finite element analysis[1] and mechanical testing on the mechanical behavior of CLFDM printed parts[2-8].

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Post-processing technologies of copper - PLA composites obtained by 3D printing FDM method

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ABSTRACT

Recently, Additive Manufacturing (AM) technology has presented a period of great progress and development, as it has been applied for several applications, including automotive, aerospace or medical components [1-3]. The main advantage of AM, compared to conventional manufacturing technologies, is the possibility to fabricate parts with very complex shapes, that can be individually tailored [2-5]. Over the last decade, 3D printers have become more accessible, versatile and cost effective, even for personal use. More and more materials are available and suitable for these technologies, starting from polymers, to metals, ceramics, or even composites [5-7]. As this technology has recently entered the market, in order to establish the optimum printing parameters, the majority of materials still require proper characterization and testing. The parameters variation decisively influences as well the physical, mechanical or chemical properties of the end product.[1, 8, 9].
The main goal of the present study is to obtain a new structured material starting from copper - PLA composite 3D printed using Fused Deposition Modelling (FDM) method, followed by a sintering process in vacuum atmosphere. Metal reinforced PLA filaments are commercially available filaments made of copper powder (80%) encased in a binder of environmentally friendly, biodegradable and carbon neutral PLA polymer. An Ultimaker 5S 3D printer has been utilized to print the specimens.
Initially, a thermal analysis (TGA and DTA) was carried out using an STA 449 F1 Jupiter® instrument from Netzsch (Germany), to determine the thermal stability of the metal reinforced PLA filaments. Prior to the TGA measurements, the filaments were dried in an oven, at 60°C for 5 hours, in order to remove the absorbed humidity of the PLA material. SolidWorks 2016 was used as a CAD software to design the specimens. The printing temperatures were chosen in agreement with the producer's specifications, taking into account also the information obtained from the thermal analysis performed on the PLA composite filaments. The fill density was chosen at 100%, which resulted in a rectilinear fill pattern and at a fill angle of 60º. The layer printing speed was set at 60 $mm \cdot s^{-1}$. The nozzle temperature used during the printing process was 215 ºC while the one of the printing bed was set to 60 ºC. The geometry of the printed specimens is presented in Figure 1. In order to reveal the structure, the printed samples were analysed using the optical microscope, Olympus BX51M (Japan). The micrographs presented in Figure 2 reveal the structure of the 3D printed specimens, composed of copper as the main component (seen as light grey areas) and PLA polymer as dark spots, uniformly distributed in the metallic matrix.

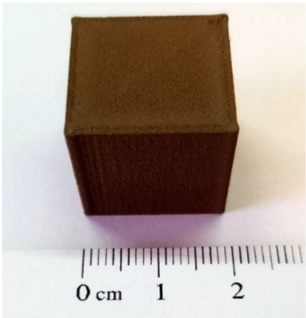

Figure 2. Copper reinforced PLA 3D printed square

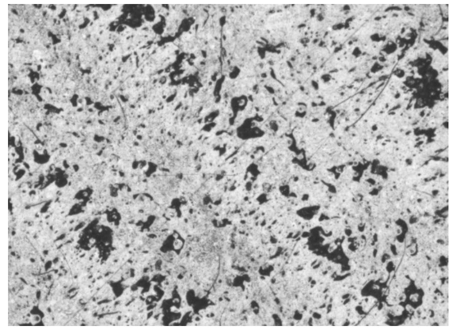

Figure 1. Optical microscopy of the 3D printed PLA-copper composite

The hardness of the printed samples was investigated using Vickers and Brinell testing methods, with the aid of a ZwickRoell (Germany) equipment. After the printing process, the PLA - copper printed composite specimen was submitted to a heat treatment in a vacuum furnace in order to remove the organic component (PLA). As the PLA decomposes at around 300°C, higher temperatures are required in order to completely remove the polymeric material. The post treatment was performed in two steps, consisting of an isothermal drying process at 205 °C for 30 min ($10°\cdot min^{-1}$ heating rate), followed by an isothermal holding at 983°C for 1 hour ($10°\cdot min^{-1}$ heating rate). The second hold at 983°C assures the diffusion between the copper particles after the remove of PLA, creating a strength bounding in the metallic matrix. The cooling was performed at high rate in normal atmosphere. After the thermal treatment, a material with a porous structure was obtained, similar to a specific class of materials called cellular materials. The morphology was further analysed using optical microscopy and the porosity of the sintered PLA + copper material was found to be around 20%.

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EBM process for lattice structure manufacturing: bending test results

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INTRODUCTION

Lattice structures are characterized by high specific mechanical peculiarities. This is due to their lightness, given by the optimal distribution of the material in the space [1]. In fact, lattice structures are constituted by strut elements topologically ordered to form a cellular grid [2]. Some traditional manufacturing processes can be used for the production of lattice structures; however, new potentialities are offered by additive manufacturing technologies [3].
In the literature, some features of lattice structures were investigated. Cansizoglu et al. [4] studied the effect of lattice geometry on mechanical characteristics, Cao et al. [5] introduced a methodology for designing rhombic dodecahedron lattice structures, and Leary et al. [6] evaluated the technological limits in the production of strut elements.
In this work, the potentialities of the EBM (Electron Beam Melting) process for lattice structure manufacturing are explored by determining the flexural characteristics of specially produced lattice specimens. Three-point bending tests were performed adopting various distances between supports for separating the effects due to normal stress from those of the shear stress. The work is enriched by an SEM analysis performed on the broken specimens, in order to recognize the failure mechanism caused by the bending load.

MATERIALS AND METHODS

The octet-truss cell characterised the lattice structures studied in the present work. This cell is formed by a 12-strut octaedron surrounded by a 12-strut face-centered cube. The strut diameter was equal to 1 mm, while the cell side to 6 mm. The upper and lower surfaces of the specimens were covered by skins, whose thickness was equal to 0.6 mm. The section of the structures was 30 mm wide and 9 mm deep, while different values were considered for the length: 70 mm, 165 mm, and 270 mm. The studied structures were made of Ti6Al4V titanium alloy and they were produced through the EBM process. Flexural tests were carried out at different span lengths (45 mm, 120 mm, and 200 mm) and a rate of 5 mm/min.

RESULTS

The load-displacement trend obtained for the tested specimens is reported in Fig. 1. The highest load was obtained for the shortest specimen, while the highest displacement for the longest one. The shortest specimen presented a linear load increment followed by a first load drop, another load increase and a second load drop, while in the other specimens the linear increment was followed by a knee, with a decreasing load rate, that ended with the load drop. Adopting different span lengths allowed the calculation of both the bending stiffness and the shear rigidity of the studied structures, that were equal to 7.04E7 N*mm^2 and 1.47E5 N, respectively. SEM analysis evidenced a ductile fracture behaviour of the tested specimen.

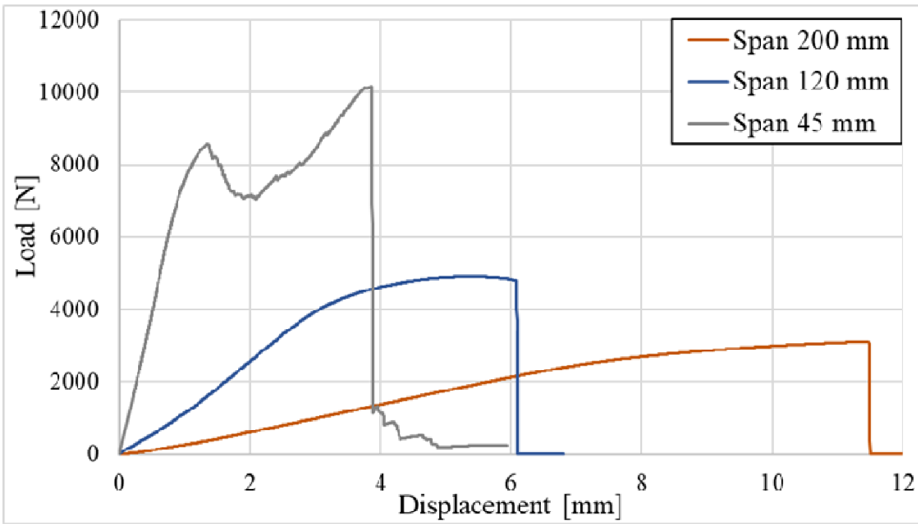

Fig. 1: load-displacement trends from three-point bending test

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Design and optimisation of 3D fast printed cellular structures

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ABSTRACT CONTENT

This work describes the activity of collaboration between the University of Parma, Department of Engineering and Architecture, and the High Speed 3D Printing Research Center of the National Taiwan University of Science and Technology in Taipei (Taiwan). Several typologies of 3D printed cellular structures are designed with inspiration to the natural world, and printed cells are studied in morphology and mechanical performances, in particular effective density, compressive stiffness, and energy absorption under cyclic loading. Interpretation of experimental testing of printed structures is tried with the support of advanced numerical models. Advantages and limitation of the technique are here shown and discussed.

In this brief contribution, three self-supporting lattice structures consististing of repetition of unitary cells are introduced, namely open (structure A), closed thin-walled (structure B) and closed thick-walled cells (structure C), Figure 1. The reticular structures are additively printed using FDM process with TPU filament, and measure sides of 8 mm and thicknesses from 0.8 to 1.2 mm [4]. The structures are designed with a honeycomb criterion, and as all the cellular lattice structures offer advantages in terms of light weight, high resistance to large stresses with great energy absorption [1]. Performances of the structures are experimentally determined by the application of repeated compression cycles with different levels of deformation, respectively 10, 20 and 30% of the specimen height, at the same strain rate. Figure 2 shows some instants of the testing. The stiffness and energy absorption, both percentage and per volume unit, are derived: energy absorption is calculated as the integral of the nominal stress-strain curve, the loss area for the stabilized cycle is evaluated after the application of 20 cyclic loadings and stiffness of the specimen is calculated as the slope of the best fit loading curve. In parallel, a series of FE models are developed within the commercial code ABAQUS© in order to characterize and optimize the 3D printed closed cell structures. The analysis is made starting from a single cell virtually "extracted" from the structure, Figure 1. In this way, given proper boundary conditions to the cell, the mechanical properties, or the study of the deformation behaviour, can be easily and quickly addressed, or several geometrical solutions compared with no need to print and test them all in laboratory. A proper FE model is defined

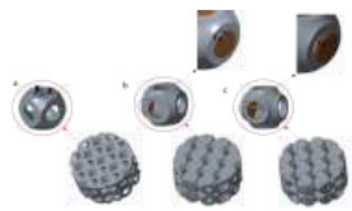

Figure 1 - Lattice structures: a) open, b) closed thin-walled, c) closed thick-walled

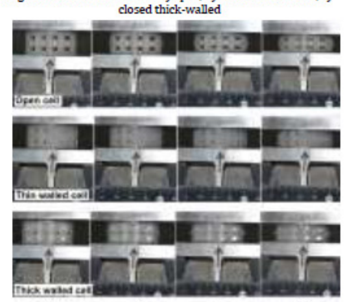

Figure 2 - Experimental tests

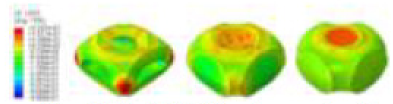

Figure 3 - Unit cells 30% deformed: compressive strains

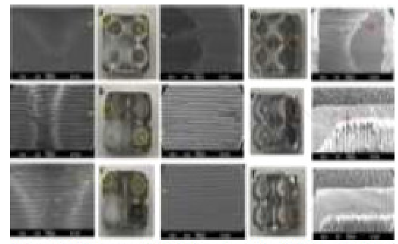

Figure 4 - SEM images of the TPU layer deposition in both longitudinal and transversal direction

