

Book of Abstracts

9th International Scientific Conference
“Rapid Prototyping. 3D & 4D Printing. Additive
Manufacturing”

16-18 September 2026, Krakow



Projekt okładki: dr hab. inż. Krzysztof Żaba, prof AGH

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About the Conference AM26



Dear Sir or Madam,

We are pleased to announce that on 16–18 September 2026 the 9th International Scientific Conference "Rapid Prototyping. 3D & 4D Printing. Additive Manufacturing" will take place. For the first time, the conference will be organised by the Faculty of Non-Ferrous Metals of AGH University of Krakow.

Previous editions were organised by the Military University of Technology (Edition VI), Rzeszów University of Technology (Edition VII) and Kielce University of Technology (Edition VIII). The event will be held at Hotel SWING in Kraków.

The conference is an international platform for knowledge exchange and for strengthening cooperation between academia and industry, providing an opportunity to present the latest achievements, emerging trends and innovative applications in, among others, the aerospace, space, automotive, defence, machinery, rail, marine industries and medicine-shaping the future of materials science.

Sincerely,

A handwritten signature in dark ink, reading "Krzysztof Żaba". The signature is fluid and cursive, with the first letters of the first and last names being capitalized and prominent.

Assoc. Prof. Krzysztof Żaba

Chair of the AM26 Conference

Conference Topics

- Additive Manufacturing
- 3D/4D printing technologies
- Prototyping technologies
- Research methods, operation and reliability of prototypes
- Conventional manufacturing technologies
- Computer simulations
- Industry 4.0/5.0 revolution in manufacturing and prototyping
- Metallic materials – manufacturing technologies and testing
- Ceramic materials – manufacturing technologies and testing
- Polymeric materials – manufacturing technologies and testing
- Polymers and polymer composites in additive manufacturing applications
- Composite materials in 3D/4D printing
- Hybrid technologies
- Laminated metallic materials
- Conventional and unconventional forming processes of printed materials
- Cyber-physical technologies
- Virtual reality (VR + AR)
- SMART MANUFACTURING, SMART CITY and SMART FACTORY
- CAx systems in the context of 3D/4D printing
- CAD/CAM/CAE/MES systems and IT systems and their industrial applications
- Educational systems in 3D/4D printing technologies
- Industrial 3D printing systems, large-format printing
- Additive-oriented design
- Reverse engineering, coordinate measuring methods, Rapid Inspection systems, 3D scanning and spatial geometry analysis
- 3D/4D printing applications in aerospace, automotive, defence, machinery, medicine, architecture, industrial design, foundry, injection moulding and forming
- Metrology in 3D Printing
- Modern measurement methods
- Adaptive systems based on machine learning and artificial intelligence methods
- Post-processing methods

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Summary of AM26

The 9th International Conference "Rapid Prototyping. 3D & 4D Printing. Additive Manufacturing" (AM26) brought together a vibrant community of researchers, industry experts, and technological innovators to discuss the latest advancements in additive manufacturing and advanced materials engineering. The conference was held under the Honorary Patronage of His Magnificence, the Rector of AGH University of Krakow, Prof. Jerzy Lis.

The event gathered 124 participants representing leading academic institutions, research centers, and industrial enterprises from across Poland and abroad. The comprehensive scientific program featured 40 oral presentations and 35 poster contributions, supported by 18 sponsors and 10 partner organizations.

The oral program was structured across seven thematic sessions and a dedicated poster session. Key scientific contributions were highlighted by distinguished experts:

Keynote Speaker:

- Dr.-Ing. David Carlos Domingos (Fraunhofer IPK, Germany) – “Global R&D Collaboration in Additive Manufacturing: From Strategy to Impact”

Plenary Speakers:

- Prof. Marco Actis Grande (Politecnico di Torino, Italy) – “A new perspective on metal powder atomization: New materials and sustainable additive manufacturing”
- Prof. Klaudia Proniewska-van Dam (Jagiellonian University Collegium Medicum, Poland) – “3D printing in clinical education”
- Rob Keogh (Boston Micro Fabrication) – “PRECISION 3D-PRINTING - when detail and microns matter”

Invited Speakers:

- Ph.D., Eng. Tomasz Gałączyński (PZL Mielec) – “Growing Role of Additive and Incremental Manufacturing in the Aerospace Industry”
- Assoc. Prof. Marta Wincewicz-Bosy, PhD, DSc (General Tadeusz Kościuszko Military University of Land Forces) – “Challenges of using AM in military logistics”
- Assoc. Prof. Bożena Zgardzińska, PhD, DSc (Maria Curie-Skłodowska University in Lublin) – “Nanostructure of 3D-Printed Materials – A View Through the Eyes of Antimatter”
- Assoc. Prof. Jarosław Jasiński, PhD, DSc (National Centre for Nuclear Research) – “Processing and Irradiation Resistance of Additively Manufactured Inconel 617 Superalloy for Nuclear Applications”
- Petr Bartek (3Dees Industries) – “Hidden advantages of MJF powder bed technology in industrial applications”
- Tomasz Garniec (MELTIO) - "WLMD (Wire Laser Metal Deposition) Technology in the Context of Sustainable Metal Component Production: From Topological Optimization to Industrial Implementation"
- Tomasz Garniec (MELTIO) – “WLMD (Wire Laser Metal Deposition) Technology in the Context of Sustainable Metal Component Production: From Topological Optimization to Industrial Implementation”

A special industry session enabled representatives from eight companies to present technological solutions, featuring a hands-on technical workshop organized by 3Dees.

The academic caliber of AM26 was reflected in the participation of major national institutions, including AGH University of Krakow, Warsaw University of Technology, Krakow University of Technology, Wrocław University of Science and Technology, Gdańsk University of Technology, Rzeszów University of Technology, Military University of Technology, Kielce University of Technology, Białystok University of Technology, Częstochowska University of Technology, Gdynia Maritime University, Jagiellonian University, Maria Curie-Skłodowska University in Lublin, General Tadeusz Kościuszko Military University of Land Forces, the Central Office of Measures (GUM), and the National Centre for Nuclear Research (NCBJ). International collaboration was represented by attendees from VŠB – Technical University of Ostrava (Czech Republic), Politecnico di Torino (Italy), and Fraunhofer IPK (Germany).

Industry participation formed a core element of the conference, with contributions from 3D Lab Sp. z o.o., Huta Stalowa Wola S.A., MELTIO, PZL Mielec, Budimex, Bulten, B3D, 3DNEES-INDUSTRIES, ZREMB RADOM, ALUSUPPLIES, Fabryka Urządzeń Kolejowych, GLOBAL, Kuca Sp. z o.o., AMTH, Hydropress, Alpha Powders, EC TEST Systems, ZEISS, 4D Fusion, Keyence, SMARTTECH3D, Wired Print, Thoni Alutec, and Narzędzia i Urządzenia Wiertnicze Glinik.

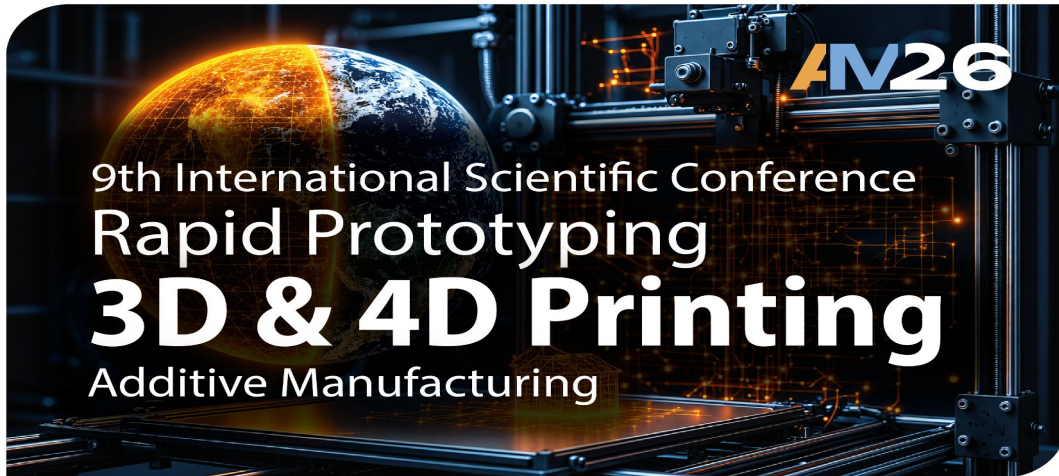
During the poster session, the Scientific Committee recognized three outstanding poster presentations:

- **1st Place:** Aleksandra Iwańczak (AGH University of Krakow) for the poster titled “Surface Modification of PBF-LB/M AlSi10Mg Alloy Using Laser Shot Peening”.
- **2nd Place:** Julia Głowacka (Adam Mickiewicz University in Poznań) for the poster titled “Material Selection and FGF Manufacturing of Future Mold Demonstrator for VAR”.
- **3rd Place:** Karol Janus (AGH University of Krakow) for the poster titled “Numerical Analysis of the SLM Process of AlSi10Mg Alloy Considering Melt Pool Geometry, Porosity and Microstructure and Its Experimental Validation”.

A extraordinary highlight of the conference’s social program was the festive gala dinner hosted deep underground in the historic chambers of the Wieliczka Salt Mine near Krakow, offering an unforgettable atmosphere for informal integration, fruitful conversations, and forging lasting international friendships.

The true success of AM26 lies in the community that built it. On behalf of the Organizing Committee, we wish to express our deepest appreciation to all speakers, delegates, session chairs, partners, and sponsors. Your scientific passion, intellectual curiosity, and generosity in sharing knowledge transformed this conference into an inspiring celebration of research and innovation. Thank you for your invaluable contributions, and we look forward to welcoming you back for the next edition.

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Session I

Tomasz Kurzynowski: *Factor-Based Methodology for PBF-LB/M Process Development*, Wrocław University of Science and Technology

Aleksandra Iwańczak, Krzysztof Żaba, Maciej Balcerzak, Łukasz Kuczek, Ilona Różycka: *Laser Power Optimization for Low-Power PBF-LB/M Processing of CuAl10Fe1 Bronze*, AGH University of Krakow

Sebastian Piecka, Michał Fedasz, Grzegorz Moneta: *A complete manufacturing route for CuCr1Zr combustion chambers: parameter development and mechanical characterization structured according to ECSS-Q-ST-70-80C*, Warsaw University of Technology

Paweł Widomski, Marcin Kaszuba, Joanna Kulasa, Magdalena Jabłońska, Zbigniew Gronostajski: *Effect of post-weld heat treatment on microstructure and wear resistance of Wire Laser Metal Deposited Dievar type tool steel*, Wrocław University of Science and Technology

Marcin Brzóska: *Effect of Post-Processing Treatments on the Surface Characteristics of DMLS-Manufactured AlSi10Mg and 316L Components*, AMTH

Paweł Ostachowski, Przemysław Snopiński, Krzysztof Żaba, Stanisław Rusz, Ondrej Hilser, Aleksandra Iwańczak: *Possibilities for KOBO technology in the field of plastic deformation additively manufactured materials*, AGH University of Krakow

Sylwia Styczyńska, Mateusz Szpak, Marek Burkot, Jacek Szpyrka: *LaserC®: From R&D Development to Field Validation*, Glinik sp. z o. o.

Factor-Based Methodology for PBF-LB/M Process Development

Tomasz Kurzynowski¹

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Keywords: PBF-LB/M, parameters, design, methodology, metal powders

Additive manufacturing technologies based on Laser Powder Bed Fusion (L-PBF) offer the possibility of manufacturing individually designed, geometrically complex products for special-purpose applications. According to reports by, among others, Gartner, Inc., Deloitte, MIT, and Goldman Sachs, additive manufacturing technologies are among the 15 most important global technological trends. Additive manufacturing is mainly used for processing metals and their alloys as well as polymers, but also ceramics and composites, which are currently the subject of advanced development activities. These technologies can have—and in many cases are already capable of having—a significant impact on reducing manufacturing and material costs, as well as eliminating certain production, assembly, and logistics operations. PBF-LB/M provides an opportunity to process technologically challenging materials and to manufacture functional products from advanced, next-generation materials with modified properties tailored to the service requirements of the manufactured components. A characteristic feature of this technology is that the mechanical properties of the final product depend on the developed parameters of the laser melting process (the so-called process window) and on the suitability of the feedstock material for a specific type of processing. This requires comprehensive investigation of the factors determining the effectiveness of the PBF-LB/M process, including powder properties, process parameters, manufacturing strategy, and the accuracy with which the geometry of the designed component is reproduced, as well as their influence on the properties of the final product. This paper presents a factor-based methodology for the design and implementation of PBF-LB/M technology for manufacturing components from both new and already established materials. The methodology considers the selection of technological, design, and material parameters that determine the quality of the final product.

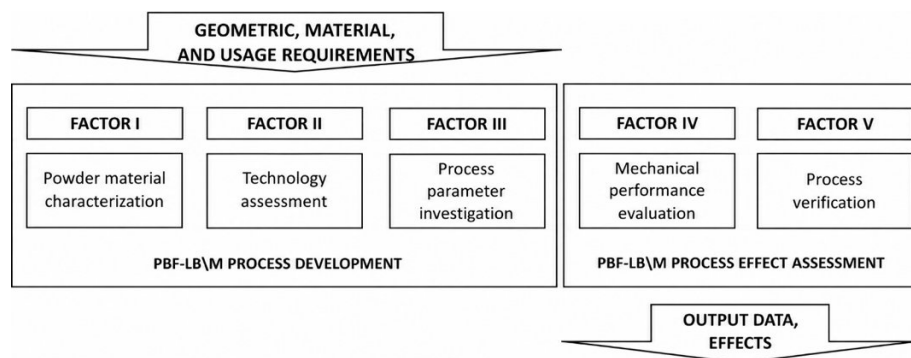


Figure 1. Factor-based methodology for material investigations of components manufactured using PBF-LB/M technology

A systematic methodological approach is essential for the proper development of PBF-LB/M process parameters and processing conditions. The proposed factor-based methodology enables the development of a comprehensive and stable additive manufacturing process, beginning with material-related factors and ending with quality-related factors describing both the process outcome and the properties of the processed material. The proposed approach enables all relevant parameters affecting the comprehensive optimization of the laser powder bed fusion process to be considered, with the objective of obtaining a homogeneous, defect-free material structure.