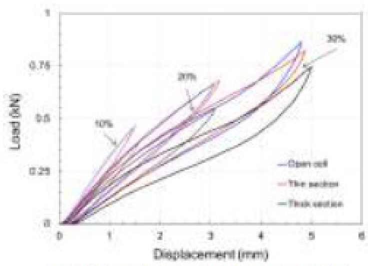

Figure 5 - Experimental load-displacement curves

regarding the TPU filament, which behaves as a viscoelastic, hyperelastic material. Also, FDM produces a non-isotropic, layered material structure that is, in most cases, up to twice weaker along the tangential direction than the transversal (Figure 4)[3]. These material properties are incorporated into the FE software through an advanced material model with hyper-elastic and hysteretic capabilities. By the experimental tests, it can be observed that the 30% of compression causes a very large deformation of the lattice structures with barrelling and principle of densification of specimens. As a result, the stiffness always decreases at the deformation increases, both for experimental and numerical tests (Figure 5). Instead, predicted values by the FE analysis are in agreement for the structure A, whilst over-estimate the stiffness of the B and C structures, especially when thick-walled. A and B behave very similarly in term of stiffness and energy absorption, even if with a discrete gap at lower strain levels, while C structure always shows lower performance by about 20%[5]. In this, several factors and their combinations play an important role, including the applied boundary conditions that probably over constrict the transversal dilatation of adjacent cells, the limited strain range of the hysteretic material model which is not sensitive to the other parameters, e.g. the temperature, and the homogenization of the response of a single unit cell, that can drastically limit the deformation. Furthermore, the samples obtained from the FDM process are typically non-uniform at different observation levels and, in general, it is found that numerous process parameters can influence the final mechanical properties of the meld polymer, (presence of pores, building orientation, temperature). In particular, the reticular structures obtained through the FDM process have already proved to be very sensitive also to the combinations of numerous process parameters used in the 3D printing phase[2]. It can be concluded that the combination of all these process parameters, but also material and external conditions, have a great influence on the mechanical properties of the final product. This must be taken into consideration in the design phase, since the results obtained analytically must be suitably analysed in relation to the combined effect of all the possible influencing and acting conditions on the printed part.

Regarding the advantages, the study shows that FE analysis can be an effective virtual design tool for studying the behaviour of different lattice structures and for identifying and optimizing their performance, before of running experimental tests.

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The use of the impression guide in the classical impression techniques

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OBJECTIVE

The purpose of this study is to analyze the dimensional stability of final impressions made with different impression materials. The novelty of the study is the creation of a printed impression guide. It was designed to help the dentist by verifying the parallelism between the abutments and highlighting the finish line of the preparation by using the pressure it exerts on the free gum. It also adds additional dimensional stability to the impression material.

MATERIALS AND METHOD

The design of this device is similar to the metal skeleton of a fixed metal-ceramic prosthetic restoration, having a cylindrical-conical shape, while respecting the shape of the dental abutment preparation, as well as the completion of the cervical preparation.
For this study were required 3 types of impression materials: alginate, silicone with condensation reaction (with two consistencies: light and putty) and polyether.
Two study models were chosen that presented third-class edentation and prepared abutments, with a chamfer finish line. The model was scanned and the dental technician designed the impression guides for the 2 models. The impressions were then made for each material and analyzed using a digital caliper.

RESULTS

Significant improves were observed in the probes using the dental impression guide.

CONCLUSIONS

The classical impression materials need improvements in the dimensional stability but their accuracy increases with the dental impression guide.

A designed six-in-lobed shaft of AlSi10Mg additively manufactured: the torque capacity assessment by linear and nonlinear buckling

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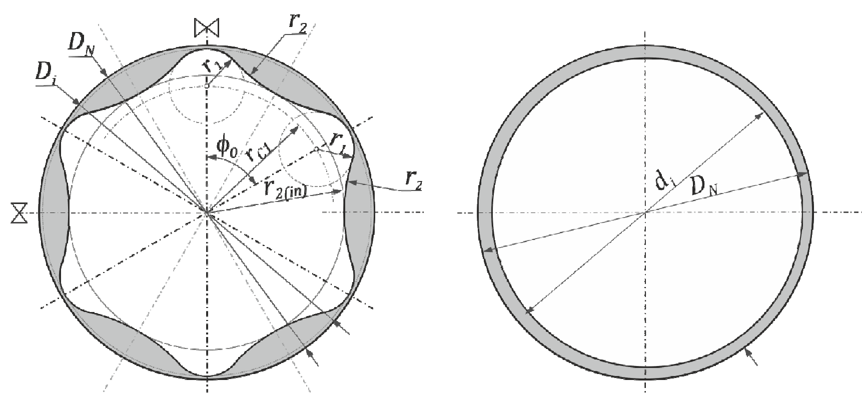
INTRODUCTION

With the advent of additive manufacturing techniques in line with the advanced CAD/CAE software as Simcenter 3D, the use of lobed shafts within the assembly of power transmission systems is expected to widely extend soon, from automotive and aerospace applications toward a variety of other industrial fields.



a) **b)**

Figure 1

Although it seems likely that the topic has been addressed previously, it does not appear to be studied enough so far. Indeed the three-lobe (P3G) and four-lobe (P4G) polygonal outer profiles, standardized by DIN, are commonly used for some practical applications [1], [2]. Further evidence comes from the paper [3], which compares the load-carrying capacity of such standardized three and four-lobed shafts for constant grinding diameter. However, there are no references made to inner lobed shafts either from the manufacturing point of view or from the perspective of their structural integrity assessment. Torsion is the main loading that these shafts carry, and most of the analytical methods available at present do not cover the wide range of possible AM geometries, here in terms of six-in-lobed cross-section shape.

This paper aims to investigate the torsional buckling capacity of a designed six inner lobed shaft with a cross-section profile schematically illustrated in Figure 1-a, which is supposed to be manufactured by direct laser sintering (DMLS) from AlSi10Mg. A parametric study was conducted to determine the adequate lobe size for a fixed outer diameter by varying the lobe radius. As shown in Figure 2-b, a reference annular shaft model made from the associated wrought material (i.e., Al6061) is considered for comparison purposes. 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]. In their study, the elastic moduli were measured in bending, and stress-strain characteristics were measured by a tensile test under the deformation control.
The commercial software Simcenter 3D, was used in this study to perform the nonlinear buckling calculations. The elastoplastic material properties and large deflections are considered in the analyses through the Multi-Step Nonlinear Solution 401. Before running the nonlinear solution, the real eigenvalues and linear buckling modes were extracted with solutions 103 (Real Eigenvalues) and 105 (linear buckling). Shell elements were utilized for all the calculation models in this study. Pure torsion is applied at one end of the shaft in question through the MPC elements, while a fixed boundary condition is considered to the opposite end.

RESEARCH OUTCOMES

The conclusion drawn from this parametric FE study can be useful for the design engineers because the effects of different geometric ratios on buckling capacity of six-in-lobed shaft 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 in-lobed 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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Residual Stress simulation in additive manufacturing: A Data-Driven Framework

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ABSTRACT

Additive manufacturing (AM), or 3D printing, has been transiting from demonstrative prototypes to functional products that are impacting a wide variety of sectors, from biomedical, electronic, and automotive to aerospace industries. However, the high thermal gradients, non-negligible part distortions, and residual stresses could adversely affect the structural integrity of additively manufactured functional component. One of the most popular AM techniques—fused filament fabrication (FFF), or material extrusion of polymers—offers the advantages of inexpensive cost, wide availability of feedstock materials, and production of lightweight components. This study focuses on the prediction of residual stress fields during FFF process using data-driven techniques. Physics-based simulations of finite element method (FEM) provide high-fidelity predictions but can be computationally expensive and time consuming. On the other hand, data-driven approaches have the promise to rapidly predict reliable results for real-time application scenarios. The residual stress field history data, created through heating and cooling additive manufacturing fabrication cycles, were collected using commercial FEM software ABAQUS. They provide training and validations for the data-driven framework.

A real-time data-driven simulation framework of additive manufacturing residual stress was proposed. The data-driven framework integrates three algorithms: (1) self-organizing map (SOM) to project the data into a few major variability dimensions for the residual stress field (2) Vector Autoregression Moving-Average with Exogenous Regressors (VARMAX) to model the dynamic relationship between the predecessor residual stress elements principal components, and subsequent residual stress elements principal components with respect to the change within FFF process parameters. (3) genetic programming (GP) as neural networks engine to facilitate the optimal configuration for the VARMAX models architecture. This procedure allowed us to perform a real-time turnaround for optimization and controls of AM process.

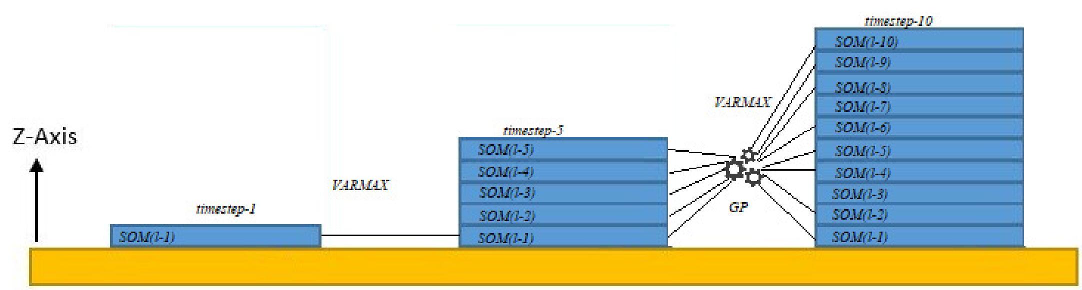

Figure 1 (data-driven simulation framework)

The numerical experiments and data-driven simulation model are based on the calculation of the time-dependent change in nozzle temperature and residual stress field. The data-driven predictions of residual stress field were validated with finite element simulation. After that, the impact of temperature on the simulation outcomes was investigated through parametric studies.

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A Review on Machine Learning Applications in Additive Manufacturing

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ABSTRACT

Additive manufacturing (AM), also known as three-dimensional printing, is gaining increasing attention from researchers and industry due to the unique advantages it has in comparison with traditional subtractive manufacturing. Additive Manufacturing (AM) is an advancing and increasingly popular manufacturing technology that embodies the revolutionary progress of the modern manufacturing industry. It is a process in which a part is made by joining material, layer by layer, directly from 3D model data. Additive manufacturing offers competitive advantage over traditional manufacturing techniques by enabling fabrication of low volume, customized products with complex geometries and material properties, in a cost-effective and time-efficient way.
Machine learning (ML) has been applied in various aspects of Additive manufacturing to improve the whole design and manufacturing workflow especially in the era of industry 4.0. In this review article, various types of Machine learning techniques are first introduced. It is then followed by the discussion on their use in various aspects of AM such as design for 3D printing, material tuning, process optimization, in situ monitoring, cloud service, and cyber security. Potential applications in the biomedical, tissue engineering and building and construction will be highlighted. The challenges faced by Machine learning in Additive manufacturing such as computational cost, standards for qualification and data acquisition techniques discussed. In this study it is observed that, in situ monitoring of AM processes will significantly benefit from the object detection ability of Machine learning. As a large data set is crucial for ML, data sharing of AM would enable faster adoption of ML in AM. Standards for the shared data are needed to facilitate easy sharing of data. The use of ML in AM will become more mature and widely adopted as better data acquisition techniques and more powerful computer chips for ML are developed.
In this paper we review research related to Machine learning applications throughout the AM lifecycle. Findings have been gathered from an extensive literature review published over the last thirteen years using keyword queries such as “additive manufacturing” and its subcategories, coupled with the concepts of “Machine learning”. We analysed over 20 papers, including journal articles and conference papers. The aims of this review are to 1) identify where ML techniques have been successfully applied in the AM lifecycle, and 2) summarize and organize findings from the existing state-of-the-art research in this domain so that new opportunities can be identified.