Laser Power Optimization for Low-Power PBF-LB/M Processing of CuAl10Fe1 Bronze

Aleksandra Iwańczak¹, Krzysztof Żaba¹, Maciej Balcerzak¹, Łukasz Kuczek¹, Ilona Różycka¹

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Keywords: CuAl10Fe1, aluminium-iron bronze, PBF-LB/M, additive manufacturing.

Additive manufacturing of copper-based alloys using laser powder bed fusion (PBF-LB/M) presents substantial technological hurdles, primarily stemming from the intrinsic physical properties of the feedstock material, such as high optical reflectivity at near-infrared wavelengths and exceptional thermal conductivity. These factors traditionally hamper effective energy coupling, often necessitating the employment of ultra-high-power laser systems to achieve dense, defect-free parts. This study presents an innovative strategy demonstrating that high consolidation and structural integrity in CuAl10Fe1 aluminum bronze can be successfully attained under low laser power conditions (up to 200 W) through rigorous, systematic parameter optimization. The research methodology initially involved a comprehensive evaluation of the virgin CuAl10Fe1 powder feedstock, incorporating particle morphology inspection, phase analysis via X-ray diffraction (XRD), and particle size distribution via sieve analysis. Key technological flow properties critical for uniform layer deposition, including Hall funnel flowability, bulk density, and tap density, were thoroughly quantified. In the processing stage, cubic specimens were fabricated across a range of laser powers spanning 100 W to 200 W. Subsequently, a rigorous quality assessment was conducted, including hydrostatic density evaluations via Archimedes' principle and surface topography characterization via profilometry. The mechanical response of the consolidated alloy was evaluated through uniaxial compression testing alongside localized microhardness mapping using the Vickers method. Metallographic cross-sections were systematically analyzed via optical microscopy to quantify porosity and defect generation, while XRD measurements confirmed the phase stability of the processed material. Precise tuning of the energy input effectively eliminated consolidation defects such as lack-of-fusion and keyholing, enabling full material densification. These findings confirm the viability of industrial-grade CuAl10Fe1 processing in low-energy PBF-LB/M systems, expanding the applicability of standard laser additive manufacturing platforms to highly conductive copper alloys.

A complete manufacturing route for CuCr1Zr combustion chambers: parameter development and mechanical characterization structured according to ECSS-Q-ST-70-80C

Sebastian Piecka¹, Michał Fedasz², Grzegorz Moneta³

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Keywords: CuCr1Zr, laser powder bed fusion, ECSS-Q-ST-70-80C, volumetric energy density, low-cycle fatigue.

ECSS-Q-ST-70-80C establishes the phase structure for verifying metallic powder bed fusion hardware but deliberately prescribes no process parameters, leaving their development to the user. The high reflectivity and thermal conductivity of CuCr1Zr further restrict the processing window. This study presents a comprehensive manufacturing route for a regeneratively cooled combustion chamber, organized into the definition, process verification, and prototype verification phases outlined in the standard. Parameter development followed a machine-learning-assisted iterative procedure. An initial matrix, generated around the manufacturer's baseline parameters, identified the densification maximum for the machine-feedstock combination; the resulting data informed a second, refined matrix, thereby reducing the specimen count. The window was applied to a productive layer thickness of 80 μm and refined against porosity and surface-quality criteria, yielding components with a relative density exceeding 99.8%. Processing conditions are described in terms of volumetric energy density, enabling direct comparison across machines. The presentation addresses the evolution of porosity across the parameter space, the tensile response in the build direction with surface-condition effects isolated through paired as-built and machined specimens, the low-cycle fatigue behavior, and the demonstrator chamber, including its manufacturing sequence and the verification of the internal cooling channels.

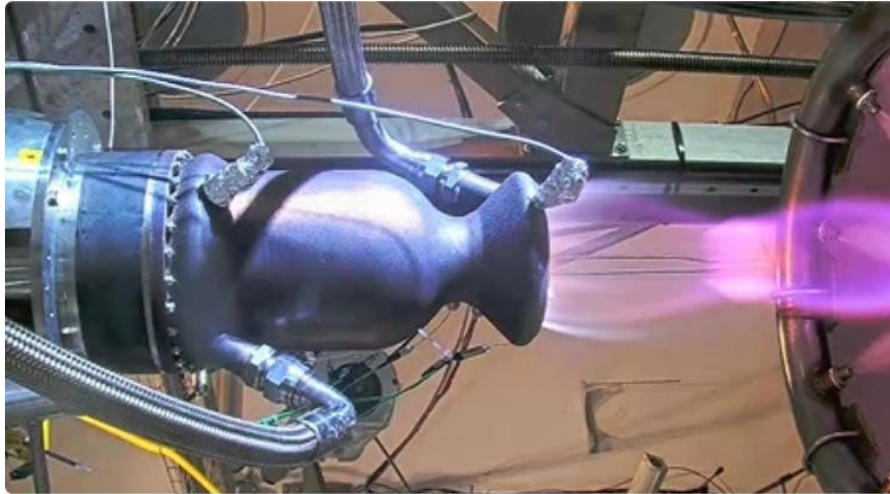


Figure 1. Demonstrator combustion chamber manufactured through the developed route during hot-fire testing.

Effect of post-weld heat treatment on microstructure and wear resistance of Wire Laser Metal Deposited Dievar type tool steel

Paweł Widomski^{1,2*}, Marcin Kaszuba^{1,2}, Joanna Kulasa³, Magdalena Jabłońska³, Zbigniew Gronostajski^{1,2}

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Keywords: additive manufacturing, wire – laser metal deposition, post weld heat treatment, wear, tool steel.

Wire Laser Metal Deposition (W-LMD) is increasingly used for manufacturing and repair of tooling components; however, its layer-by-layer thermal cycling produces complex microstructures that strongly affect wear performance. In this study, a newly developed Dievar-type tool steel was fabricated as a 1.0 mm diameter wire feedstock for W-LMD, and the influence of post-weld heat treatment (PWHT) on microstructure and wear resistance was investigated.

Five processing conditions were examined: as-deposited; tempering at 550°C and 600°C; and quenching and tempering at 550°C and 600°C. Wear behaviour was evaluated using ball-on-disc testing under dry sliding conditions, while SEM, EDS, and EBSD were used for microstructural characterization.

PWHT significantly affected wear resistance. The lowest wear coefficient was obtained for the as-deposited condition tempered at 550°C, indicating the highest wear resistance. This condition was therefore selected for detailed microstructural analysis. SEM revealed a layered structure typical of W-LMD, predominantly consisting of tempered martensite. EBSD identified localized bands of retained austenite within selected layers, associated with refined microstructural regions and varying thermal histories during deposition. KAM maps indicated elevated local strain within the deposit, while EDS revealed compositional gradients across the substrate–deposit interface.

The results demonstrate that appropriate PWHT can effectively tailor the microstructure and improve the wear resistance of W-LMD Dievar-type tool steel. Tempering at 550°C provided the most favourable combination of microstructural stability, strain distribution, and tribological performance.

Possibilities for KOBO technology in the field of plastic deformation additively manufactured materials

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Keywords: Powder Bed Fusion – Laser Beam / Metals, additive manufacturing, KOBO extrusion, structure, mechanical properties.

PBF-LB/M (Powder Bed Fusion – Laser Beam / Metals) is an additive 3D printing technology that involves laser melting of metal powders in a bed. It enables the formation of components that are impossible to produce using conventional subtractive machining techniques. The resulting products are characterized by a density close to theoretical, similar to that of cast or plastically processed components. The KOBO method, on the other hand, is an unconventional technology for plastic forming of metals and its alloys with high strain ratio and rates. This paper presents the possibilities of using KOBO extrusion to formation the structure and mechanical properties of the resulting extrusion, aiming to achieve the most favorable combination of strength and ductility.

The research was funded by the National Science Centre, Poland, based on the decision number 2024/53/B/ST8/003574

Effect of Post-Processing Treatments on the Surface Characteristics of DMLS-Manufactured AlSi10Mg and 316L Components

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Keywords: DMLS, surface roughness, postprocessing, 316L, AlSi10Mg.

Additive manufacturing provides significantly greater design freedom compared with traditional manufacturing methods, such as machining or casting. LPBF technologies enable the production of complex, lattice-like geometries of printed components. This makes it possible to optimize existing designs in terms of weight, as well as to develop components with performance characteristics superior to those of conventionally manufactured parts. Cooling components can serve as an example of such applications. In addition, additive manufacturing technologies can shorten the order-to-delivery lead time, which is particularly beneficial for prototyping and reverse engineering.

Despite the advantages described above, metal parts manufactured by LPBF methods are characterized by several limitations, including high production costs, poor surface quality, and complex microstructure that is difficult to control. Both the microstructure and surface quality can be modified during the printing process as well as during post-processing. Numerous process parameters affect surface quality and microstructure during printing. These process parameters are often independent of one another, resulting in a very large number of possible parameter configurations. To date, no universal combination of laser operating parameters and other process parameters has been developed that could be applied to all geometries while maintaining a competitive printing time.

For companies specializing in metal additive manufacturing services, where there is a high degree of variability in the shapes and dimensions of printed components. Individual adjustment of printing parameters for each part would be a time-consuming process, resulting in increased production costs. Therefore, such companies typically use several validated parameter sets applicable to specific geometries. This approach has several consequences: the production planning process is faster and less complex; however, the printed parts may exhibit certain defects. To standardize the manufacturing process, various post-processing treatments are used, which can be applied to a wide range of printed part geometries.

This study investigates the problem of high surface roughness in DMLS-manufactured AlSi10Mg and 316L metal components. The selection of the investigated materials was based on the high demand for these materials in the metal additive manufacturing service market. The contour region was selected as the main scanning region for investigation. The surface treatments selected for roughness reduction were glass bead blasting (GB), sandblasting (SB), vibro-finishing (VF), and electropolishing (EP). The selected surface treatment methods can be adapted to process a wide range of geometries without the need for machine retooling.

Different configurations of process parameters and treatment durations were investigated. The effects of individual treatment configurations on selected mechanical and surface properties were evaluated, including surface roughness using a contact measurement method (Ra, Rz, and Rv parameters) and hardness using the Vickers method with an ESATEST system. Additionally, microscopic observations of the treated and untreated surfaces were performed.

LaserC®: From R&D Development to Field Validation

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Keywords: LaserC®; laser metal deposition (LMD); hardfacing; drilling tools; wear-resistant metal matrix composites

Roller cone drill bits and polycrystalline diamond compact (PDC) bits operate under severe abrasive and impact conditions, making the durability of hardfacing critical to tool service life. This work presents the industrial development, field validation and subsequent optimisation of LaserC® technology for the protection and life extension of drilling tools. The technology was developed by Glinik Drilling Tools within a completed R&D project co-financed by the Polish National Centre for Research and Development (NCBR) (POIR.01.01.00-0705/18-00).

LaserC® enables the automated and accurate deposition of wear-resistant metal matrix composite overlays on complex tool geometries. In laboratory testing, the LaserC® coating achieved an abrasion resistance value of 45.4 (reference material – Hardox 450), compared to 8.23 for gas-welded hardfacing. The coating also demonstrated an impact strength of 112.5 J/cm², which exceeds the value of 58.6 J/cm² recorded for gas-welded coatings. Metallographic examination confirmed a fine-grained microstructure, homogeneous distribution of reinforcing particles, low porosity, and an absence of cracks.

The coatings were subsequently evaluated in field trials conducted under typical drilling and operating conditions during oil and gas exploration activities in the North Sea and the Middle East. Compared with the reference solutions, the LaserC®-treated tools demonstrated improved wear resistance and service performance. Field observations provided valuable insights into the dominant wear mechanisms and the factors that govern coating performance in challenging operating conditions.

These results informed the subsequent optimisation of the matrix composition, reinforcing phases, and deposition parameters. The developed LaserC® approach offers a data-driven method for hardfacing and regenerating drilling tools, combining additive manufacturing with advanced, wear-resistant materials and precise laser deposition.