Keyword: additive manufacturing, machine learning, Industry 4.0

Photopolymerized AM materials: modelling of the printing process, mechanical behavior and sensitivity analysis

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ABSTRACT

The physical-chemical process of photopolymerization has been recently exploited in new technologies of making objects used in Additive Manufacturing (AM). Among them, it is worth mentioning the Stereolithography (SLA), the first technology ideated, and all the successive developed technologies such as the Digital Light Processing (DLP), the Projection Micro-Stereolithography, and the Microstereolithograpy, all of them based on the same principle. The photopolymerization process allows getting polymeric components characterized by intricate geometries and even with micro-size dimensions, a result almost impossible to be achieved with standard technologies.

Photopolymerization enables to produce elements used in medicine, bio-engineering, soft-robotics, automotive, aerospace, nanotechnology, functional materials etc. [1], with a minimum level of unused material.

Photopolymerization is a chemical-physical process that can be precisely controlled through a specific setup of the AM technology being used, leading to specific properties of the final material of the AM obtained element.

Often, the influence of the AM process parameters on the mechanical properties of manufactured components has been investigated by means of empirical methods based on the trial and error approach, operating by collecting a large amount of experimental data. However, when physical material properties fulfilling some quantitative prescriptions are required, an accurate modelling of the physical-chemical transformation taking place is necessary [1]; recently published works operating in this direction have been published [2]-[3].

Photopolymerization is based on the physical-chemical network cross-linking formation taking place at the molecular scale. In this process, the starting raw material (a liquid monomer resin doped with a certain amount of photoinitiator molecules) is irradiated by a laser source which progressively induces the network of polymer chains to form and grow, leading to a solid polymer (Fig. 1a).

In this work, an overview of the developed multi-physics model and its computational implementation in a FE framework are presented. In particular, the role played on the curing process and on the final mechanical properties by the laser light intensity and by its moving speed are considered. The influence of the uncertainty of the process parameters is also investigated through a simplified sensitivity analysis. Sensitivity analysis is an important statistical tool for the evaluation of the different responses of an engineering system arising because of little variations of the input.

In this work, the engineering system being studied is represented by a vat of liquid monomer resin which is photopolymerized getting a simple structural element (a single-layer rectangular beam), and whose mechanical response is carefully analyzed.

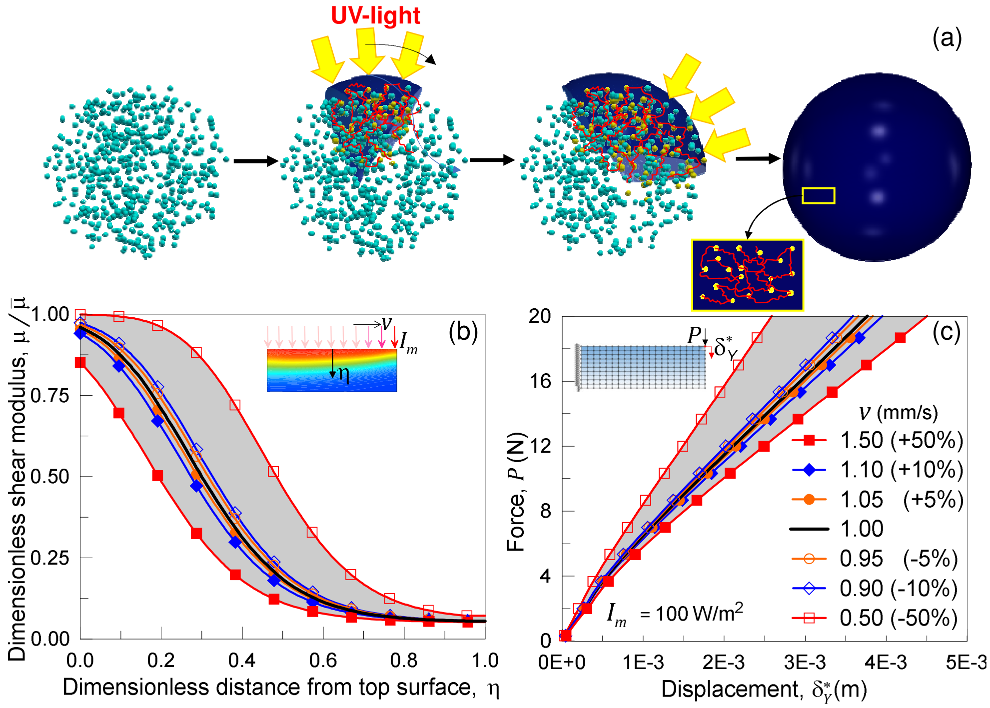

Figure 1. *Schematic view of photopolymerization process (a). Sensitivity analysis to quantify the effect of the laser speed on the shear modulus of the photopolymerized component (b) and on its mechanical response (c).*

We performed some sensitivity analyses in order to quantify the effects of uncertainties of the speed and peak light intensity of the laser beam on the mechanical properties of the final printed component (Fig. 1b) and of its mechanical behavior (Fig. 1c). For the sake of clarity, it is worth mentioning that, usually, speed and peak light intensity are deterministic quantities; however, the investigation approach based on a progressive and controlled tuning of the input quantities we consider, allows understanding the link between AM process parameters and mechanics of final components, a key aspect in the realm of AM technologies. Moreover, the adopted approach is useful for AM optimization as well as for predicting the effect of alterations of input parameters induced by external sources or environmental phenomena.

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Numerical simulation of selective laser sintering of polyamide 12

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The selective laser sintering process is one of the seven technologies of 3D printing or the manufacturing additive combines the manufacturing processes of parts in volume by adding or agglomerating material, by stacking successive layers. 3D printing makes it possible to produce a real object: a designer draws the 3D object using a computer-aided design tool; The selective laser sintering process is a rapid prototyping technique by selective laser sintering without liquid phase. It is used to create 3D objects, layer by layer, from polyamide 12 powders which are sintered or fused together with the energy of a high-power laser, such as a CO_2 laser. this process requires a numerical simulation and a mathematical modeling to understand all the thermal phenomena which interact in the bed of polyamide 12 powder, this work present a numerical thermal simulation of the bed of polyamide 12 powder by the software COMSOL to calculate a maximum temperature in the center of the spot laser of the polyamide 12.

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From μ-CT images to mechanical properties using the Finite Cell Method

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ABSTRACT

Lattice structures produced by means of Selective Laser Melting (SLM) technology have gathered an increasing attention due to their unique mechanical and thermal properties which make these kind of structures particularly attractive for aerospace and biomedical applications. Even if SLM allows to produce components with complex geometrical features, cellular lattices structures often push this technology towards its limit. Therefore, non-destructive post-production tests are desirable to assess the actual mechanical properties of the manufactured parts. In particular, fatigue life estimation is a critical issue when we consider lattice components.
Numerical simulations can provide an effective, non-disruptive tool to estimate fatigue life. Yet, numerical characterization of SLM lattices is not straightforward since the original as-designed geometry is substantially different from the actual, as-build geometry produced by means of SLM. Accordingly numerical analysis computed on the as-designed geometry might deliver results very different from experimental measurements. Thus, in order to obtain reliable numerical simulations we have to be consider the as-build geometry as acquired for instance by means of micro computed tomography (μ-CT).
In this talk, we present an immersed boundary method, namely the Finite Cell Method (FCM), suitable to directly compute on μ-CT images. The key concepts beneath FCM and a description of an efficient implementation of the proposed method will be addressed.

Keywords: Additive manufacturing, selective laser melting, high cycle fatigue, finite cell method, micro-CT, stainless steel 316L

Models for process simulation of additively manufactured polymers based on SLS technique

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ABSTRACT

Since its invention in the early 80s, additive manufacturing (AM) has revolutionised the concept and the process of objects production. Differently from the classical techniques based on material subtraction, AM allows to produce components depositing the material layer by layer. Concerning polymeric materials, powder bed fusion is one of the most versatile AM techniques. Specifically, Selective Laser Sintering (SLS) employs a high-power laser which selectively hits the surface of a thin layer of powder following the path prescribed by the section geometry. During the process, the polymeric material is kept near its melting temperature, so that the laser provides only the amount of energy needed for fusion and sintering of the particles. Once the process is finished, the whole system is cooled down under controlled conditions, trying to keep a uniform temperature to avoid residual internal stresses. Finally, the piece is extracted and dusted, while the rest of the material can be used for another printing [1].

Despite the widening of materials available for sintering and the high potential for practical applications, the diffusion of this technology is still limited with respect to other techniques, mainly due to the difficulties in controlling the complete transformation of the material and the final mechanical properties of the products [2]. Nowadays, industrial fields require 3D-printed objects to meet performance and reliability standards comparable to those achieved with traditional manufacturing. Despite incredible progress, ultimate properties of laser-sintered components, such as the elongation at break, still appear to be approximately one order of magnitude lower than in comparable injection moulded parts [3]. Thus, predicting the final mechanical properties and their correlation with the printing parameters becomes crucial in the context of structural integrity of laser-sintered components.

Many authors investigated the mechanical properties of final parts through empirically based correlations with the process parameters. Such an approach can provide reliable results, but it is restricted to few materials and prescribed conditions. A theoretical approach, derived from a physically based description of the transformations occurring during printing, coupled with a reliable computational approach considering both the physical and mechanical evolution of the material, appears more promising.

SLS involves multiple physical problems coupled together, the main being the optical, thermal and mechanical ones. Among the various transformations to which the material is subjected, we consider the process of particles merging and material densification to be the dominant one. Furthermore, we take the densification ratio as the dominant parameter affecting the final properties of the component. Differently from other works in literature, based on the implementation of a heat transfer function decoupled from the mechanical behaviour, we

propose a multiscale approach to take into account the processes in a representative domain (Fig.1). Through a microscale description of the viscous sintering of polymers [4], we can model the actual particles interacting with each other during the transient thermal condition at the passage of the heat source and extract the densification ratio. The results from the microscale are then upscaled to the continuum and implemented in a finite element model used to simulate the thermo-mechanical behaviour during the creation of multiple layers on top of each other.

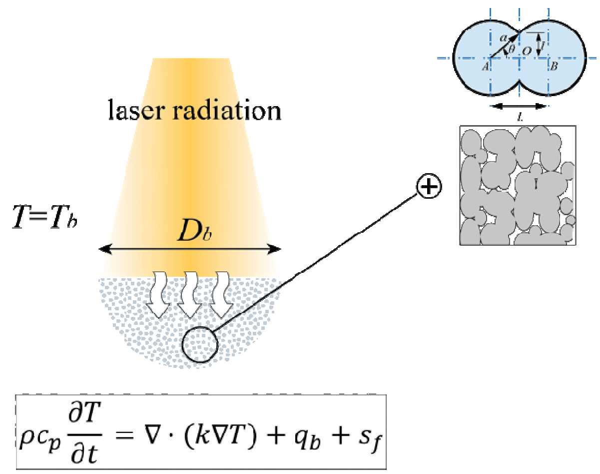

Fig.1: Schematic of the thermal-mechanical process in SLS, described by the heat transfer equation at the continuum level, and microscale mechanism of viscous sintering.

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Numerical evaluation of fatigue life of AM robot's head with initial crack

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INTRODUCTION

To become a reliable production process, additive manufacturing (AM) has to deliver structures whit the same (or better) structural integrity as the traditionally produced structures. As a consequence, analysis of fatigue behaviour of AM structures must be carried out, and predicted fatigue life must be within predefined boundaries. Sometimes AM structures have stress concentrators or even initial cracks (as a result of drawbacks of technology) and numerical methods are proven to be a powerful tool [1] in the analysis of the damaged structures' life. The purpose of the presented study is to demonstrate the abilities of the numerical methods in simulating the crack growth in AM structures with complex shapes, such as the head of the robot used in the education of pre-school kids.

NUMERICAL SIMULATION OF CRACK GROWTH

The AM structure analyzed here is used as the body casing of the robot being developed for educational purposes (Fig. 1a). After the printing process, critical area(s) for potential damage occurrences have been identified (Fig. 1b). Improved finite element analysis (FEA) implemented in ANSYS Workbench software was used, FE model was created, and mesh with the initial crack was generated. Since the total mass of all the equipment in the robot's head was estimated to 300 g, the load of 3N was applied (Fig. 2a). Properties of the material (Acrylonitrile Butadiene Styrene) were taken from the ANSYS material database of additive manufacturing materials. Paris coefficients were taken from the research presented in [2].

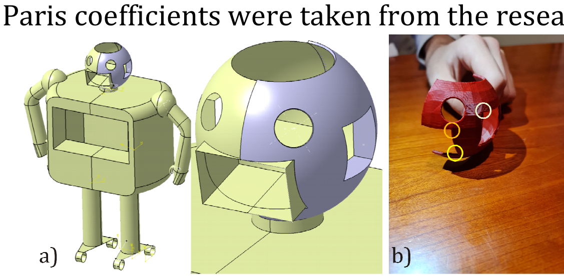

Fig. 1 a) Analysed part of robot's head casing; b) Critical areas for crack appearance

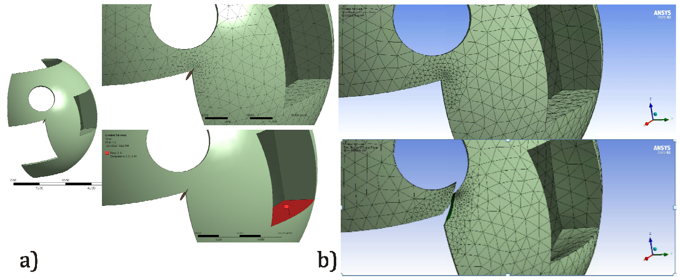
Fig. 2 a) Finite element model, mesh, and load; b) Crack propagation

RESULTS AND DISSCUSION

Crack growth in the robot's head obtained in FEA is presented in Fig. 2b. During the simulation, the mesh was refined only in the vicinity of the crack front. Stress intensity factors (SIFs) were determined (Fig. 3) using built-in SMART technology. The obtained SIFs values were relatively high, indicating the fast and stable crack growth. The obtained number of cycles (N=14) was low, assuming stress ratio R=0. The analyses were carried out for alternative crack positions as well, and it was observed that all alternative cracks did not grow (the SIFs were negative).

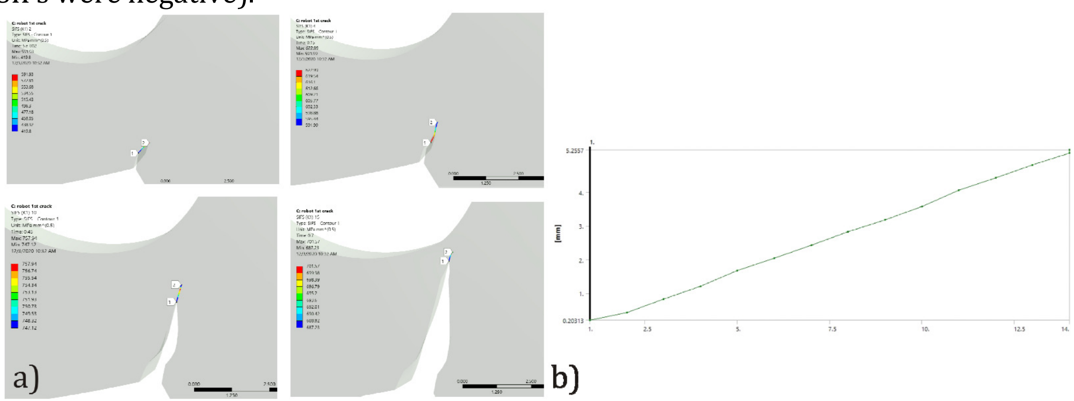
Fig. 3 a) SIFs during the crack growth; b) Crack size vs SIFs

Based on the carried-out study, it can be concluded that the application of numerical methods is inevitable for fatigue analysis of the damaged structures of complex shapes made by AM. Several possible crack locations can be analysed, and the most probable location can be identified, without time-consuming experiments. However, experimental investigation of the specimens is necessary to obtain realistic material data, as well as Paris coefficients. The influence of the filament type and filament orientation must be considered too.

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The benefits of Immediate dentin sealing (IDS)

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OBJECTIVE

The purpose of this study was to determine if there are significant differences between the standard delayed dentin sealing (DDS) and the immediate dentin sealing (IDS).
In the classic method, the standards delayed dentin sealing (DDS) for indirect composite and porcelain restorations, clinicians usually prepare the tooth, take an impression, and cement a provisional restoration at an initial appointment, followed by bonding the indirect restoration with some combination of adhesive and resin cement. A better approach to this, by reviewing multiple studies, articles and clinical experience seems to be the immediate dentin sealing (IDS). This technique involves immediate application and polymerization of a resin coating to the freshly cut dentin right after the preparation, before taking the impression.

MATERIALS AND METHODS

This review was made from 9 studies and articles on the topic.

RESULTS

Multiple advantages have been cited for the immediate dentin sealing technique, most notably improved bond strength, fewer gap formations, decreased bacterial leakage and reduced dentin sensitivity. More so, IDS has a positive impact on tooth structure preservation, patient comfort and long-term survival of indirect bonded restorations.

CONCLUSIONS

By comparing the two techniques for indirect bonded restorations, the standard delayed dentin sealing to immediate dentin sealing, we can observe that IDS improves bonding and eliminates concernes about the thickness of the adhesive layer among other advantages, thus leading to an increase in the longevity of the restoration.

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About Photogrammetry Applied in Mechanical Field

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ABSTRACT

The Photogrammetry is the technique to convert a real geometry of a part into 3D computer file starting from images and is used in the following particular fields: archaeology, cultural heritage, forensics, biology, full head and body scanning, topography and mapping, art and design, geology, ecology. The mechanical field is not widely presented in the literature in correlation with Photogrammetry. Maybe the doubt about the accuracy is one of the possible reasons of this absence.

This presentation will illustrate the reverse engineering process of some mechanical parts using the following software packages: Agisoft Photoscan, Geomagic Design X (formerly Rapidform XOR), SolidWorks, GOM Inspect, Cloud Compare.

Also, the presentation aims to compare some free and commercial application packages used in Photogrammetry, based on the same images taken from an axial turbine blade and finally answer the question if this technique can be used in the mechanical field to get a precise 3D reconstruction of large objects with complex geometries.

Influence of Printing Parameters on Plain-Strain Fracture Toughness Results for PLA Polymer

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EXTENDED ABSTRACT

Besides ABS (Acrylonitrile Butadiene Styrene), PLA (PolyLactic Acid) is one of the most used materials in FDM (Fused Deposition Modeling) technology. Due to its environment friendly nature i.e., PLA originates from renewable resources such as corn starch, cassava roots etc., compared to petroleum-based ABS, PLA is recently favourited as the 1st material of choice for FDM 3D printing. Another advantage of PLA is the apparent ease in 3D printing i.e., PLA has a low material shrinking over the course of 3D printing. Disadvantage of PLA material in comparison with ABS is in the area of mechanical properties. Printing parameters effect on overall mechanical properties, and the thoughtful selection of printing parameters may give the best mechanical properties of the material as an output. Previous research shows how chosen printing parameters effect on mechanical properties of PLA polymer, [1-3]. Conclusion of previously mentioned research papers show that infill density, layer height and infill pattern have the highest impact in mechanical properties of finished parts, in that particular order.

Majority of manufacturers that make polymer filaments for FDM technology heavily rely their datasheets only on tensile tests and their documentation usually lacks any data concerning fracture mechanics parameters. For example, plain-strain fracture toughness info may be assessed using only standard tensile grips, or three-point bending test fixture on regular tensile testing machine (Fig. 1). Standard for plain-strain fracture toughness is ASTM D5045-14, which contains info on tests that can be performed on SENB (Single Edge Notched Bend) and C(T) (Compact Tension) specimens.

Our research is focused on SENB specimens of PLA material with variation in layer height i.e., 0.3mm, 0.2mm and 0.1mm, and infill density i.e., from 10% to 100% with an 10% increment, resulting in 90 specimens overall (Fig. 2). For the tests to be valid specimens must meet the plain-strain criterion and the thickness of outlines must be lower that the length of a pre-crack. Hence, before fracture toughness tests one must be sure that pre-crack penetrated through the outlines, therefore the crack path will be in the expected direction. Previous research conducted by Valean et al. [4], proves that it is appropriate to 3D print the notch, rather that to mill it on the machine. Final results show that, depending on selected printing parameters, fracture toughness values may range from 0.38 to 2.58 $MPa \cdot m^{1/2}$. Hence, the result shows that the selection of printing parameters is of utmost importance when designing a part that will be 3D printed.

Fig. 1. Shimadzu AGS-X 100kN capacity tensile testing machine, from the Faculty of the Mechanical Engineering, University of Belgrade

Fig. 2. Some SENB tested specimen batches

Acknowledgements
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Defects and quality controls in SLS industrial 3D printing

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ABSTRACT

SLS Technology permits to create three-dimensional objects staring from powder of polymeric material. A layer of powder is pre-heated to a certain temperature and is then selectively targeted by a high-power heating source (Laser beam) causing the powder to partially melt and densify. The layer height typically ranges between 0.08 and 0.14mm in the industrial field. Single part dimension can reach 1000 mm in multilaser machines.
The purpose of this study is to give an overview of the defects and quality controls that are usually performed in the SLS industrial printing. Indications about accuracy, both dimensional and mechanical, usually accepted by the market, will be given. Typical defects that are found on the printed parts will be discussed. It is anticipated that a wide range of defects including distortions and poor mechanical properties are due to thermal issues, both during the building and cooling down process. Relatively simple quality controls allow defects to be spotted on single parts and construction batches. A more difficult job is to link the defects to the causes that produced them. Avoiding major mistakes (when possible) in part orientation, building density, powder handling and temperature set up is usually the key to keep a balance between quality and productivity in SLS technology.