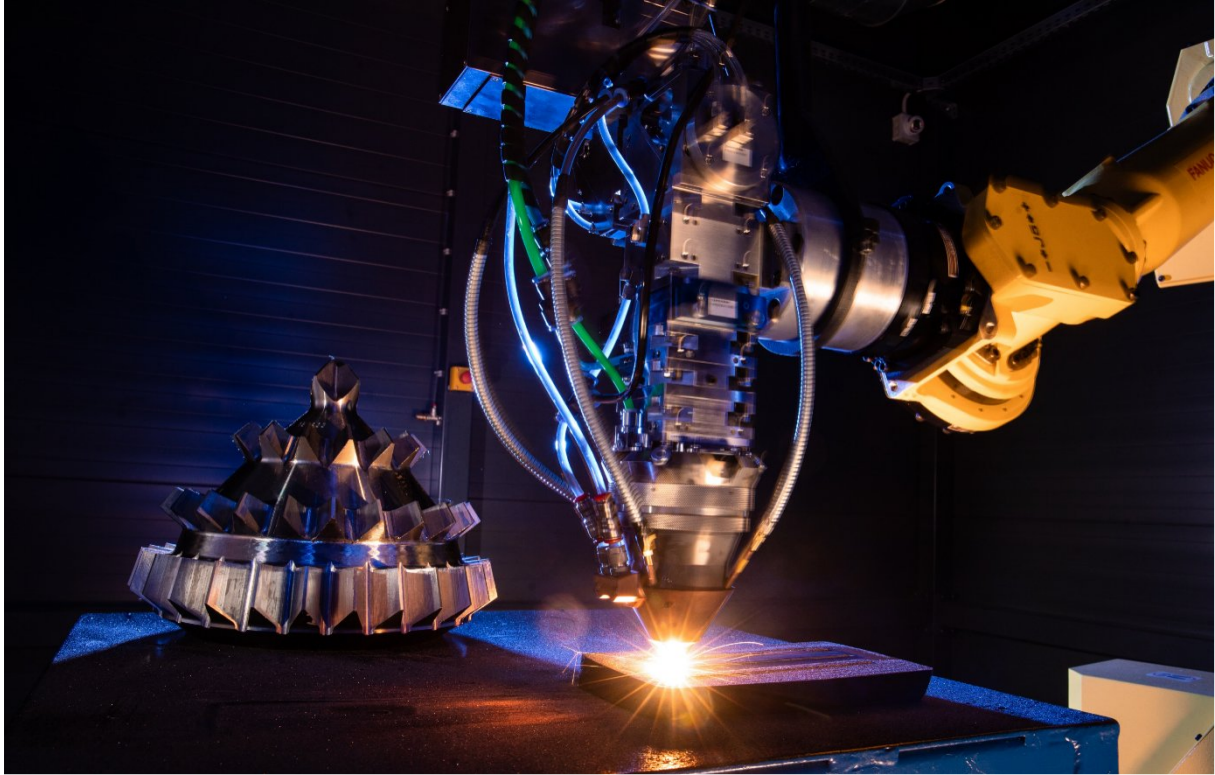


Figure 1. LaserC®

Session II

Lucyna Jaworska, Dorota Tyrała, Adam Tchórz, Joanna Kowalska, Maciej Ziętara: *Preparation of powders and homogeneity testing of composite materials and refractory alloy powders intended for sintering, including direct AM methods*, AGH University of Krakow

Weronika Wańczyk, Magdalena Jankowska, Klaudia Trembecka-Wójciga, Joanna Ortyl: *Light-based 3D printing as a method for producing highly customized ceramic bone scaffolds intended for implantology*, Cracow University of Technology

Krystian Zyguła, Piotr Ledwig, Grzegorz Cios: *The use of in-situ reaction to produce titanium-based composite powders in the ultrasonic atomization process*, AGH University of Krakow

Michał Rzepecki, Alina Kuśnierz, Andrzej Rybak, Joanna Ortyl: *Investigation of composite 3D printed molds for manufacturing processes*, Cracow University of Technology

Beata Leszczyńska-Madej, Ewa Małkowska, Marcin Madej, Anna Wąsik, Julia Kwiatkowska, Paweł Nieroda: *FAST/SPS Processing of HEA-Ti₃SiC₂ Composites: From Microstructural Evolution to Mechanical Performance*, AGH University of Krakow

Piotr Matysik: *Development of a manufacturing technology for complex and personalized components based on improved two-stage design methods and a new innovative casting technique that represents a break-through in the aluminum casting industry*, Thoni Alutec

Anna Wąsik, Mateusz Gawron, Marcin Madej, Paweł Nieroda, Beata Leszczyńska-Madej: *Phase Evolution and Mechanical Performance of FAST/SPS-Processed HEA-Ti₃SiC₂-SiC Composites*, AGH University of Krakow

Preparation of powders and homogeneity testing of composite materials and refractory alloy powders intended for sintering, including direct AM methods

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Keywords: powders, metal-ceramic composites, sintering, homogeneity, microstructure 3D image.

The fundamental difficulty in obtaining metal matrix composite materials reinforced with ceramic particles and refractory metal alloys is the lack of suitable powders and mixtures. This problem is even more pronounced in the case of additive sintering methods. This raises the issue of evenly distributing the reinforcing phase throughout the composite and requires testing to confirm material homogeneity.

Recently, there has been increasing interest in tool materials. Some concepts for cemented carbides have already been implemented. But the metal binder (such as Co) melts or softens to bind the hard carbide particles, though high local energy input can trigger cobalt vaporization. Direct SLS rarely achieves 100% theoretical density on its own, often requiring secondary infiltration (e.g., with bronze) or post-sintering furnace additional processes.

Rapid heating and cooling cycles generate significant thermal shock, leading to cracking and internal residual stresses inside the hardmetal matrix. SLS vs. SLM fully liquefies the pool, yielding higher initial density but aggravating thermal stress and cobalt loss compared to controlled-sintering approaches.

Composites with a higher metallic phase content pose even more challenges. Designing these materials requires consideration of the density and particle size of the combined phase powders to ensure the homogeneity of the composite when preparing the sintering mixtures. Applications of SLS technology to produce diamond grinding wheels with a specially structured structure are gaining increasing interest. Diamond is a metastable phase that graphitizes at temperatures around 750 °C. Methods for improving diamond resistance through the use of thermal barrier coatings will be presented, as well as X-ray computed tomography studies of particles distribution in ceramic composite containing diamond, Figure 1.

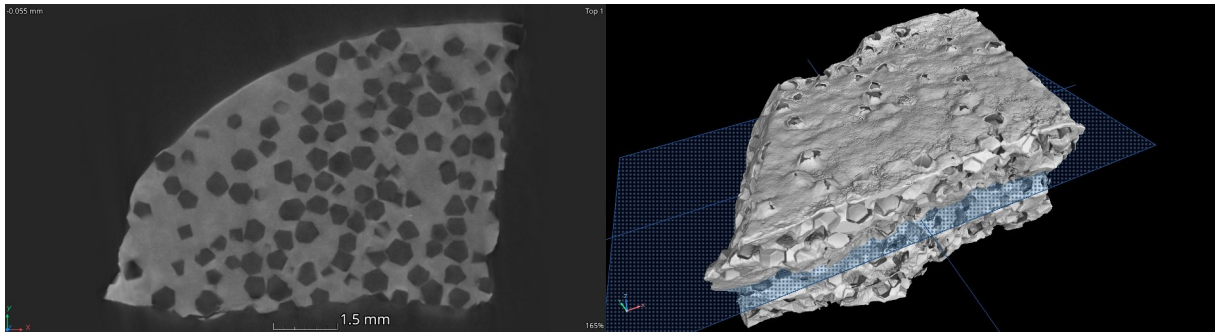


Figure 1. X-ray computed tomography studies of the particles distribution in ceramic composite containing diamond

The second presented issue will be the preparation of refractory metal alloy powders, taking Zr-Ti as an example, using the mechanical alloying method and the ultrasonic method.

Light-based 3D printing as a method for producing highly customized ceramic bone scaffolds intended for implantology

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Keywords: 3D printing, photopolymerization, ceramic particles, zirconium oxide, bone scaffolds.

Light-based 3D printing is promising as an approach to manufacturing highly personalized ceramic bone scaffolds for tissue engineering and implantology [1]. Technologies such as stereolithography and digital light processing enable the production of patient-specific structures characterized by high dimensional accuracy, controlled porosity, and interconnected pore networks that promote bone regeneration. In this study, zirconia (ZrO_2) was used as the ceramic material due to its high strength, fracture resistance, biocompatibility, and chemical stability [2]. Furthermore, controlled porosity can reduce the effective stiffness of zirconia structures to values similar to those of bone and may help reduce stress shielding compared to conventional, dense metal implants [3]. A novel photo-curable resin containing ceramic particles for photopolymerization was developed and optimized. The study included an analysis of photopolymerization kinetics, rheological characterization, and photo-DSC measurements to evaluate behavior during curing and processability. The binder removal and sintering processes were examined in terms of shrinkage, porosity, dimensional stability, and final microstructure. The mechanical properties of the sintered scaffolds were also evaluated. The results indicate the potential of light-based additive manufacturing for producing customized zirconia scaffolds with precisely controlled architecture.

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The use of in-situ reaction to produce titanium-based composite powders in the ultrasonic atomization process

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Keywords: titanium matrix composites; in-situ reaction; powder metallurgy; atomization.

Titanium matrix composites (TMCs) are gaining increasing attention due to their low density and unique combination of corrosion and high-temperature creep resistance, high stiffness, and exceptional abrasive wear resistance. Therefore, industrial sectors such as aerospace, automotive, and advanced technology industries show a significant demand for this class of materials. Powder metallurgy is the primary technology used to produce TMCs. In particular, the use of B_4C particles and in-situ reactions during the fabrication of TMCs has become a widely adopted approach. Based on the exothermic reaction between Ti and B_4C particles, two additional reinforcing phases, TiB_x and TiC , are precipitated. The dynamic development of laser-based additive manufacturing (AM) processes creates new opportunities for the fabrication of TMCs, as in-situ reactions can be initiated during the melting of successive powder layers. However, the use of elemental powders in AM is limited by the trade-off between in-situ alloying, porosity reduction, and microstructural homogeneity. Composite powders may overcome these limitations by enabling dense, chemically homogeneous materials with reinforcing precipitates coherent with the matrix.

The aim of this study was to optimize the production process of composite powders using ultrasonic atomization of green compacts prepared from titanium-based elemental powder mixtures with the addition of B_4C particles, to obtain alloy powder of suitable quality for AM processes. Seven chemical composition variants were selected for the study, allowing the influence of the reinforcing phase content on in-situ reactions, as well as the possibility of simultaneous in-situ alloying and strengthening, to be evaluated. Subsequently powders were mixed in a double-cone mixer, and then cold compacted in a closed die. The average relative density of the green compacts was in the range of 73-77%. Then compacts were subjected to atomization using an ATO Lab+ ultrasonic atomizer. The optimal atomization conditions were defined, which enabled successful processing of all mixtures into composite powders.

The analysis of the produced powders was based on XRD, SEM-EDS and EBSD investigations. Fig. 1a and b show the diffraction patterns for all variants of the obtained powders. The presence of α and β phase peaks in the alloyed powder mixtures confirmed the effectiveness of the proposed method for producing master alloy powders. For the addition of 1% B_4C , no additional reinforcing phases were detected, indicating the absence or only a minimal volume fraction of precipitates. For higher B_4C contents, additional peaks were identified as TiC or TiB_xC_y phases. Fig. 1c-e present selected SEM images of the

powders after atomization, together with the EDS analysis results. The atomization process resulted in spherical particles with a low satellite content. The microstructure of a Ti6Al4V+2%B₄C particle consists mainly of acicular α -phase precipitates. In addition, two characteristic types of precipitates were identified, which are acicular and blocky precipitates, marked as 1 and 2, respectively. The EDS analysis revealed the presence of Ti, B, and C in these precipitates, indicating that an in-situ reaction occurred. The EBSD maps for Ti+3%B₄C (Fig. 1f) confirmed the presence of TiB, TiB₂, and TiC phases, which agrees with the XRD results.

As a result of this study, a method for producing Ti-based composite powders with addition of B₄C using ultrasonic atomization of green compacts prepared from elemental powders was developed and verified. Phase and microstructural analyses confirmed the occurrence of an in-situ reaction between titanium and B₄C particles during atomization, as well as the formation of Ti-containing phases enriched in carbon or boron. The possibility of simultaneous alloying and in-situ strengthening in multicomponent powder mixtures was confirmed.

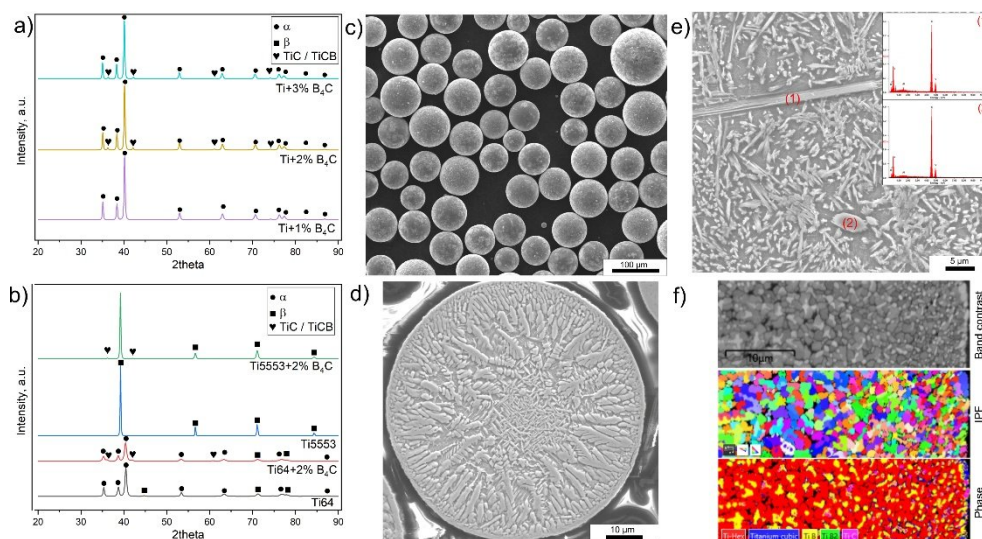


Figure 1. a), b) Diffraction patterns of produced powders, SEM images of c) Ti5553+2%B₄C powder particles, cross-section of d) Ti6Al4V powder particle, and e) Ti6Al4V+2%B₄C particle with EDS analysis results, f) EBSD maps of a Ti+3%B₄C powder particle.

Acknowledgements

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Investigation of composite 3D printed molds for manufacturing processes

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Keywords: 3D printing, printed molds, SLA printing, printable composites.

Prototyping components using commonly employed manufacturing methods, such as injection molding and compression molding, is often associated with the time-consuming fabrication of expensive metal molds produced using subtractive manufacturing methods.

In this research, 3D-printed molds for injection molding, compression molding, and rubber vulcanization were investigated. A commercially available photocurable resin, Ultracure RG3280, provided by Forward AM, was used for mold fabrication. This material is characterized by high stiffness at room temperatures and relatively high glass transition temperature compared with other commercially available acrylic resins for SLA 3D printing. The molds were tested by ABB using industrial-grade injection molding machines and compression presses.

Based on the experimental results, the most critical parameters requiring improvement were identified. To enhance mechanical performance at elevated temperatures and improve impact strength, the addition of glass fibers and wollastonite was investigated. The resulting composites were mechanically characterized using three-point bending tests conducted at room temperature and at 50, 100, and 150 °C.

The research was carried out as part of collaboration between Cracow University of Technology and Corporate Technology Center of ABB Sp z o.o. The research was carried out as part of project “Doktorat Wdrożeniowy” No. DWD/9/0332/2025, funded by the Ministerstwo Nauki i Szkolnictwa Wyższego.

FAST/SPS Processing of HEA–Ti₃SiC₂ Composites: From Microstructural Evolution to Mechanical Performance

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Keywords: CoCrFeMnNi alloy, Ti₃SiC₂, FAST/SPS, phase evolution, secondary phases.

High-entropy CoCrFeMnNi-based composites containing 5, 10 and 15 wt.% Ti₃SiC₂ were consolidated by field-assisted/spark plasma sintering (FAST/SPS) at 1050 and 1060 °C. The study focused on the stability of the Ti₃SiC₂ MAX phase and its influence on phase and microstructural evolution during consolidation. The obtained materials exhibited relative densities of 94.74–96.68%, while changes in Ti₃SiC₂ content and sintering temperature did not produce a systematic improvement in densification. XRD analysis revealed that Ti₃SiC₂ was only partially stable under the applied FAST/SPS conditions. In addition to the FCC HEA matrix and residual MAX phase, TiC, chromium carbides and Mn–Ni–Si intermetallic phases were identified. Microstructural observations confirmed increasing contributions of reaction-derived regions with increasing Ti₃SiC₂ content. The results indicate that Ti₃SiC₂ acts not only as a reinforcing phase but also as a source of elements participating in reactions with the HEA matrix during consolidation. These transformations modify the final microstructure and contribute to the observed changes in hardness and compressive behavior. The study highlights the importance of MAX-phase stability in controlling the properties of FAST/SPS-processed HEA–Ti₃SiC₂ composites.

Acknowledgements

This research was funded by the Excellence Initiative – Research University (IDUB) program at AGH University of Krakow No. 18275.

Development of a manufacturing technology for complex and personalized components based on improved two-stage design methods and a new innovative casting technique that represents a breakthrough in the aluminum casting industry

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Keywords: 3d Printing, On-Demand Manufacturing

A unique technology in the field of aluminum casting has been developed to address the challenges facing this sector of the economy in the European region. The objective was to develop a unique technology integrating the most efficient processes for manufacturing complex and customized aluminum components for the following sectors: energy, robotics, railways, medicine, and machinery. Unique features and functionalities of the project's outcome: a proprietary method for pouring castings with a spiral-shaped main sprue, a modified traditional casting method, as part of the technology for producing complex components in accordance with the On-Demand Manufacturing concept. The scope of work included designing the optimal shape of the main sprue and verifying it using the MAGMA software. Based on the results obtained from the casting process simulation and verification under industrial conditions, a library of mathematical representations of spirals was developed. Through the use of this innovative technology, process efficiency was increased and the quality of complex parts was improved.

Phase Evolution and Mechanical Performance of FAST/SPS-Processed HEA–Ti₃SiC₂–SiC Composites

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Keywords: high-entropy alloy, FAST/SPS, MAX phase, microstructure, mechanical properties

Hybrid high-entropy alloy (HEA) composites reinforced with Ti₃SiC₂ MAX phase and SiC particles were fabricated by FAST/SPS to investigate the effects of sintering temperature and Ti₃SiC₂ content on their phase composition, microstructure and mechanical properties. The powders were consolidated at 930–1050 °C and characterized using XRD, SEM, relative density measurements, hardness testing and compression tests.

XRD analysis revealed partial destabilization of the Ti₃SiC₂ MAX phase and the formation of TiC, chromium carbides and intermetallic phases. At 1000 and 1050 °C, liquid-phase formation was accompanied by substantial microstructural reconstruction and changes in the phase composition. Representative SEM micrographs of the composites sintered at 930 and 1000 °C, together with material expelled through the die–punch clearance at 1000 °C, are presented in Fig. 1. The highest relative density (95.84%) and compressive strength (1817 MPa) were obtained for the HEA–10Ti₃SiC₂–5SiC composite sintered at 950 °C, whereas the highest hardness (1267 HV1) was achieved for the HEA–20Ti₃SiC₂–5SiC composite sintered at 1050 °C.

Overall, the results indicate that 950 °C provides the most favorable balance between densification and compressive strength, while higher temperatures intensify phase transformations and promote increased hardness.

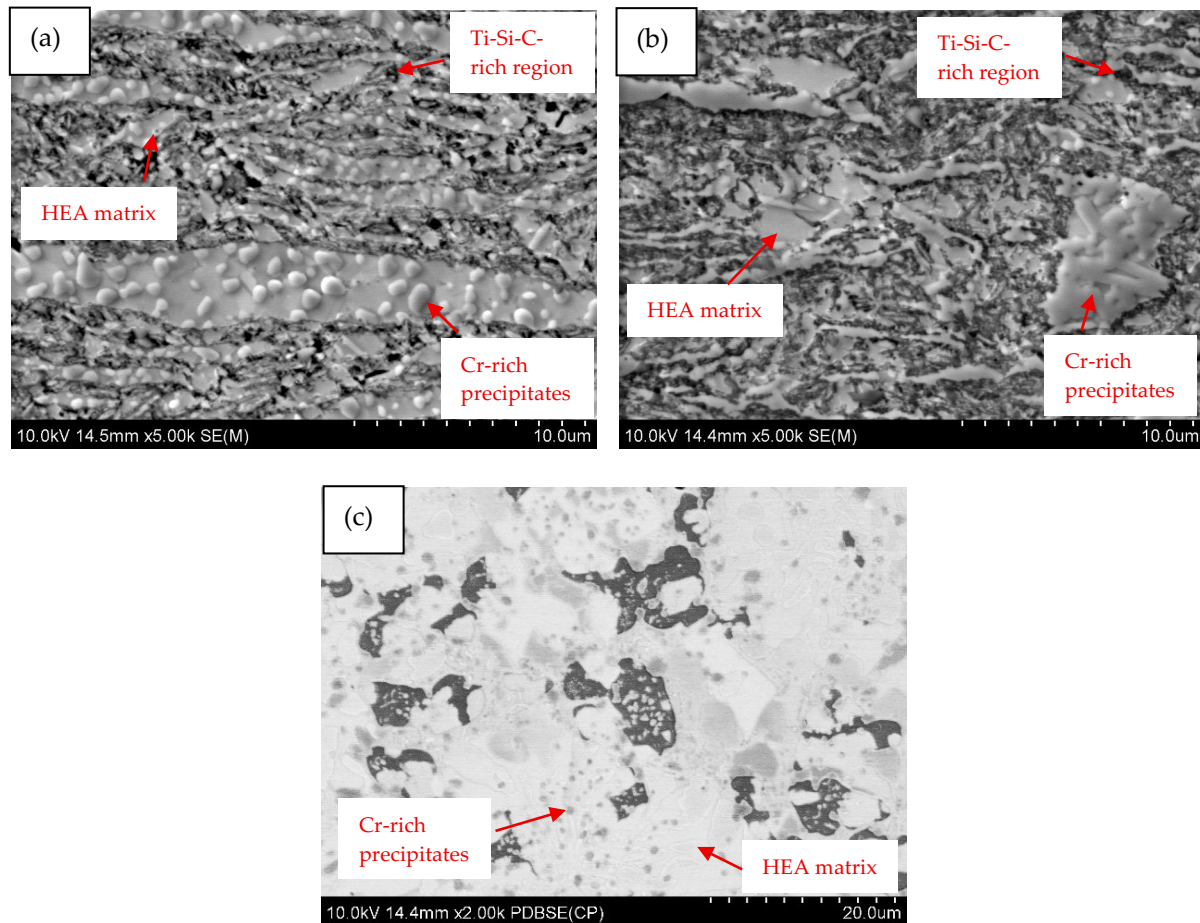


Figure 1. SEM micrographs of the HEA-20Ti₃SiC₂-5SiC composite consolidated by FAST/SPS at: (a) 930 °C and (b) 1000 °C; (c) material expelled through the die-punch clearance during consolidation at 1000 °C.

Acknowledgements

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Session III

Jakub Pochodaj: Additive technologies as a factor of antifragility of military supply chains during armed conflict, General Tadeusz Kościuszko Military University of Land Forces

Krzysztof Grzelak, Jakub Łuszczek, Janusz Kluczyński, Bartłomiej Sarzyński, Agnieszka Klimek: Mobile Additive Manufacturing Station, Military University of Technology

Paweł Kasza: Analysis of the Application of Subtractive Manufacturing in the Production of Prototypes Using Additive Manufacturing Methods, Kielce University of Technology

Mateusz Cieślik, Agata Rodak, Krzysztof Formela, **Jacek Ryl:** Beyond 3D Printing: Rapid Manufacturing of Functional Electrochemical Interfaces, Gdańsk University of Technology

Sebastian Wróbel, Alexander Eckhoff: In-situ alloying and Ultrasonic Atomization of High-Strength Aluminum Powders for LPBF, 3D Lab

Lucas de Figueiredo Soares, Gustavo Reis de Ascencao, Renan Oss Giacomelli, David Carlos Domingos, Rodrigo Santiago Coelho: Prediction of defect-induced thermal oscillations via numerical simulation of additively manufactured parts, validated using in situ monitoring data, Fraunhofer IPK

Additive manufacturing as a factor in the antifragility of military supply chains during armed conflict.

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Keywords: military logistics, additive manufacturing, supply chains, civil-military cooperation

Combat service support on the modern battlefield differs significantly from the long-established image. The experience of recent armed conflicts has demonstrated the need to change the approach to logistic support processes and highlighted the significant roles played by disruptive technologies, including additive manufacturing.

While the discourse around 3D printing for military often focuses on the production of unmanned systems, additive technologies demonstrate remarkable potential across areas of logistic support as well.

The central argument of this presentation is that, at the tactical level, the particular utility of additive technologies lies in rapid prototyping, the capacity for dynamic mass production of replacement parts, and the enhancement of supply chain antifragility.

Modern military operations are not conducted in isolation; therefore, successfully achieving national security and defense objectives requires collaboration with the civilian sector—particularly regarding breakthrough technologies such as additive manufacturing. This necessitates a mutual understanding of the needs and operational realities of the end-user: the soldier on the battlefield.

This presentation is based on an analysis of literature and documentation, as well as the author's own domestic and international experience—drawing specifically on insights gained through participation in the European Defence Agency's "Additive Manufacturing for Logistics Support" project.

Mobile Additive Manufacturing Station

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Keywords additive manufacturing technology, logistics support, mobile AM systems.

Additive manufacturing technology, when applied in the military domain, can complement military technical support systems by enabling selected components to be manufactured close to their point of use, thereby becoming an integral part of the logistics support system. The Polish Armed Forces are currently conducting conceptual work on the implementation of an additive manufacturing technology system, including its application within the aforementioned scope. One of the practical components of the system under development is the Mobile Additive Manufacturing Station (MAMS), developed at the Military University of Technology in cooperation with the Inspectorate for Armed Forces Support. The solution was designed as a demonstrator of mobile manufacturing capabilities intended to support logistics operations under field conditions and to validate the proposed solutions during national and international training activities.



Figure 1. Interior of the MAMS, showing the post-processing area (left), the additive manufacturing area (right), and the CAD/CAM and 3D scanning area (centre)

The station was conceived to enable additive manufacturing processes to be conducted under conditions representative of the actual military operating environment. Consequently, the system was integrated into a SARNA II special-purpose body mounted on a STAR 266 M2 truck chassis, providing mobility and allowing the workstation to be rapidly deployed regardless of the area of operations. The station interior was divided into three primary functional zones dedicated to the preparation of manufacturing documentation, the manufacturing process, and post-processing. This configuration enables the entire manufacturing workflow to be performed, from the creation or modification of a digital model, through additive manufacturing of the component, to basic finishing operations and preparation of the part for subsequent use.

Analysis of the Application of Subtractive Manufacturing in the Production of Prototypes Using Additive Manufacturing Methods

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Keywords: 3D printing, Additive manufacturing technologies, postprocessing, prototyping, CNC subtractive machining, geometric surface structure, dimensional and geometrical accuracy

3D printing enables rapid prototyping, the manufacturing of components with complex geometries, and a reduction in production costs. Despite the numerous advantages of additive manufacturing technologies, challenges related to surface quality and the accurate reproduction of component geometry remain. This presentation focuses on the application of subtractive machining as a post-processing method for components manufactured using Material Extrusion (MEX) technology. Cylindrical specimens were produced using MEX technology and subsequently subjected to turning. The conducted research demonstrated that subtractive machining, particularly turning, can be an effective method for improving the geometric accuracy and functional properties of 3D-printed components. The aim of the presentation is to demonstrate the potential of subtractive machining technologies for the finishing of 3D-printed components, assess their effectiveness, and discuss the limitations and challenges associated with post-processing of MEX-manufactured parts.

Sample Name	Before Finishing, mm	samples before and after subtractive machining.		
		Depth of cut a_p in mm		
		0.3	0,5	1
A1	29.77	29.32	29.02	27.98
A2	29.79	29.42	29.01	28.02
A3	29.62	29.33	28.98	28.00
A4	29.42	29.43	28.99	28.02
A5	29.52	29.38	28.99	27.99
B1	30.07	29.41	29.00	27.99
B2	30.12	29.39	29.01	28.01
B3	30.17	29.41	28.98	28.00
B4	30,09	29,42	29,01	28,02
B5	30,16	29,38	28,99	27,98

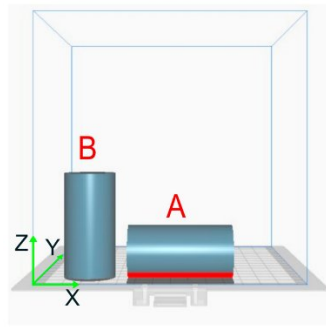


Figure 1. Placement of samples on the 3D printer platform, including markings



Figure 2. Sample during turning

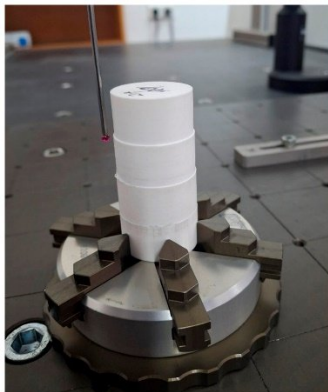


Figure 3. Appearance of the sample and its fixation

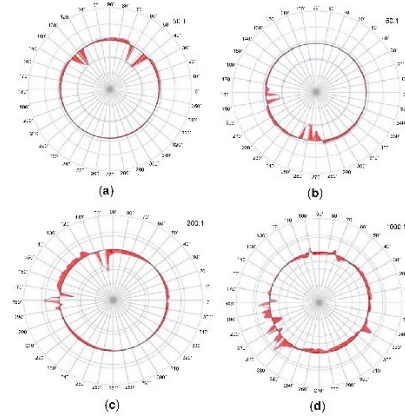


Figure 4. Roundness profile for sample

Beyond 3D Printing: Rapid Manufacturing of Functional Electrochemical Interfaces

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Keywords: additive manufacturing, electrochemical interfaces, carbon-based composites.