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Design for additive manufacturing and post processing of cellular lattice structure

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ABSTRACT

Traditional manufacturing which is subtractive in nature generally has been associated with more material and energy wastage than required. Final products manufactured exceeds the level of performance as materials are added in similar concentration even in non-stress region. Hence human made load bearing structures are dense solids like steel, concreate, glass, etc., but nature design its structure with cellular solids like cedarwood, cork, trabecular bone, etc. This is difficult to achieve through traditional manufacturing techniques due to manufacturing constraint associated with subtractive manufacturing. Hence, a very promising technology to fabricate and replicate the natural cellular structure in design is Additive Manufacturing (AM). Design for additive manufacturing and post processing (DfAM&PP) is an important concept for designing a product with additive manufacturing. This study is on design for additive manufacturing and post processing with lattice structure and classification of this lattice structure. Material extrusion process is used for additive manufacturing of lattice structure. Presently two most often used AM post processing steps are support removal and surface finish which accounts most of the AM technology. Support removal process is most tedious and challenging process which accounts more than half of the total process time in additive manufacturing. Further during support removing the printed parts often gets damaged and further surface finish operation is employed to smoothen the surface which was earlier supported by the support structure. Design of supportless lattice structure could solve the post processing challenge and bring high speed printing concept. Scanning electron microscope (SEM) is done to analyse the defect and material testing is done with uniaxial compression test for strength analysis[1–6].

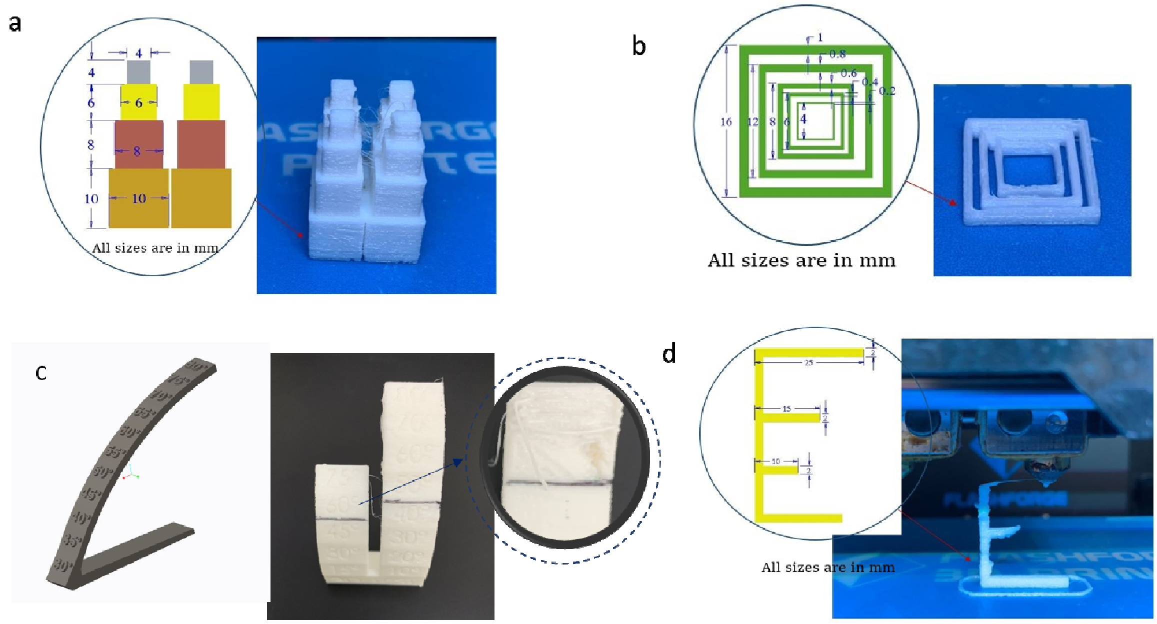

Figure1: Four important design parameter for additive manufacturing and post processing (DfAM&PP) a) minimum feature size b) mimimum wall thickness c)minimum overhang angle d)minimum parallel ledges

Keywords: Additive manufacturing, Material extrusion process, Cellular lattice structures, Support-less lattice structure, Closed cell lattice structure

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Experimental testing of two short-fiber reinforced composites: PPA-GF33 and PPS-GF40

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ABSTRACT

This paper presents the experimental testing of two short-fiber reinforced composites (SFRC). The two materials are a polyphthalamide with 33% glass fiber inclusion (PPA-GF33) and a polyphenylene sulfide with 40% glass fiber inclusion. Rectangular plates were obtained from these two materials by injection moulding. Specimens type 1BA, according to ISO 527-2, were cut out with orientations of 0°, 15°, 30°, 45°, 60° and 90°, with respect to the longitudinal direction of the plate. The cutting was conducted using a CNC water jet machine. Tension tests were performed at room temperature, in order to determine the mechanical behaviour. Results are presented in the form of stress-strain curves, considering different orientations of the specimens. The experimental results were processed in order to assess the differences that appear due to fiber orientation. A comparison between the two materials was performed in terms of Young’s modulus, tensile strength and tensile strain.

Fatigue life evaluation of an additively manufactured SAE 316L steel shaft under rotational bending: FEA versus DIN 743

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INTRODUCTION

When the static structural assessment is performed using FEA, the subsequent fatigue analysis generally relies on the local stresses. The main reason is that the local stresses are readily available to be directly used as input for the durability assessment. However, the stresses are only part of the input, and the results might be inherently inaccurate due to some other input (i.e., the AM-material data in the present case). Therefore, when using FEA, the advantage of obtaining very accurate stresses from the computational model can be reversed by the fatigue assessment's inaccuracy if the problem at hand is far from being deep in detail understood.

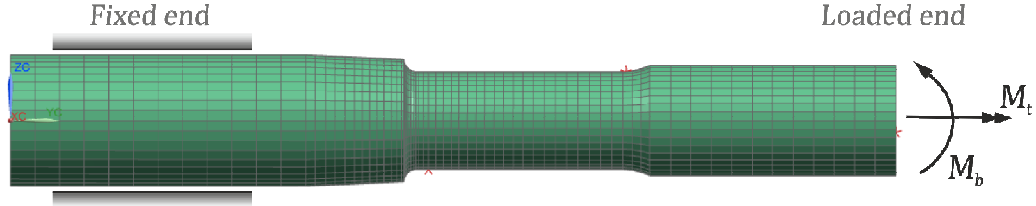

Figure 1

To get the full advantage of FEA's accuracy, a standard handmade fatigue calculation should be performed, i.e., either a fatigue analysis based on nominal stresses and the theoretical stress concentration factor or a fatigue strength calculation based on local stresses with correct S-N data. It is suggested that additional effort should be spent on the static stress assessment since an accurate stress level and its distribution at the critical location is essential to determine either nominal stresses and or the stress gradient.
This paper aims to compare FEA-based fatigue calculation results and the German standard DIN 743 for an additively manufactured SAE 316L steel shaft under rotational bending. A parametric study was conducted to determine the strength safety factor, the fatigue safety factor, and the AM-produced shaft's fatigue life relative to a reference FEA model built-on the associated wrought material (i.e., stainless steel 316L). Here, it is worth mentioning that, in the structural engineering literature, ever-growing, detailed comparison studies of these two procedures for a specific AM-produced material, using numerical examples, are not available at all.

MATERIALS AND METHODS

To perform the FEA-based durability assessment, the material's static and fatigue properties (i.e., AM-produced 316L) are specified according to Mower et al. [4]. In their study, the elastic moduli were determined in bending, and the stress-strain characteristics were measured in tensile under the displacement control. Further, the data for the S-N fatigue curve was acquired under the conditions of fully reversed loading. Surface polishing effects and fabrication orientation effects, as well as the hot isostatic pressing upon the mechanical properties of AM-produced 316L, were analyzed[4].
The commercial software Simcenter 3D, was used in this study to perform fatigue life evaluation of an additively manufactured SAE 316L steel shaft under rotational bending. The model was first solved for static stress and strain results. Then, a durability solution process with a fully reversed loading pattern was superimposed. As the initial static event has two excitation loads (i.e., the applied torque in line with the bending moment), their results are superimposed to provide the overall durability response.
Hexahedral elements were utilized for all the calculation models in this study. A bending moment and a torque couple are applied at one end of the shaft through MPC elements creating fluctuating normal stress with R = -1, in line with constant shear stress, while a fixed boundary condition is considered to the opposite end (see Figure 1).
For comparison purposes, the analytical assessment based on the well-known DIN 743 [3] design standard is presented. As will be shown, it implies both a safety analysis against fatigue and a plastic deformation assessment.

RESEARCH OUTCOMES

The need for a good understanding of those key-factors that balance between strengths and weaknesses of each approach in question (i.e., FEA versus DIN 743) was the main idea to accomplish the present work. Essentially, a systematic development is proposed to be carried out by comparing the results of the two aforementioned fatigue life assessment procedures toward grasping their potential within the context of using the AM-produced 316L material for machine design applications.

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Experimental study regarding the optimization of metamaterial structures with Kelvin cells

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ABSTRACT

The applications of cellular materials in engineering structures is growing constantly due to their specific characteristics. Relatively good mechanical properties at low densities recommend their use in fields such as automotive, aerospace, naval and rail transportation [1, 2, 3]. The improvement of the composite structures based on foams is closely related to selection of the materials with the appropriate properties. In recent years, due to the advancement of rapid prototyping technologies, metamaterial cellular structures are beginning to experience a wider range of applications. These types of structures can be tailored to individual applications, as computer aided design allows for wide structural variations and numerical analyses can accurately predict their behaviour [4].

The aim of this study was to investigate the effect on mechanical properties of several types of alterations of the Kelvin structure (tetrakaidecahedron). Considering the stress concentration that occurs in the joints of the structure, several fillet radii were considered (Figure 1 a). Another considered alteration was regarding the load bearing of the structure, through the introduction of reinforcement beams that connect opposite joints of the structure with regards to its centre (Figure 1 b). Both alterations can expected to increase the mechanical properties of the structures. However, their addition comes with an increase in relative density.

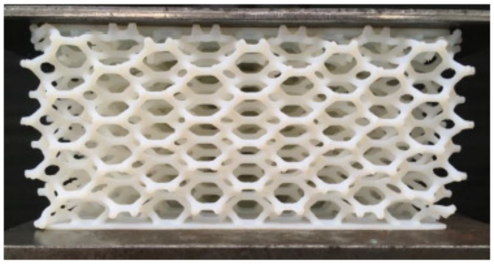
a) b)

Figure 1. The basic Kelvin cell with fillet radii (a) and the reinforced Kelvin cell (b)

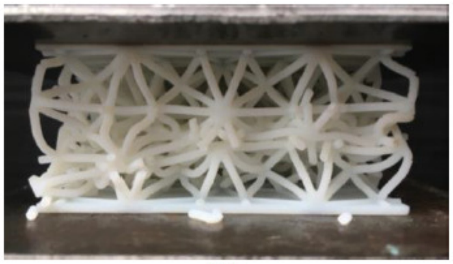
Preliminary investigations consisted in the numerical determination of the variation of relative density of the structures with the geometrical parameters (strut diameter to length ratio and fillet radius to length ratio). With the obtained results, the geometric parameters of each structure were chosen so that the three variations will have the same relative density.