Rapid manufacturing technologies, including material-extrusion 3D printing, direct ink writing, inkjet and screen printing, but also direct laser writing and related techniques, are increasingly used to fabricate electrodes and integrated analytical devices for sensing, energy, and other electrochemistry-related applications. Their successful implementation relies on the deliberate design of functional polymer-based composites that combine processability, electrical conductivity, mechanical stability, and electrochemical activity.

This contribution presents our approach to controlling the complete manufacturing pathway of carbon-based electrode materials, from feedstock formulation and processing to the electrochemical properties of the final structure. Particular attention is given to conductive thermoplastic composites developed for 3D printing. Their composition is tailored through the selection of polymer matrices, plasticizers, conductive and electrocatalytic additives. We have formulated and processed into printable, conductive filaments poly(lactic acid)-based composites containing carbon black, detonation nanodiamonds, or waste-derived carbon fillers. The relationships between filler dispersion, rheological behavior, electrical percolation, and electrochemical charge-transfer kinetics, as well as the importance of post-processing technologies, are discussed. The versatility of the developed materials is demonstrated using electrochemical sensors manufactured by different rapid fabrication routes. For example, our entirely 3D-printed electrochemical cell was used for antibiotics determination in industrial wastewater, reaching nanomolar detection limits over repeated analyses.

In-situ alloying and Ultrasonic Atomization of High-Strength Aluminum Powders for LPBF

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Keywords: ultrasonic atomization, in situ alloying, aluminium alloy, laser powder bed fusion (LPBF), powder characterization

This work presents a technological pathway for the production of an innovative AlMgSiAg aluminium alloy with enhanced mechanical properties, specifically optimized for additive manufacturing (AM) applications.

The desired alloy powder was produced using ultrasonic atomization. High-purity elemental feedstock materials were alloyed either in an induction furnace or directly in an induction melting module (IMS) integrated with an ultrasonic atomization module, enabling alloying and atomization within a single process. Electromagnetic stirring was used to promote mixing and homogenization of the elemental constituents, while argon flow was additionally applied in the IMS module to further enhance the efficiency of the homogenization process.

The resulting powders exhibited high quality, a narrow particle size distribution, high sphericity, and the desired chemical composition. The powder was subsequently evaluated for its suitability for additive manufacturing, and the process parameters for laser powder bed fusion (LPBF) were optimized. The optimized powder was used to manufacture specimens for mechanical testing in order to evaluate the material performance and validate the selected printing parameters. Further research will focus on a comprehensive assessment of the mechanical properties and, if necessary, further modification and optimization of the powder chemical composition.

Table 1. Ultrasonic atomization - process parameters

Argon flow [l/min]	Amplitude US [%]	Power US [W]	Temp. crucible [°C]	Temp. platform [°C]	Time [min]
25	40	450 - 500	750 - 780	480 - 500	10 - 15

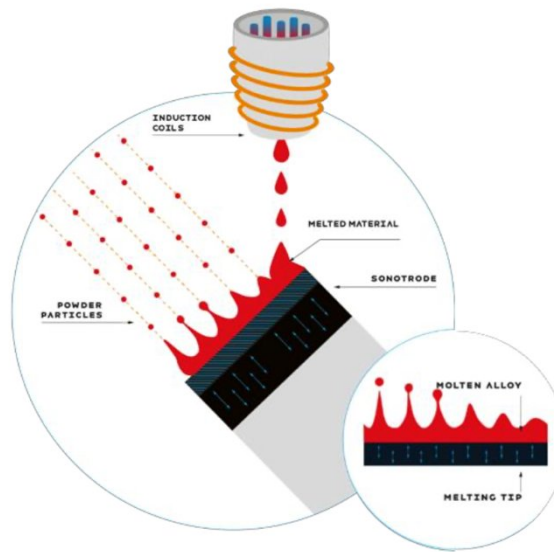


Figure 1. Visualization of ultrasonic atomization

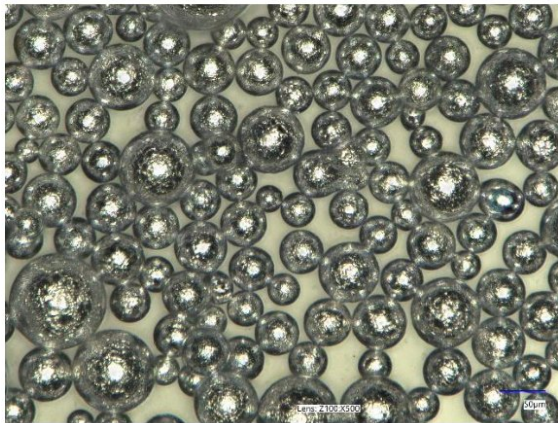


Figure 2. Photo of the material x500 (unsieved powder)

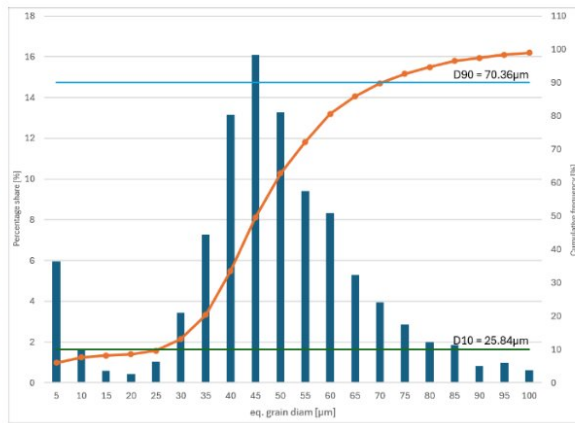


Figure 3. Histogram of particle size distribution (unsieved powder)

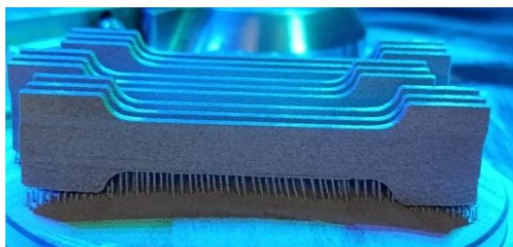


Figure 4. 3D-printed tensile specimens for mechanical testing



Figure 5. 3D-printed discs for mechanical testing

Prediction of defect-induced thermal oscillations via numerical simulation of additively manufactured parts, validated using in situ monitoring data

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Keywords: Additive manufacturing, Selective laser melting, Numerical simulation, Thermal.

Metal additive manufacturing involves the successive deposition of molten material, generating complex thermal cycles through repeated heating, cooling, and reheating that can lead to defects such as porosity and residual stresses. Thermal and thermomechanical simulations have been used to reproduce these cycles and to support the understanding and mitigation of defect formation.

Within this framework, this work proposes implementing thermal simulations to evaluate changes in the cooling cycle induced by internal defects in components manufactured by L-PBF. The goal is to identify thermal signatures associated with these defects that can be detected using in situ monitoring techniques.

The thermal simulations were carried out using the Simufact Additive, considering a component containing internal defects of different sizes and evaluating the influence of different laser absorptivity values. Validation was conducted by correlating the simulated thermal cycles with those experimentally obtained from an in-situ monitoring system equipped with an infrared camera.

The simulation has indicated heat accumulation in defect regions, with the intensity varying as a function of defect size (Figures 1 and 2). The acquired thermal images were processed to extract relevant thermal features, which were then compared with the simulation results. Based on these findings, it was possible to identify the model that most accurately represents the experimental behavior, as well as to determine the key thermal features for defect detection.

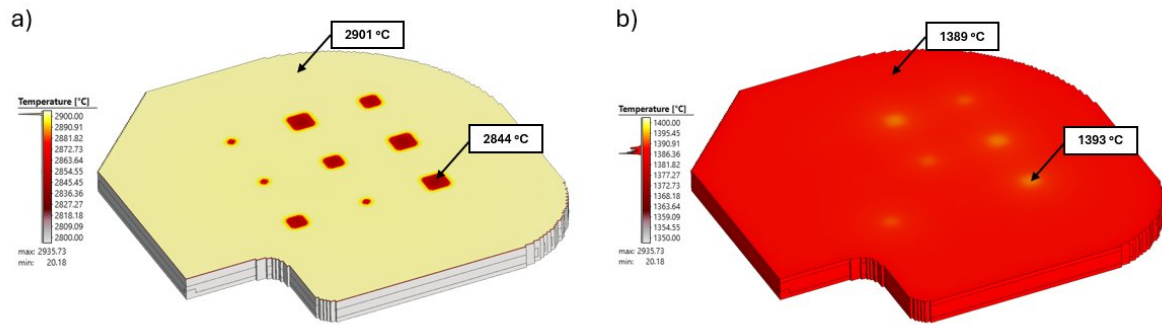


Figure 1. Results from the thermal simulation, showing the temperature distribution within the layer at two different stages of the cooling process.

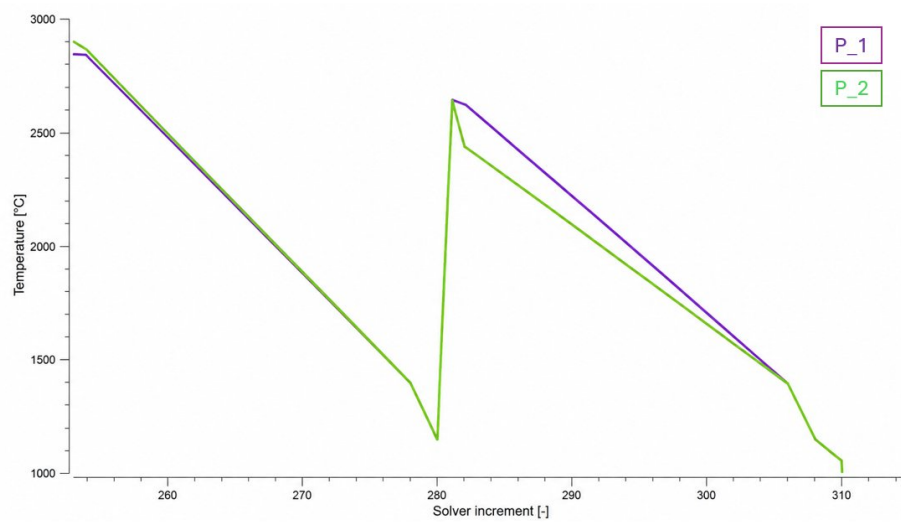


Figure 2. Cooling curves measured above a defective region (P₁) and a defect-free region (P₂), obtained from thermal simulations.

Session IV

Mariusz Dębski, Grzegorz Budzik, Łukasz Przeszłowski, Bogdan Kozik: *Strength analysis of lattice structures manufactured by material extrusion*, Rzeszów University of Technology

Aleksandra Zalewska, Beata Paczosa Bator: *Application of 3D Printing – Fused Deposition Modeling – for the Single-Step Fabrication of a Sensor Platform for the Quantitative Determination of Nitrates*, AGH University of Krakow

Eliza Romańczuk-Ruszek, Zuzanna Szałaj, Milena Krzymowska, Skrodzka Patrycja, Krzysztof Żaba, Robert E. Przekop: *Direct Ink Writing of Silicone Elastomers Modified with a Mineral Filler*, Białystok University of Technology

Andrzej Zakręcki, Tomasz Nabagło: *From medical need to functional mechatronic system. The integrated rapid prototyping workflow for a 3D-printed forearm orthosis and a teleoperated humanoid manipulator*, AGH University of Krakow

Małgorzata Gontarz-Kulisiewicz, Grzegorz Budzik, Tomasz Dziubek, Bartłomiej Sobolewski, Łukasz Przeszłowski, Krzysztof Żaba: *Analysis of additively manufactured polymer disc solutions*, Rzeszów University of Technology

Klaudia Trembecka-Wójciga, Weronika Wańczyk, Magdalena Jankowska, Joanna Ortyl: *Bimodal ZrO₂-based Ceramic Nanocomposite Resins for DLP 3D Printing of Scaffolds*, Cracow University of Technology

Janusz Kluczyński, Ireneusz Szachogłuchowicz, Jakub Łuszczek, Marta Lipińska, Janusz Mierzyński, Krzysztof Grzelak, Lucjan Śniezek, Marcin Wachowski: *Experimental Assessment of Modular Spur Gears with Additively Manufactured Components*, Military University of Technology

Strength analysis of lattice structures manufactured by material extrusion

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Keywords: additive technologies, lattice structures, strength tests, polymeric materials, weight reduction.

Additive manufacturing technologies enable the fabrication of components with complex internal geometries, including lattice structures, which allow weight reduction while maintaining favourable mechanical properties. On the one hand, such structures exhibit effective mechanical properties resulting from their internal architecture; on the other hand, their mechanical behaviour directly depends on the geometry of the unit cell, its spatial arrangement, and its orientation relative to the loading direction. This study presents the results of experimental tests conducted on polylactic acid (PLA) specimens manufactured using the material extrusion process on a Prusa MK4S 3D printer. The specimens were produced in five configurations: a reference configuration, in which weight reduction was achieved by applying a 30% infill density, and four variants incorporating different lattice structures. Mechanical properties were evaluated by means of static compression and three-point bending tests. The results demonstrated that appropriately designed lattice geometries can improve the mechanical properties compared with the conventional approach based on reducing the infill density. However, the application of lattice structures was also associated with a considerable increase in manufacturing time. The results indicate that the selection of internal architecture should consider a trade-off between mechanical performance, weight reduction and manufacturing time.

Application of 3D Printing – Fused Deposition Modeling – for the Single-Step Fabrication of a Sensor Platform for the Quantitative Determination of Nitrates

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Keywords: 3D printing, rapid prototyping, Fused Model Deposition, potentiometry, chemicals sensor.

This study presents a rapid, low-cost fabrication route for miniaturized potentiometric chemical sensors using fused deposition modeling (FDM) 3D printing, addressing key limitations of conventional sensor manufacturing methods such as solvent casting, dip-coating, and screen-printing, which are labor-intensive and poorly suited to rapid design iteration. Single- and dual-electrode sensor systems with two distinct geometries were fabricated using a Flashforge Creator Pro 2 printer and two commercially available PLA-based filaments: an electrically conductive filament for the electrode body and a standard non-conductive PLA for the insulating structural components. This single-printer, dual-filament approach enabled direct fabrication of functional electrode architectures without post-processing metallization or conductive paste application. Printed sensor surfaces were polished, and nitrate-selective membranes were subsequently applied to the active areas. Potentiometric characterization yielded calibration slopes close to the theoretical Nernstian value of 55 mV/decade, a low detection limit of 10^{-6} M, and a wide linear range spanning 10^{-5} to 10^{-2} M. Electrochemical impedance spectroscopy and chronopotentiometry were used to further assess electrode performance, revealing a potential drift of 0.340 mV/s and a resistance of 0.778 M Ω for the best-performing sensor. The results confirm that FDM-based additive manufacturing, combining conductive and non-conductive PLA filaments on a single printer, is an effective strategy for producing single- and multi-electrode sensor arrays. This approach reduces fabrication costs and production time while allowing flexible, on-demand reconfiguration of electrode geometry, demonstrating strong potential for developing fully integrated, additively manufactured chemical sensing platforms.

Acknowledgement

Research project supported by the program “Excellence Initiative – Research University” at AGH University of Krakow.

Direct Ink Writing of Silicone Elastomers Modified with a Mineral Filler

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Keywords: 3D printing, Direct Ink Writing, silicone elastomers, mineral filler, printability

Elastomeric materials, including silicones, are widely used for their biocompatibility and high elasticity. Traditional manufacturing methods limits producing complex geometries and components with varied properties. 3D printing like Direct Ink Writing (DIW) method offers a solution, but the challenge is to appropriately select the material's rheology and its final properties.

This study concerns the modification of a commercial silicone elastomer using a natural, sedimentary carbonate-silica filler (opoka). The aim of the study was to select 3D printing parameters and modify mechanical properties. An analysis of the properties of the developed composites was conducted, including rheological tests, compressive strength tests, microscopic observation, and micro-CT.

The results show that the use of the tested mineral filler affects shear thinning, which directly contributes to improved printability and print path stability. Structural analysis confirmed the homogeneous dispersion of filler particles in the matrix, the absence of agglomerates, and structural integrity without internal air bubbles. In addition, the modification resulted in an increase in the compressive strength of the composites.

Research has shown that control of the opoka content allows for the adjustment of the material's behavior during printing, as well as its final mechanical properties. The developed composites show interesting potential for applications, including in biomedical engineering and soft robotics.

From medical need to functional mechatronic system. The integrated rapid prototyping workflow for a 3D- printed forearm orthosis and a teleoperated humanoid manipulator

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Keywords: SLS, HP MJF, FDM, SLM, 3D-printing materials, PA12, AlSi10Mg, Ti-6Al-4V.

This study presents an integrated rapid prototyping workflow for personalised medical devices and advanced mechatronic systems, covering user-need identification, geometry acquisition, CAD design, material selection, additive manufacturing, integration, and validation. Two complementary case studies are discussed.

The first concerns a personalised forearm orthosis designed from anatomical data acquired with a Structure Sensor Pro scanner. The workflow includes geometric processing, patient-specific fitting, design optimisation, and production using selective laser sintering and HP Multi Jet Fusion with polyamide PA12, followed by DyeMansion post-processing. The technologies are compared in terms of mechanical properties, dimensional accuracy, surface quality, repeatability, and suitability for personalised medical-device production.

The second case study addresses rapid prototyping of a teleoperated humanoid manipulator whose drives communicate wirelessly with a measurement exoskeleton worn by the operator. The development path covers functional concept definition, kinematic modelling, iterative FDM prototyping, and a metal prototype intended for SLM processing from AlSi10Mg and Ti-6Al-4V powders.

Both cases demonstrate a common digital design-to-manufacturing chain based on iterative modelling, rapid fabrication, functional assessment, and evidence-based redesign, while accounting for ergonomics, human-machine interaction, anatomy, material performance, and integration with conventional components.



Figure 1. 3D-printed forearm orthosis made from PA12 using HP Multijet Fusion technology and post-processed on DyeMansion's devices

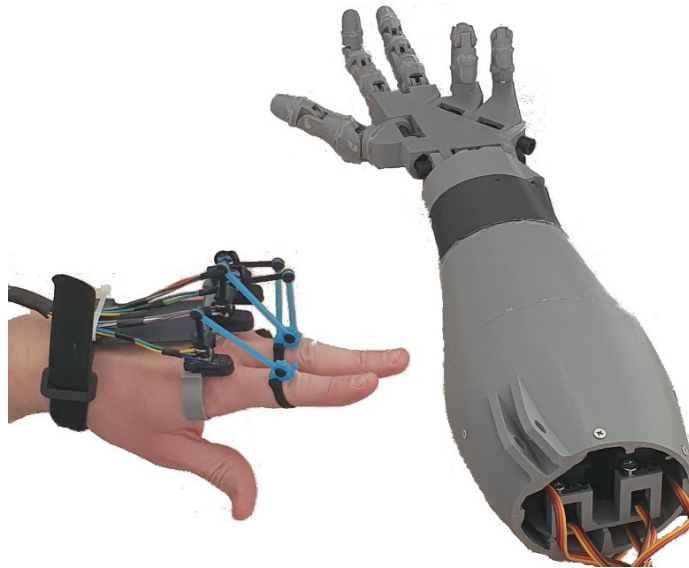


Figure 2. 3D-printed demonstrator of a forearm and hand robotic manipulator made from Z-PET using FDM technology, prepared to be controlled remotely by an operator

Bimodal ZrO₂-based Ceramic Nanocomposite Resins for DLP 3D Printing of Scaffolds

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Keywords: DLP 3D printing, ceramic nanocomposite, zirconia, photoinitiators, tissue engineering.

This study presents a bimodal ZrO₂-based ceramic nanocomposite resin system optimized for digital light processing (DLP) 3D printing, targeting advanced bone scaffold fabrication. Formulations combining submicron yttria-stabilized zirconia and zirconia nanoparticles (up to 20 wt%) were developed to enhance ceramic particle packing, minimize polymerization shrinkage, and improve the dimensional stability of printed structures (Table 1). Furthermore, the effect of two photoinitiators-commercial TPO and novel (E)-1,1-dimethoxy-1-phenyl-4-(4-methylsulfanylphenyl)-but-3-en-2-one (DMPP-(L)-SMe)-on curing behavior and photopolymerization efficiency was comprehensively investigated. Rheological and Photo-DSC analyses demonstrated that the bimodal filler system significantly alters viscosity, gelation time, and acrylate group conversion while enabling stable processing of highly filled resins (Figure 1). The optimized photocurable suspensions were successfully printed into complex gyroid structures. Post-printing, the green bodies underwent debinding and sintering at 1500 °C to form polymer-free ceramic scaffolds (Figure 2). Microstructural and mechanical evaluations revealed that the final ZrO₂-based prints retained their designed geometries and exhibited superior compressive strength (up to ~18 MPa) and structural integrity. These findings highlight the potential of combining bimodal ceramic particle distributions with tailored photoinitiator selection for the efficient DLP additive manufacturing of robust, porous ceramic components.

Table 1. Photocurable resin formulations dedicated to 3D printing (all photocurable resin components are listed by weight).

Resin	Monomers	Submicron ZrO2 Content (%)	Nano ZrO2 Content (%)
0% NPs	HDDA/TMPTA (80/20)	60%	0%
5% NPs		60%	5%
10% NPs		60%	10%
15% NPs		60%	15%
20% NPs		60%	20%

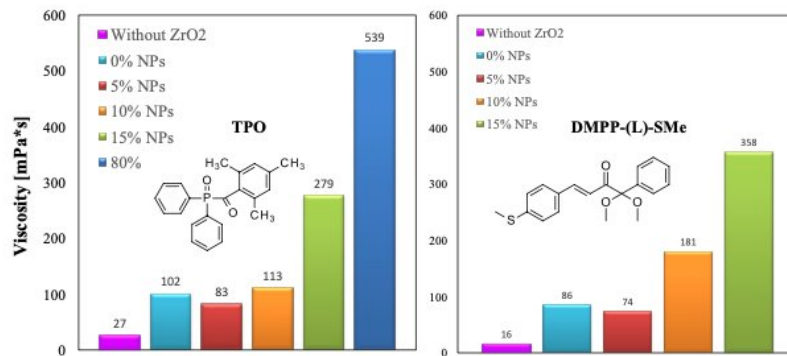


Figure 2. Viscosity of photocurable resin formulations with varying zirconia nanoparticle (NPs) content, using TPO (left) and DMPP-(L)-SMe (right) as photoinitiators.

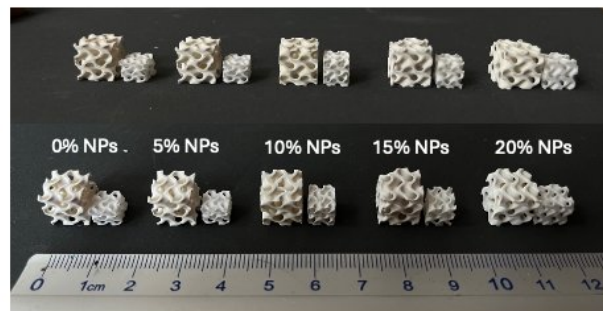


Figure 2. Materials before (green bodies – larger cubes) and after (brown bodies – smaller cubes) thermal treatment.

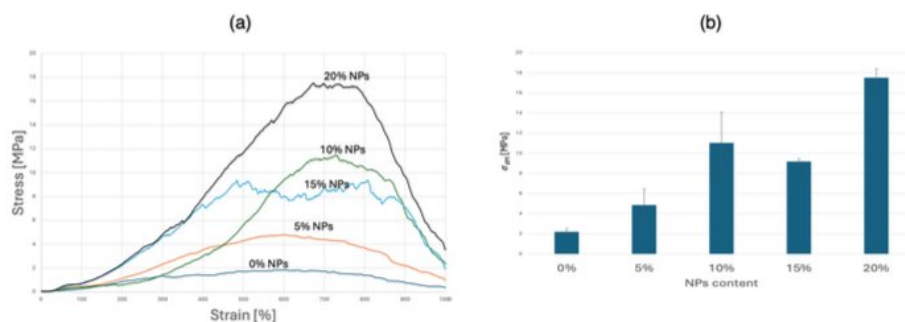


Figure 3. Mechanical analysis of final materials: (a) Stress–strain curves and (b) Compressive strength of 3D-printed ceramic scaffolds.

Analysis of additively manufactured polymer disc solutions

Małgorzata Gontarz-Kulisiewicz¹, Grzegorz Budzik¹, Tomasz Dziubek¹, Bartłomiej Sobolewski¹, Łukasz Przesłowski¹, Krzysztof Żaba²

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Keywords: gear disc, 3D printing, FFF, additive manufacturing, geometry.

Integrated CAx (Computer Aided Technologies) systems significantly support dynamic technological development. They provide increasingly broad possibilities for producing both conventional and unconventional, geometrically complex components. Subtractive processes play a significant role in manufacturing processes. However, AM (Additive Manufacturing) methods are increasingly used in industry and constitute one of the main branches. The issue of reducing material consumption while maintaining strength parameters similar to those of unmodified components is related to the design and manufacturing of components, including machine components. A fundamental element in machines and devices is the gear transmission. The design of the gears allows for modification of the geometry to reduce the weight of the gears, which affects the weight of the entire system.

The research focused on analyzing the impact of modifying the discs of polymer gears made of a polymer material (ABS; Acrylonitrile Butadiene Styrene) using the FFF (Fused Filament Fabrication) method on their durability. Several design solutions were analyzed to modify the disc geometry of mating gear pairs. Test results for gear pairs with different disc design solutions were compared to those for a pair of gears without modifications. Parameters taken into account in the analysis included test duration until failure and temperature at the meshing point. The results show that it is possible to reduce the weight by approx. 30% compared to the unmodified gear pair while maintaining similar values for the analyzed parameters.

Experimental Assessment of Modular Spur Gears with Additively Manufactured Components

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Keywords: additive manufacturing, laser powder bed fusion of metals, 21NiCrMo2 steel, form-fitting connections, laser hardening.

The paper presents final results of experimental investigations of modular spur gears manufactured using laser powder bed fusion for metals (PBF-LB/M) of 21NiCrMo2 steel. The investigated components included gears with conventionally manufactured rings and additively manufactured, topologically optimized hubs, as well as gears with additively manufactured rings and hubs. The study covered surface geometry and roughness, hardness and microhardness, internal imperfections, microstructure, and fatigue performance under tooth bending and contact loading. Particular attention was paid to the effects of carburizing, induction hardening, tempering, gear grinding and laser hardening of the form-fitting joint. Microstructural characterization was complemented by electron backscatter diffraction (EBSD) analyses of the rings and hubs to evaluate crystallographic features related to PBF-LB/M and heat treatment. Contact fatigue tests showed low tooth flank damage; for two-part gears, the maximum area fraction of spalling was 0.062%, compared with 0.158% for conventional gears after 5×10^6 cycles at approximately 419 MPa contact stress. In bending fatigue, an additively manufactured ring tooth reached 10^7 cycles at a maximum root stress of 200 MPa. The results confirm the potential of combining additive and conventional technologies in functional modular gears and indicate directions for further optimization of manufacturing and post-processing.