The investigated structures consisted of 9 x 9 x 5 cells for the regular Kelvin structures and 5 x 5 x 3 cells for the reinforced structure (due to limitations in strut thickness). The structures

were manufactured through rapid prototyping on a Sratasys ObJet24 printer, using the PolyJet technology.
The rapid prototyped structures were subjected to compression on a Zwick Z005 universal testing machine, using a crosshead travel speed of 2 mm/min (Figure 2).



a)



b)

Figure 2. Compression tests on the basic Kelvin structure with fillet radii (a) and on the reinforced Kelvin structure (b)

The results show that the fillet radii determined all around better properties comparted to the regular structure: higher stiffness, strength and absorbed energy. The reinforced structure exhibited higher strength and stiffness, but, due to the buckling of the reinforcement beams, developed a sudden drop in load bearing capabilities and thus a lower absorbed energy value (Figure 3).

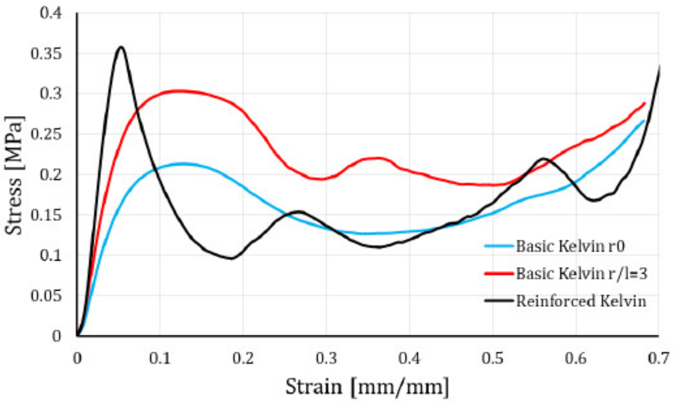


Figure 3. Compression test results for the investigated structures

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Numerical analysis of interlaminar tensile strength in fibre-reinforced AM composites

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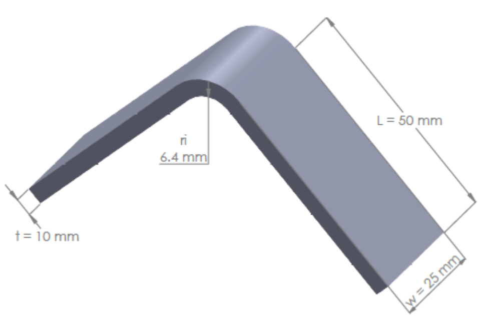
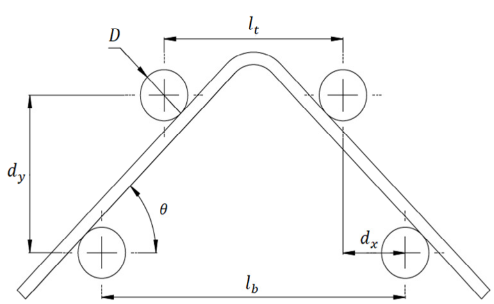
ABSTRACT

The low interlaminar tensile strength of fibre reinforced composites materials produced by fused deposition modelling presents serious challenges in the design of structures with pronounced radii of curvature. Numerical and analytical models were performed to determine the normal stress in the interlaminar layer of a composite material produced by additive manufacturing, with fibreglass, Kevlar or carbon fibre reinforcement in a nylon matrix. To determine which parameters significantly influence the failure of the material, changes were made in the fibre volume fraction and the print density of the core. The results obtained show that the magnitude of the interlaminar normal strength decreases by up to 78%, from Carbon fibre to fibreglass or Kevlar as reinforcing materials. Infill density and fibre volume fraction are factors that do not significantly affect the interlaminar normal strength.

Keywords: Fused deposition modelling, interlaminar strength, composite material, additive manufacturing.

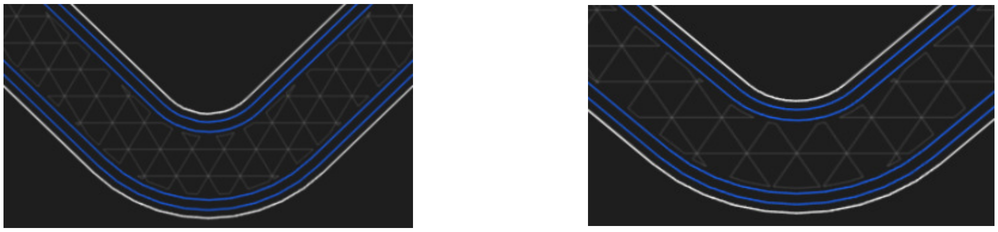


a)



b)

Figure 1. Specimen geometry (a) and test setup (b) to measure ILTS under ASTM D6415.



a) b)

Figure 2. Reinforcement pattern in the specimen with two carbon fibre rings and filling density 50% (a) and 40% (b).

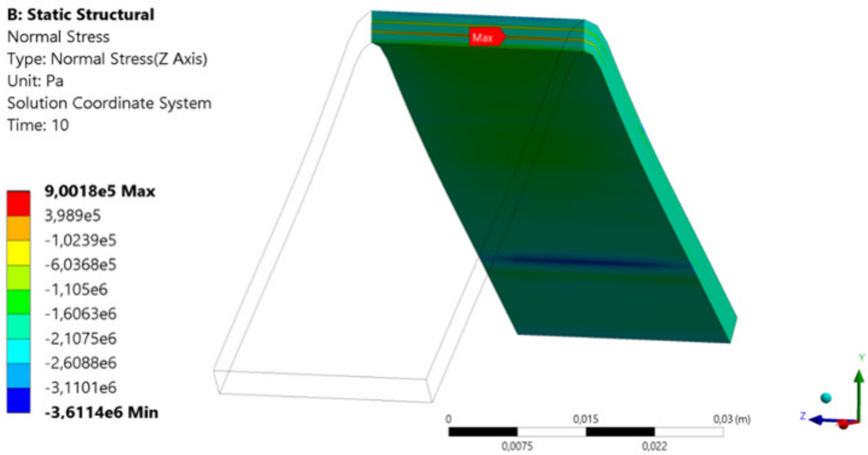


Figure 3. ILTS distribution in the reinforced specimen with four rings of carbon fibre and 50% of filling density.

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Progressive damage in pipes of composite material through finite elements

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ABSTRACT

Pipes based on composite materials have shown excellent features in recent investigations. Properties of these materials include a high mechanical resistance and wear, electrical insulation, flexibility, anticorrosive, they are incombustible, which does not generate flame propagation, a low cost compared to steel, longer life cycle, with imputrescibility and resistant at high temperatures. In this work, the analysis of the progressive damage using the finite element method was carried out for a pipe made of fibreglass woven material under typical loads, pressures and temperatures for this element in service. The mechanical characterization of the composite material was experimentally developed by tensile tests ASTM D3039 and ASTM D5766. A non-linear model was used, taking into account the degradation of stiffness with increasing loads. This model is progressive and is based on the theory of continuous damage and Matzenmiller's work. In addition, we studied the influence of the internal diameter, the number of bonded fibre layers, the internal pressure, the interior fluid temperature and the distance underground in the stress distribution and the safety factor. This model is useful to provide estimates of the remaining life in buried pipes.

Keywords: FEM, modelling, composite material, fibreglass.

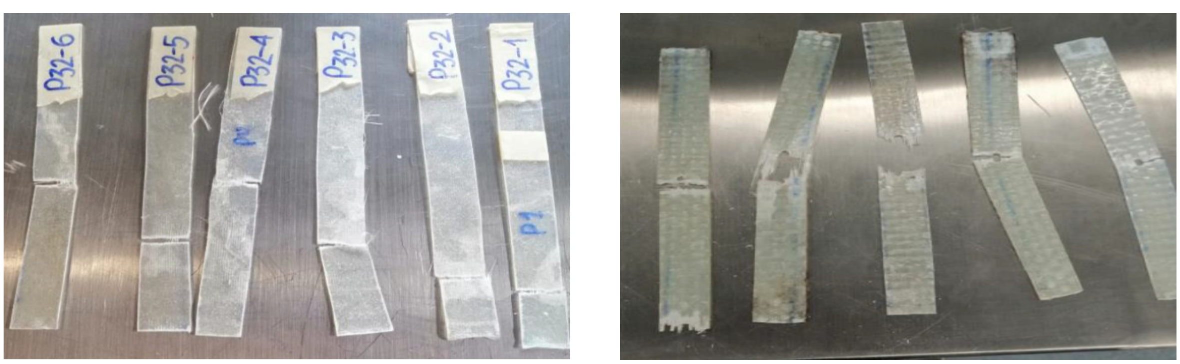

Figure 1. Specimens for tensile tests and open hole tests under ASTM D3039 and ASTM D5766.

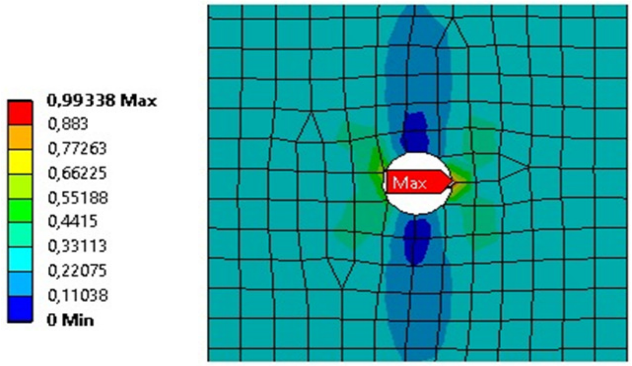

Figure 2. Damage results for open hole test according to ASTM D5766.

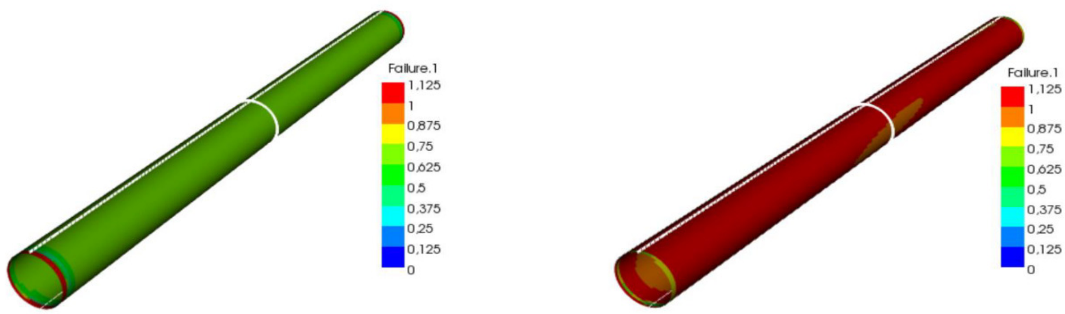

Figure 3. Partial and total failure in the composite pipe.

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Fracture behaviour of pla and advanced pla-x material

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ABSTRACT

PLA (PolyLactic Acid) originates from renewable resources making it better solution for environment in comparison with petroleum-based ABS material. Anyhow, from point of view of structural integrity, its mechanical and fracture properties are not sufficient. In order to improve fracture behaviour, second-phase particles are added to polymer matrix. Here, wide range of second-phase particles are used to produce different advanced PLA materials (''PLA-X'') and compare their fracture behaviour using tensile testing and fracture mechanics testing, i.e. K_{Ic} evaluation.