Session V

Piotr Bała, Krzysztof Fryzowicz, Grzegorz Cios, Rafał Dziurka: *Processing–Microstructure–Property Relationships in L-PBF-Processed Maraging Steel*, AGH University of Krakow

Krzysztof Żaba, Krzysztof Szymański, Maciej Balcerzak, Ilona Różycka, Łukasz Kuczek, **Piotr Żabiński**: *Effect of Surface Finishing on the Corrosion Resistivity of 3D Printed M300 Steel*, AGH University of Krakow

Katarzyna Skibińska, Aleksandra Iwańczak, Maciej Balcerzak, Łukasz Woźniak, Sławomir Kąc, Krzysztof Żaba, Piotr Żabiński: *Improvement in corrosion resistance of M300 steel 3D prints by electrochemical deposition of a thin, uniform nickel layer*, AGH University of Krakow

Andrzej Mamala, Szymon Kordaszewski, Paweł Strzępek, Michał Sadzikowski, Grzegorz Kiesiewicz, Małgorzata Zasadzińska: *Copper 3D Printing - Effect of Fused Filament Fabrication Infill Patterns on Shrinkage and Basic Properties*, AGH University of Krakow

Kamil Burczy, Grzegorz Budzik, Aleksander Banaś, Radosław Wojtuszewski, Marcin Głodzik, Tomasz Altamer: *Analysis of Large Format 3D Printing Applications in Industry*, PZL Mielec

Marcin Hojny: *How Industry 4.0/5.0 Redefines the Engineer's Responsibility*, AGH University of Krakow

Tomasz Dębiński, Marcin Hojny: *Augmented, virtual and mixed reality in modern industrial applications*, AGH University of Krakow

Processing–Microstructure–Property Relationships in L-PBF-Processed Maraging Steel

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Keywords: Laser Powder Bed Fusion (L-PBF); maraging steel; microstructure; mechanical properties; nitrogen uptake.

Laser Powder Bed Fusion (L-PBF) provides new possibilities for manufacturing maraging steels with complex geometries and tailored properties. This work investigates the relationships between processing conditions, microstructure and mechanical performance of L-PBF-processed MS1 maraging steel. Process parameters were optimized to obtain high-density material, while the influence of the processing atmosphere and subsequent heat treatment was evaluated.

Particular attention was paid to nitrogen uptake from the shielding atmosphere. Nitrogen can dissolve in the melt pool during processing and affect phase formation, precipitation and the resulting mechanical response. By controlling laser parameters and melt-pool conditions, the interaction between the gas atmosphere and the alloy can therefore become an additional tool for material modification.

The results demonstrate that the final performance of L-PBF maraging steel is governed not only by conventional process parameters and post-processing, but also by atmosphere–material interactions. Understanding these relationships enables more effective tailoring of microstructure and properties in additively manufactured maraging steels.

Acknowledgements: Research project supported by the program “Excellence Initiative – Research University” for the AGH University of Krakow.

Effect of Surface Finishing on the Corrosion Resistivity of 3D Printed M300 Steel

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Keywords: 3D printing; DMLS method; M300 steel; corrosion; surface finishing.

Additive manufacturing (AM) technologies encompass a range of modern production methods aimed at automating the layer-by-layer fabrication of objects based on suitably prepared CAD models, while minimizing the use of traditional machining tools. AM has been identified as one of nine cutting-edge technologies that play a significant role in the fourth industrial revolution. This advanced and widely adopted manufacturing technique is particularly beneficial for producing small components, complex geometrical products, and custom-made elements, all while optimizing structure and minimizing material waste

The purpose of this study was to investigate the influence of synthesis parameters and surface finish on the corrosion of DMLS-printed M300 steel components and to evaluate their applicability in corrosive environments. In order to assess the influence of the corrosive environment, potentiodynamic and long-term corrosion tests were carried out in this study, together with microscopic and EDS studies on 3D-printed M300 steel samples synthesized using the DMLS method with different laser powers. The results show that DMLS-produced M300 steel is vulnerable to corrosion in corrosive environments. The effect of the laser power used on the corrosion resistance was also demonstrated, which generally decreases with increasing laser power. This study confirms the influence of the surface condition of the components on the corrosion phenomenon. Despite the higher corrosion resistance of unpolished components, they lose mass to a higher degree in a corrosive environment. This study also shows the influence of temperature on the corrosion phenomena occurring, demonstrating its negative effect. This study also presents the microstructure of the surface of the samples after the tests, showing the degradation of the surface due to corrosive actions. The analysis of the test results suggests the protection of M300 steel components produced using the DMLS method for the case of operation in corrosive environments.

Acknowledgement

the work was financially supported by program “Excellence initiative – research university” for AGH University of Krakow” (Grant no. 18004), IDUB AGH Activity 21

Improvement in corrosion resistance of M300 steel 3D prints by electrochemical deposition of a thin, uniform nickel layer

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Keywords: additive manufacturing, PBF-LB/M, M300 steel, electrodeposition, corrosion

Additive manufacturing (AM) is a key element of Industry 4.0, enabling the production of complex geometries, rapid prototypes, tooling, and customized parts. It helps lower costs and reduce carbon emissions through efficient material usage and on-demand fabrication. M300 steel demonstrates good corrosion resistance in aqueous sodium chloride (NaCl) environments at room temperature, where pitting is the predominant form of degradation. However, corrosion remains a concern in additively manufactured components due to their unique microstructures and defects, such as voids formed during printing. As a result, their corrosion behavior differs from that of conventionally cast materials, with localized pitting. Studies indicate that M300 steel parts produced by AM require appropriate protection when exposed to corrosive environments, such as a 3.5% NaCl solution. In this work, 3D prints of M300 steel were electrochemically covered with Ni to increase their corrosion resistance in 3.5 % NaCl solution. Electrodeposition parameters, like composition of the electrolyte and its temperature, deposition time, and applied current density, will be tested to obtain a thin, uniform nickel layer. Two corrosion testing methods will be used: long-term corrosion testing and potentiostatic testing. The obtained results will be compared with the as-printed samples.

Acknowledgement

Research project supported by program “Excellence initiative – research university” for AGH University of Krakow” (Grant no. 17043).

Copper 3D Printing - Effect of Fused Filament Fabrication Infill Patterns on Shrinkage and Basic Properties

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Keywords: Metal Fused Filament Fabrication, copper 3D printing, postprocessing, shrinkage.

Currently, Selective Laser Melting (SLM) dominates the field of copper 3D printing. However, the Metal Fused Filament Fabrication (Metal FFF) technique shows great promise for specific niche applications, enabling the production of multi-material layered components and closed cellular structures. Nevertheless, the complex post-processing stage involving debinding and sintering induces dimensional distortion in the components, and their final density remains significantly lower than expected in the bulk material. This phenomenon exerts a critical impact on the macroscopic properties of the parts. This paper investigates the 3D printing of copper using the Metal FFF method and analyses the effect of various infill patterns—specifically grid, cross-hatch, Archimedean spiral, and Hilbert curves—on shrinkage behaviour (value and potential anisotropy), density, electrical conductivity, and hardness of the final component. The experimental results demonstrate that within the investigated scope, the choice of infill pattern does not induce shrinkage anisotropy under correct the post-processing parameters. Starting with a green parts density of approximately 3.9 g/cm³, the sintered parts achieved a density ranging from 4.4 g/cm³ to 5.3 g/cm³, an ambient electrical conductivity of 23 MS/m to 33 MS/m, and a hardness of approximately 20 HV.

This research was supported by program „Excellence initiative – research university” for the AGH University of Krakow.

Analysis of Large Format 3D Printing Applications in Industry

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Keywords: additive manufacturing, 3D printing large format, industry, polymers.

This paper presents an overview of 3D printing applications across key industrial sectors, including maritime, energy, defense, and automotive industries, with a primary focus on the aviation sector. Particular attention is given to Large Format Additive Manufacturing (LFAM) utilizing thermoplastic polymer composites and its potential to support the production of aircraft elements, particularly composite parts. The study addresses the critical aspects of polymer composite selection for high-performance applications and outlines the operational characteristics of high-capacity extrusion systems. Furthermore, it examines existing mechanical configurations of executive systems, focusing on gantry structures and industrial robot integrations. The paper highlights current technological capability, structural challenges, and future development perspectives for Large Format Additive Manufacturing in advanced aerospace and industrial applications.

How Industry 4.0/5.0 Redefines the Engineer's Responsibility

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Keywords: gas leak detection, compressed gas installations, multimodal data fusion, acoustic emission, vibration analysis, machine learning, anomaly detection

Industry 5.0 is the next era of industrial transformation, which goes beyond the existing assumptions of Industry 4.0. The key difference between these two approaches concerns the role of humans in the production process. While Industry 4.0 focuses on automation, digitization, and machine integration, Industry 5.0 restores humans to a central role, emphasizing collaboration between people and technology. This change significantly redefines the role and responsibility of engineers, who are no longer just designers of machines or algorithms, and becomes an architect of complex cyber-physical systems in which sensors, real-time simulation models, artificial intelligence algorithms, decision-making systems, advanced interfaces in virtual/augmented reality technology, and above all, people coexist. The lecture will present examples of industrial implementations of systems declared as Industry 4.0/5.0 solutions, which ended at the level of monitoring systems and advanced data visualization, as well as examples of systems that have achieved a level of partial decision-making autonomy. Particular emphasis will be placed on the evolution of classic monitoring and support systems towards autonomous (or partially autonomous) systems, where the engineer's responsibility undergoes a fundamental change (Fig. 1).

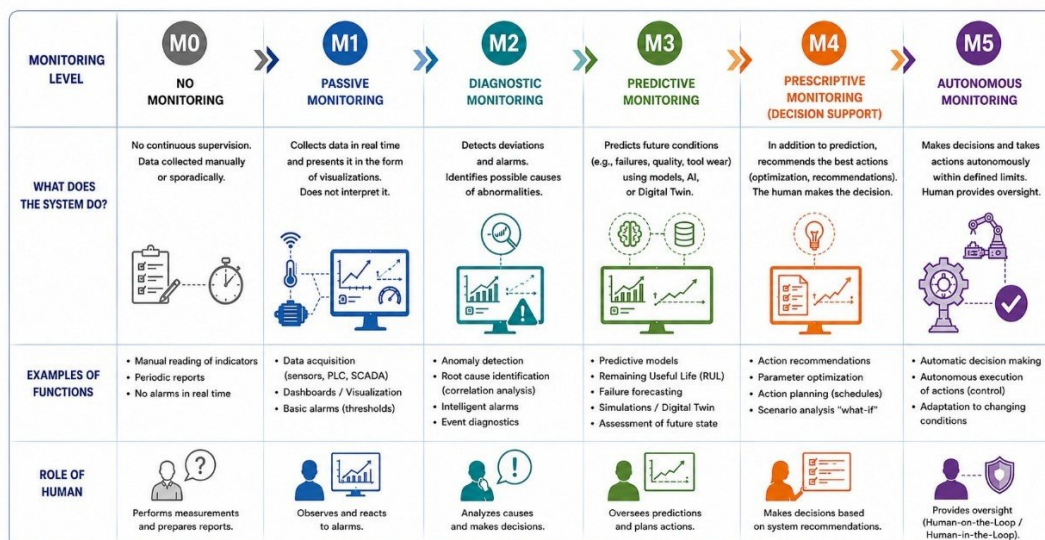


Figure 1. Levels of industrial monitoring systems

In this aspect, the formal definition of autonomy levels, the architecture of the decision loop

taking into account human supervision (human-in-the-loop and human-on-the-loop approaches), the procedures for verification and validation of digital twin operational components (e.g., real-time computing systems), and the approach to risk management in operational (industrial) conditions. The lecture is an attempt to take an engineering and practical look at the problems in the era of increasing system autonomy, and at the same time, it is an invitation to discuss how to design and implement systems based on Industry 4.0/5.0 technologies in an effective and realistic way.

Acknowledgement

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Augmented, virtual and mixed reality in modern industrial applications

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Keywords: digital twin, virtual reality, augmented reality, mixed reality, simulation module.

1. Introduction

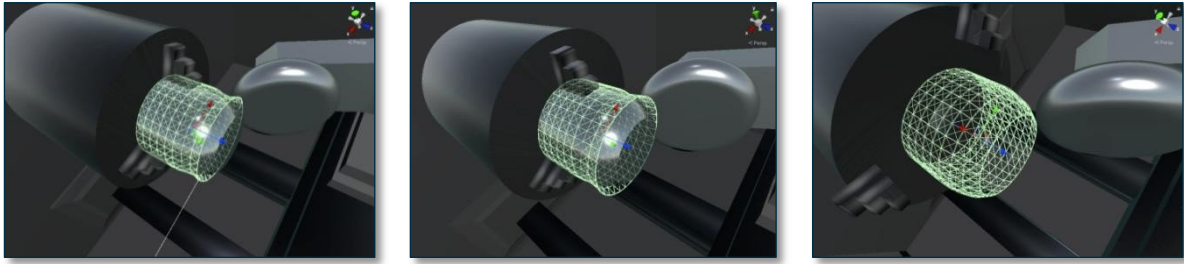
The concept of Industry 4.0 assumes a complex technological and organizational transformation of enterprises, with the implementation of integrated digital solutions, one of its key components [1]. In order to increased production efficiency, reduced costs, and increase safety, modern industry is increasingly adopting advanced technologies that support both design and manufacturing processes. The integration of solutions such as digital twins, metamodels, artificial intelligence (AI), and virtual reality (VR), augmented reality (AR), and mixed reality (MR) technologies enables improvements in many areas of industrial operations, including product design, assembly line operation, and quality control. The growing potential of stereoscopic visualization technologies in the design and implementation of manufacturing processes has led to increasing interest from both the scientific community and industry investors.