Fracture behavior in polymers may vary from brittle to ductile depending on strain rate, temperature and molecular structure. In this case five batches of PLA and advanced PLA-X material are tested according to ISO 527-2 standard for tensile testing, which defines 1 mm/min strain rate. Main printing parameters are the same for all batches of both materials, as presented, with other necessary details, in [1, 2].

Stress-strain diagram of advanced PLA material with identical printing parameters as with observed PLA material, is shown in Fig. 1. In comparison with brittle PLA material, PLA-X material shows ductile behavior in all tested samples. Ductile behavior of PLA-X specimens is shown in their stress-strain diagram from Fig. 1. PLA-X specimens show great repeatability until achieved Ultimate tensile strength (in this case equal to Yield strength), which is 34.75 MPa on average and with standard deviation of only 0.25 MPa. Ultimate tensile strength is noticeably lower in PLA-X than in PLA material. Average Elastic modulus is 3.9 GPa, with standard deviation of 82 MPa. Elastic modulus of PLA and PLA-X specimens show similar values, both with very low standard deviation. There is a noticeable difference in strain values on PLA-X specimens. Overall strain of PLA-X specimens ranges from 4.77% up to 17.21%. Unequal strain values between samples are due to amorphous nature of PLA plastics and to uneven distribution of added second-phase particles.

Fracture toughness was tested in accordance with ASTM D5045-14 using SENB specimens, as shown in Fig. 2 in different states of testing. Corresponding fracture toughness was in the range K_{Ic}=2-2.5 MPa$\sqrt{m}$. These values are very low, therefore modificatons are needed to improve structural integrity of components made of PLA(X).

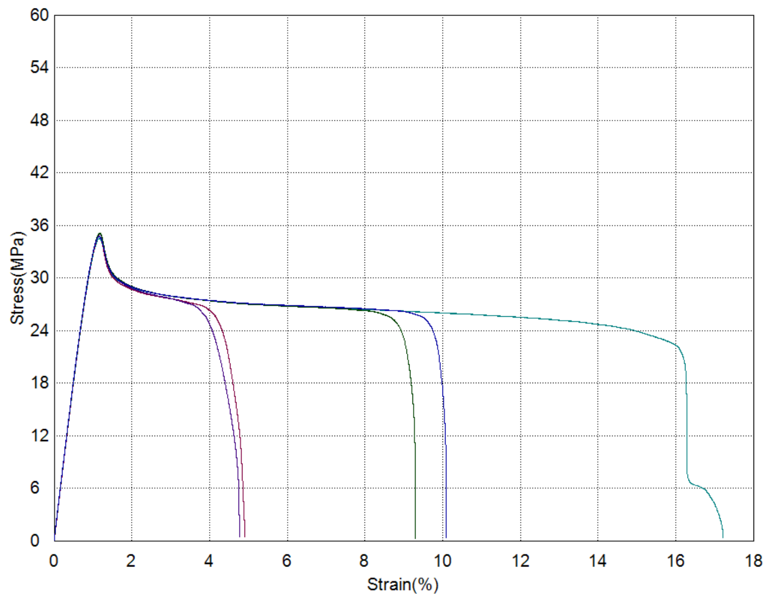
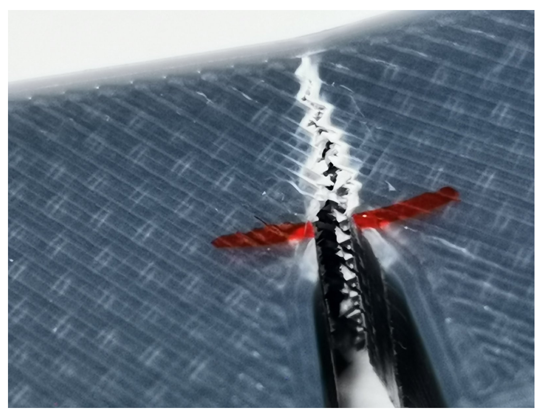


Fig. 1. Stress-strain diagram of PLA-X material batch

a)  b) 
Fig. 2. a) SENB Specimens, b) crack growth

ACKNOWLEDGEMENTS

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Mechanical properties comparison between new and recycled PETG obtained from FDM waste

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INTRODUCTION

The recycling of materials and the efficient use of resources is nowadays fundamental in a circular economy perspective. This concept also applies to additive manufacturing (AM) where waste can be reused to produce new material. Using mostly thermoplastic polymers, Fused Deposition Modeling (FDM) is an AM technique which allows to melt waste materials and, successively, using a suitable extruder, obtain new filament. In the process, polymers are subject to multiple re-melting and polymer orientations by extrusion operations. The aim of this work is to evaluate the influence of the recycling process over polyethylene terephthalate glycol-modified (PETG) mechanical properties by tensile testing of samples produced using pure and recycled material. Furthermore, filament itself has been tested to evaluate recycle process influence before FDM printing.

EXPERIMENTAL CAMPAIGN

The experimental campaign was divided into two main phases: the first saw the production of specimens starting from virgin material obtained from pellets: the filament for printing was made using the Felfil Evo desktop extrusion system (Felfil srl, Castelfidardo, Italy) . The spools of filament were used to print the specimens in two different orientations in space: horizontal and vertical in the printing area. The printing batches consisted of 5 specimens each: at the end of the first phase, the broken specimens and the waste material were shredded using Felfil Shredder. With the new spool of recycled filament, the initial printing phase of the samples has been repeated, keeping unchanged the orientations and printing parameters. In parallel, tensile tests were conducted on both virgin and recycled filaments to determine its mechanical characteristics. Tensile specimens were produced on two consumer-grade printers, a Prusa MK3 (Prusa Research, Prague, Czech Rep.) and a BQ Witbox 1 (BQ, Madrid, Spain), adopting the same printing parameters. The replication of the same campaign using different machines (and users) made it possible to evaluate the influence of the machine itself on the mechanical properties of the material produced, confirming the fact that the type of machine and the production environment could affect the final result, even starting from identical printing parameters.

EXPERIMENTAL SETUP

Mechanical properties have been measured by tensile testing, according to the ASTM D638 standard [5]. The tests were carried out on a desktop format MaCh5 universal testing machine, produced by MaCh3D (MaCh3D srl, Parma, Italy), capable of a maximum load of 5 kN and a total stroke of 110 mm. The machine exploits a proprietary shape of the grips with the advantage of reducing the test execution times, eliminating the degrading effects of traditional fixtures on the specimen and minimizing operator errors [6]. The waste material and broken specimens were recycled (shredded and extruded) with the Felfil Evo shredding and extrusion system.

RESULTS

Results show that recycled material presents slightly worse mechanical properties than the virgin one, in both printing orientations. The same can be said about the filament: the recycled one has lower ultimate stress than the pure material. On the other hand, mechanical properties of the processed materials of the two printing systems are almost equivalent, presenting average values included within the reciprocal standard deviations. For manufacturing techniques based on the use of thermoplastic polymers, such as FDM, it is possible to efficiently recycle non-compliant parts and / or substrates. The material obtained, however, has slightly lower mechanical properties than the virgin one: a careful mechanical characterization of the material obtained is therefore necessary before using it to obtain functional parts.

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Fracture toughness in additive manufacturing by selective laser sintering. An overview

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INTRODUCTION

The additive manufacturing (AM) technologies are relatively new and not yet mature, the mechanical and geometrical properties of the parts being directly affected by the process setup. For this reason, many researchers are focusing their work on establishing the technology-property relation by conducting mechanical tests [1, 2], structural evaluation [3] and assessing the geometrical aspects [4, 5]. Selective laser sintering (SLS) is one of the AM technology that belongs to the *powder bed fusion* branch. It uses raw material in powder form and a laser source for sintering the particles together. The sinterization process led to a porous structure in the entire volume of the part, which directly influence the mechanical properties. Despite of intensive research on fracture mechanics of classical obtained materials [5-8], few studies cover the fracture behavior of polyamide processed by SLS.

The paper presents an overview of the authors work on fracture properties of selectively sintered polyamide (PA2200). Because the fracture properties of AM materials are dependent on the process parameters, the work highlights the influence of in-plane orientation, spatial orientation, energy density and structural defects on mode I and II fracture toughness.

MATERIALS AND METHODS

One type of AM material was used in the study: the polyamide PA2200 produced by Electro Optical Systems - EOS GmbH. This is a multiuse material with relatively high strength and stiffness and good manufacturing resolution. It can be used in a large variety of applications starting from visualization to ready to use parts. Its biocompatibility makes it a good candidate for disposable elements in medical field. The AM process was conducted on EOS Formiga P100 (EOS GmbH Electro Optical Systems) using the parts designed according to ASTM D 5045-99 and ASTM D 5528 – 01 respectively. The mechanical tests were conducted on 5 kN Zwick machine followed by data analysis and computation of fracture toughness parameters. The structure of the study is presented in the figure 1 were the process variables used for each fracture mode can be identified.

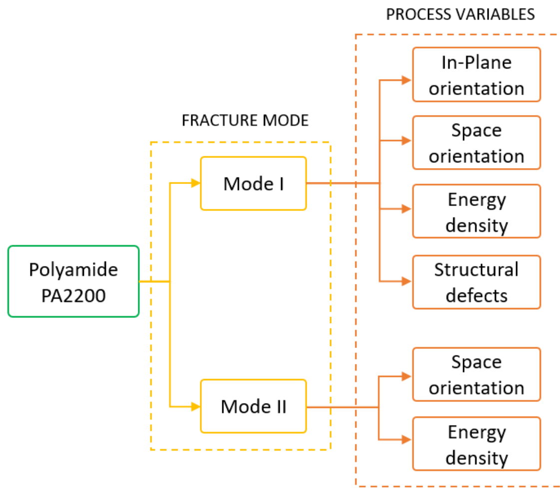

Fig. 1. Structure of the study for determining the fracture properties

RESULTS AND DISCUSSIONS

Significant influence of the process parameters on the fracture properties was identified. Mode I and II fracture toughness was graphically represented according to every individual variable. With very little exceptions, the fracture properties are linearly dependent on density energy and spatial orientation of the sample. Less evident influence was detected for in-plane orientation of samples. Also, the incidence of the structural defects on the fracture properties was underlined in the study.

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Charpy Impact Properties and Numerical Modelling of Polycarbonate Composites

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ABSTRACT

Polycarbonate composites are widely spread in many industries, for the manufacturing of various products, such as household appliances, electronic devices etc. Their relatively good price to quality ratio permitted them to emerge in various fields inside the automotive industry, too. Although these composites are being used with high fidelity by many research and development engineers, their mechanical properties are highly dependent on the manufacturing processes of the final-end applications, on the fiber orientations with respect to the loads they would be subjected to, the type of the loading, environmental conditions and many other aspects.

This paper presents the Charpy impact behaviour of three polycarbonate grades, compared to each other, in notched and unnotched conditions, as follows: *Makrolon 2405* – base material/unreinforced polycarbonate -, *Makrolon 9415* – polycarbonate with 10% glass fiber – and *Makrolon 8035* – polycarbonate with 30% glass fiber -. The experimental measurements clearly demonstrated the effect of the fiber to volume ratio on the impact strength - calculated by the relations given in ISO 179-2 [1] -, of the material: as the fiber ratio increases the impact strength decreases, exhibiting brittle behaviour.

The impact characterization of the notched specimens can facilitate the material selection for applications with higher geometrical complexities, as studied previously by various authors, including H. Hirose et al. [2], where stress concentrators cannot be totally eliminated. In addition, the material models obtained based on the correlations of the numerical simulations with the experimental testing, as similarly investigated by W. Hufenbach et al. [3], will increase simulation accuracy, and can speed up product development cycles, with less sample manufacturing and repetitive testing for validation reasons.

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Simulation of the behavior of lattice structured impact absorbers manufactured by additive manufacturing

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ABSTRACT

Impact absorbing structures are present in a wide range of applications. The use of these components aims to protect occupants and/or loads in transportation structures against high levels of forces or excessive structural deformations during impact events.
Thin-walled structures are widely used as impact absorbers as its combines light weight and high–energy absorbing capacity [1,2]. Tubular impact absorbers have great efficiency when subject to longitudinal impact loads, due to the large energy absorption during dynamic plastic buckling with folding formation, relatively large load path available and compact size [3]. The crashworthiness efficiency of tubular energy absorbers can be improved by the introduction of infills into tube, like foams [4], honeycombs [5] or lattice structures [6].
The use of lattice infills generally involves complex geometry, that is, in most cases, hard or impossible to manufacture by conventional manufacturing processes. Additive manufacturing opens great possibilities in the field, due to the great control of internal component geometry and range of available materials [7].
In this paper, the impact absorption capacity of empty a square tubular energy absorber was evaluated. The crashworthiness performance of empty (reference) tube and tubes filled with cross lattice structure infill (fig 1) with different thicknesses were compared.

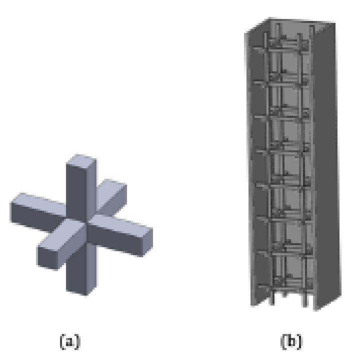

Fig. 1 – Cross cell (a) and lattice filled tube (cut) (b).

Parameters related to the peak and average crush force, energy absorption capacity and total mass of the component were considered in order to quantify the crashworthiness performance of the components.

The analysis was accomplished using an Abaqus Explicit model. The material used in simulation was aluminum AlSi10Mg. This material is available to laser melting additive manufacturing processes. Material properties were based on literature [8].

The results revealed that lattice structures can improve energy absorption performance of tubular absorbers. Lattice infill also influenced the buckling mode of the tube (fig 2), affecting energy absorption behavior.

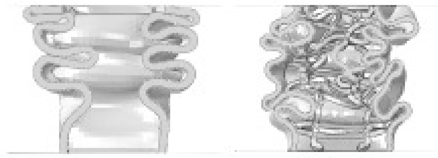

Fig 2 – Buckled structures. Empty tube (left) lattice infill tube (right).

The crashworthiness efficiency was also improved by optimization between the thicknesses of tube walls and the cells of lattice structure.

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The effects of layers orientation on impact energy evaluation of FDM printed specimens

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ABSTRACT

In nowadays, Fused Deposition Modeling (FDM) has started to be used more and more in the manufacture of customized components. However, the materials made by 3D printing show different mechanical properties in different directions due to the inherent anisotropic features of the printing process [1, 2].

This paper investigates the effects of layers orientation on impact energy of Acrylonitrile Butadiene Styrene (ABS) test specimens, obtained by additive manufacturing (AM), having three deposition directions (0°, 90° and 45°), Figure 1.a.

The specimens were tested with a hammer: CEAST 9050 Pendulum Impact System.

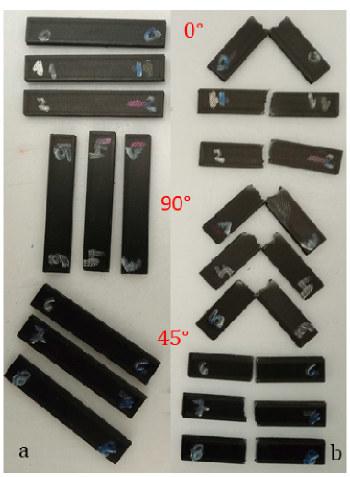

Figure 1. Specimens before (a) and after (b) impact tests

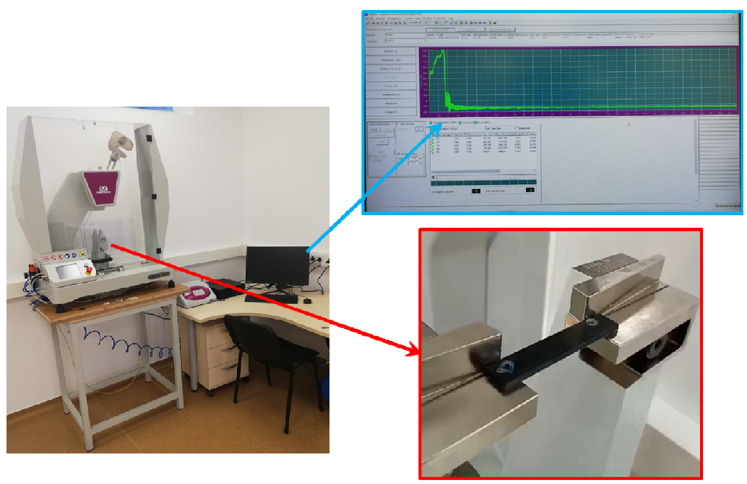

Figure 2. CEAST 9050 Pendulum Impact System

Instrumented Charpy impact tests, were conducted on un-notched specimens, in edgewise direction, according to standard ISO 179-1. Based on measured velocity and impact force at impact, impact energy was computed, Figure 2 and 3.

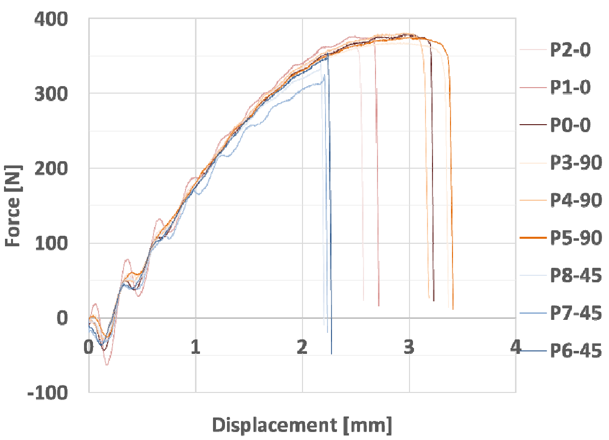

Figure 2. Force – Displacement curves for specimens to the impact tests

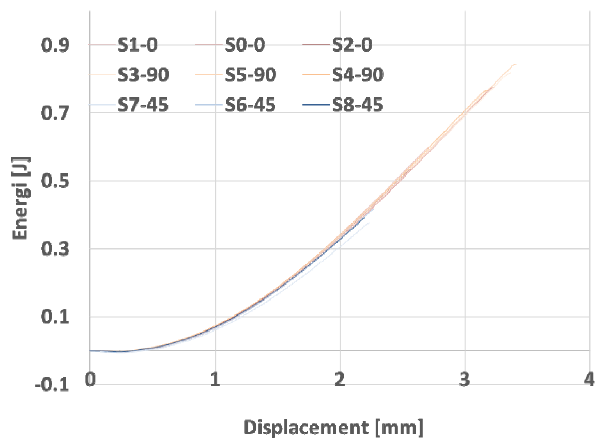

Figure 2. Energy – Displacement curves for specimens to the impact tests

The average of energy obtained during impact tests, for specimens with the layers orientation at 45° was about 0.39 J, and for those with layers orientation at 0 and 90, respectively was 0.63 J and 0.81 J. A hinge break failure mode was observed to most of the un-notched specimens, excepting specimens with the layers orientation at 45°, Figure 1.b.

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Additive manufacturing in dentistry

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ABSTRACT

Additive manufacturing is an industrial production name for 3D printing, a computer controlled process that creates three dimensional objects by depositing materials, usually in layers. It is used in various fields such as industries, aerospace, art, medicine and design[1-3].
Various additive manufacturing technologies are currently used, such as Stereolitography(SLA), Selective laser sintering(SLS), Fused deposition modelling(FDM), Direct metal laser sintering(DMLS), Polyjet 3D printing(PJP), Electron beam melting(EBM). Each of them adopts different methods of production of the physical model[1].
Nowadays, additive manufacturing is used in different fields of dentistry to improve patient outcomes. It can be used for preoperative planning, education, custom manufacturing and making surgical guides for a reliable operation. The process starts with creating a virtual image with a 3D scanner or CAD software. The product will be generated by different additive manufacturing technologies which fulfill the complex challenges occurred in the medical field. The top technologies preferred in the area of dentistry are stereolithography used for aligner fabrication, and direct metal laser sintering used for producing high-quality metal dental crowns[4-6]. Restorations that were made using the DMLS technique revealed the lowest marginal gap between the implant abutment and the single crown restoration[7]
This technology is now becoming accessible, providing better health care for the patients and offering more information for the dentist about the patients diagnosis and treatment plan[8-9].
Various additive manufacturing technologies can bring benefits in dentistry. They can be used for requirements such as crowns, implants or bridges. Dental prosthesis can be manufactured using binding jet technology with parameters as binder amount, drying time or drying powder level. Using 3D printing results in obtaining an accurate implant with a higher strength and lower cost[10].
Studies comparing the accuracy of restorations manufactured by additive technique shown that it was higher than that of the restorations manufactured by substractive methods. Another advantage is that the inventory and the virtual models can be stored in a digital form, reducing the inventory costs[11].
Additive manufacturing allows dentists to use a variety of materials for prosthodontics such as ceramics and metal alloys. The method is quick and simple, patients teeth will be scanned resulting in a virtual model with high accuracy. The next step is the printing of the crown, or even of a complete denture with gum and teeth. Dental implants or models can be printed using multi-materials.
Additive manufacturing has an excellent perspective in dentistry because it allows the capability of enhancing product customization and reduces the costs. It has disrupted the traditional fabrication of medical models. This technology is beneficial in surgical planning by

providing visual aid to the physician team, enhancing the surgery planning. It has potential to fabricate prosthetic restorations and implants with complex geometry in a short period of time[1].

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Modern Techniques in the Detection of Dental Caries

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INTRODUCTION

Early and accurate diagnosis of dental caries is a challenge that dental practitioners are faced with everyday. An ideal caries diagnostic tool detects dental caries in early stages and helps dental practitioners in choosing an appropriate treatment plan. The aim of the study is to present and compare various methods of dental caries detection and assessment.

METHODS

This study analyzed both non-cavitated and cavitated dental caries. For the detection and assessment non-cavitated caries lesions, the following methods are evaluated: Rluorescence (DIAGNOdent, VistaCam iX), optical coherence tomography (OCT), near-infrared trans-illumination, and laser technology (Canary System). For the detection and assessment of cavitated caries lesions, the following methods are evaluated: caries detector dyes, Rluorescence (SiroInspect), and optical coherence tomography (OCT).

CONCLUSIONS

Each system discussed has its own beneRits and drawbacks. As a powerful non-invasive and non-radiated method, OCT seems to have the most potential in achieving accurate and reliable detection and assessment of caries.

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