2. The implementation of modern VR interfaces in industry

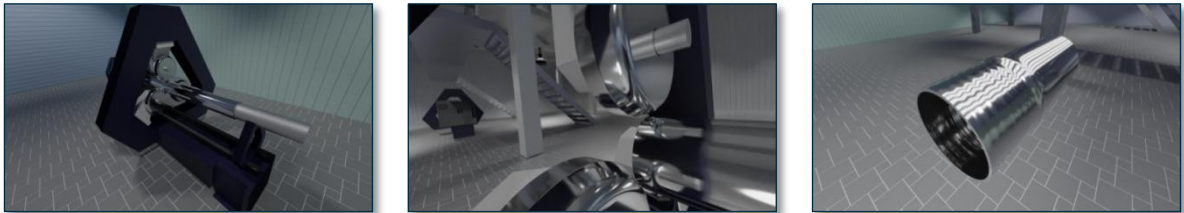
Technologies (VR/AR/MR) introduce a new way for users to interact with a controlled technological process. Virtual Reality (VR) completely excludes the real world and is experienced using VR headsets. It immerses users in a new 360° virtual environment, giving them the feeling of being somewhere else. Augmented Reality (AR) improves users perception of the real world by displaying additional visual information or virtual objects. It requires users to be present at a specific location and is experienced using tablets or dedicated headsets. Mixed Reality (MR) combines the real world with virtual elements, allowing users to interact with both real and digital objects. It embeds virtual objects into the real environment and enables users to interact naturally with their surroundings, creating a sense of the coexistence of the real and digital worlds.

The presentation will focus on the features and capabilities of VR/AR/MR systems and their use as an interactive interfaces, illustrated by examples of implemented technological processes with geometric modelling functions, such as:

3. Rotary forming simulation system



4. Flow forming simulation system for long products



a. A simulation system for the sheet metal levelling process



b. Training system for a physical simulation machine



The proposed method of user interaction with technological processes opens up new possibilities for managing and monitoring key parameters.

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Acknowledgement

This research was funded by the AGH University IDUB programme, Action D21.

Session VI

Jakub Michalik, Marcin Hojny: Multimodal hybrid methods for gas leak detection in small-diameter in-building pipeline systems, AGH University of Krakow

Jerzy Jóźwik: Summary of the Activities of the Polish Metrological Union, Lublin University of Technology

Aleksandra Bochenek, Tomasz Kozior, Jerzy Bochnia, Dominik Malara, Michał Nawotka, Jakub Jedliński, Dariusz Jasiński, Krzysztof Gębarski: Analysis of 3D printed freeforms by use of comparative study containing various 3D scanning strategies and equipment, Central Office of Measures

Wiktor Szot, Analysis of Stress Relaxation Changes in Additively Manufactured Components during Long-Term Exposure to Atmospheric Conditions, Kielce University of Technology

Dominik Malara, Tomasz Kozior, Jakub Łuszczek, Aleksandra Bochenek, Michał Nawotka: Metrological issues in measuring the surface of 3D-printed components, Central Office of Measures

Wojciech Słysz, Michał Religa, Karol Nawrot, Mateusz Wojtas: Automated In-Process Component Assembly During FFF: Design and Preliminary Validation of the AssemblePrint Hybrid Manufacturing System, WiredPrint sp. z o. o.

Multimodal hybrid methods for gas leak detection in small-diameter in-building pipeline systems

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Keywords: gas leak detection, compressed gas installations, multimodal data fusion, acoustic emission, vibration analysis, machine learning, anomaly detection

Compressed gas installations are a critical part of industrial, laboratory, and healthcare infrastructure, where leaks can disrupt processes and, in medical systems, threaten patient safety. Leak detection in in-building installations is particularly difficult because small pipe diameters, branched topology, numerous fittings, and variable gas consumption strongly attenuate and distort diagnostic signals. The presentation reviews pressure, flow, acoustic, ultrasonic, and vibration-based methods, with emphasis on their practical limitations in detecting small leaks under operational noise. It also examines hybrid monitoring systems that combine multimodal measurements with mass-balance models, negative pressure wave analysis, Real-Time Transient Models, and machine learning. Special attention is given to the shortage of labelled failure data. Unsupervised sequence-to-sequence autoencoders with attention mechanisms can detect anomalies without leakage samples in the training set and may outperform classical supervised approaches. The effectiveness of such systems depends on the complete processing chain, including sensor selection, signal conditioning, feature extraction, data fusion, and robust inference. Future development is expected to focus on physics-informed neural networks and transfer learning, which can improve model generalization and reduce the amount of local training data required for deployment in new installations. The presentation will also describe author's prototype as fundamentals for discussion of future directions in critical gas pipelines and sources monitoring systems.



Figure 1. A cloud-based distributed intelligent monitoring system for medical gas pressures

Acknowledgement

This research was funded by the AGH University IDUB programme, Action D21.

Summary of the Activities of the Polish Metrological Union

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Keywords: metrology, Polish Metrological Union, measures

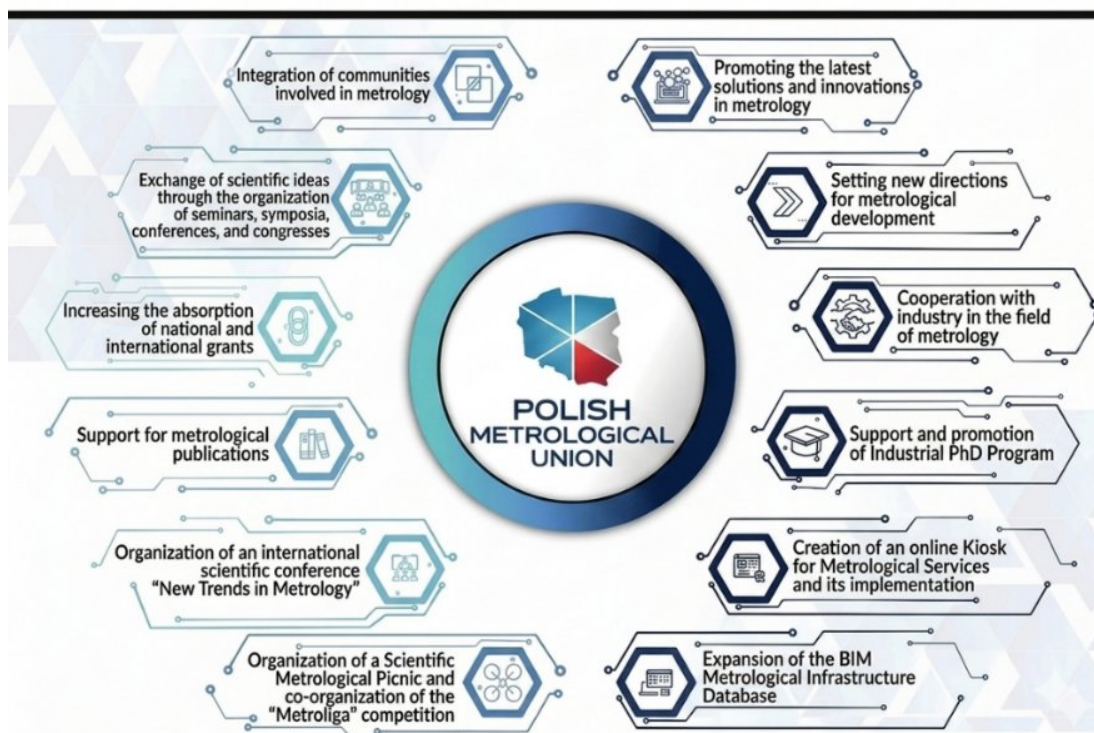
The font size for the document is Palatino Linotype, size 11 for the main text, 10 for tables, and 18 for the title. The spacing and paragraphing shown in this format should be maintained throughout the document. The Polish Metrological Union was established in 2021 on the initiative of the Ministry of Education and Science. The PMU actively promotes metrology through participation in science festivals and educational events, co-organizes the “Metroliga” competition for secondary school students, and has introduced Mobile Metrology Laboratories equipped with portable measurement kits. These laboratories bring modern measuring equipment to schools, particularly in rural areas and small towns, helping to increase metrological awareness and encourage young people to pursue technical education.

To support the metrological community, Polish Metrological Union has organized two international conferences, “New Trends in Metrology”, and the Economic Congress “Metrology of the Future”. The third edition of the NTiM conference is planned for October 2026. Additionally, the Polish Metrology Union, as a supporter and promoter of the Metrology Cluster’s activities, recruits new members for the Cluster.

The project has also delivered three editions of Metrology Workshops for young researchers, PhD candidates, and students at the Świętokrzyski Laboratory Campus of the Central Office of Measures and accredited Coordinate Metrology Laboratory of Cracow University of Technology.

Another initiative is the development of the Metrological Services Kiosk, based on the Metrological Infrastructure Database created during the previous edition. The system improves access to research infrastructure and facilitates information exchange on available metrological services.

Together, these activities strengthen cooperation between scientific and industrial communities, improve access to metrological infrastructure, and enhance public awareness of the importance of metrology for science, innovation, and economic development in Poland.



Analysis of 3D printed freeforms by use of comparative study containing various 3D scanning strategies and equipment

Aleksandra Bochenek², Tomasz Kozior^{1,2}, Jerzy Bochnia¹, Dominik Malara^{1,2}, Michał Nawotka², Jakub Jedliński³, Dariusz Jasiński³ and Krzysztof Gębarski³

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Keywords: Metrology, 3D printing, Additive Manufacturing, 3D Scanning.

This work focuses on presenting results of measurement geometric freeform of the sample manufactured in three different additive technologies: material extrusion (MEX), selective laser sintering (SLS) and PolyJet Matrix (PJM). Each sample was examined using three different 3D scanners manufactured by SMARTTECH Sp. z o.o. and used to create comparative studies. There were used two types of scanners: with rotational table and with a robotic arm controlling the scanner's position. The results showed significant differences in the number of measured measurement points and the ability to analyze freeform geometric features, depending on the selected measurement strategy – the angle of the 3D scanner camera and the kinematics of the scanning system. This study is a continuation of authors previous works that allows widening the scope of challenges behind choosing best measurement strategy and equipment for challenging geometries of the specially designed sample in the form of a 50 mm cube with holes and freeform shapes on its walls (Figure 1). Depending on strategies and angles used during scanning process the content of the freeform inspection changes from insufficient data to full matching of the model with CAD project. The average matching for the individual technologies did not differ significantly. However, more noticeable differences between fittings of the results were observed depending on the use of each 3D scanner. This research aims to show the significance and limitations of 3D scanning in fast developing world and economy where complicated geometrical forms like presented freeform are far too time-consuming to be inspected by coordinate measuring machines (CMMs). This study uses data developed for another work covering deeper analysis of set experiments focusing on designed openings of the samples and overall fitting of the scans to the model. That part of research is currently under publication process.

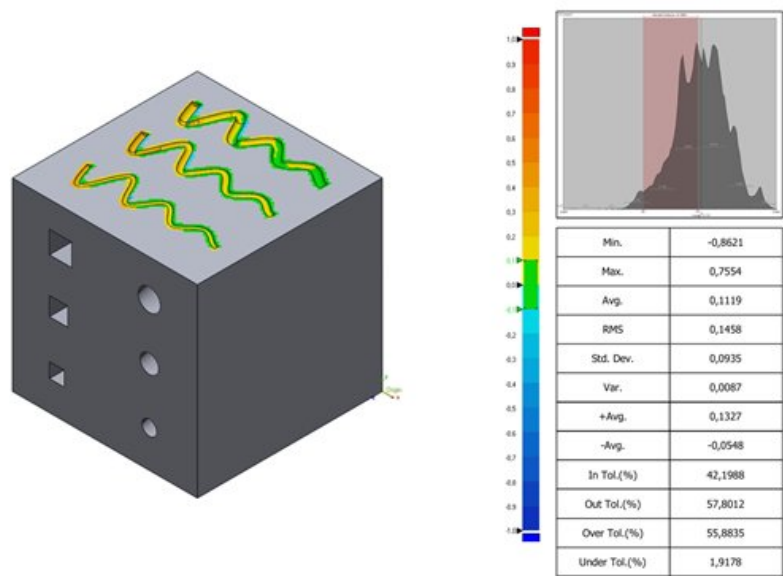


Figure 1. Measurement model with freeform graphical analysis

Analysis of Stress Relaxation Changes in Additively Manufactured Components during Long-Term Exposure to Atmospheric Conditions

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Keywords: additive manufacturing, stress relaxation, Clear Cast V1 resin, MSLA technology, Maxwell-Wiechert model

Additive manufacturing technologies are increasingly used for the production of functional components applied in various industrial fields and everyday applications. One of these technologies is Masked Stereolithography (MSLA), which uses a liquid photopolymer resin that is selectively cured layer by layer using light radiation. The mechanical and rheological properties of photopolymers may change during long-term exposure to environmental factors such as UV radiation, temperature variations, and humidity, affecting their durability and reliability.

The aim of the study was to analyze the effect of natural atmospheric exposure on the stress relaxation behavior of specimens made of photopolymer resin using the MSLA method. The samples were manufactured in accordance with the requirements of ISO 527 and subjected to natural atmospheric conditions. Stress relaxation tests were performed once a month, always on the same day, using the same samples, which enabled monitoring of changes in the rheological properties of the material as a function of exposure time. The analysis focused on stress relaxation curves and characteristic parameters described using the Maxwell-Wiechert model. The results enabled the evaluation of changes in the rheological properties of the photopolymer during successive stages of atmospheric exposure. The study provides valuable information for assessing the long-term durability and reliability of MSLA-manufactured components under real operating conditions.

Metrological issues in measuring the surface of 3D-printed components

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Keywords: 3D printing, Surface topography, Fused filament fabrication, Selective laser sintering.

The development of 3D printing technology has led to the widely used of additively manufactured components in many industrial sectors. Today, these are no longer just prototypes, but fully functional products with complex surfaces and free-form shapes. Their use in sectors such as the medical and metal industries, in addition to the development of standards for additive manufacturing technologies, such as ISO/ASTM 52901:2017, requires precise determination of their dimensional and geometric properties.

One of the key aspects of printed part measurement is the analysis of surface topography. The surface topography can be isotropic or anisotropic, depending on the technology used and the orientation of the print. Methods for measuring the geometric structure of surfaces, as classified in the EN ISO 25178-6 standard, can be divided into contact and non-contact methods. Each has advantages and limitations that affect its suitability for measuring additively manufactured components.

In the case of optical methods, the problem of non-measured points (NMP) may occur, while contact methods may cause damage to the surface under study. This study presents a comparison of three optical methods: Focus Variation, Confocal Microscopy and Vertical Scanning Interferometry, as well as a contact method, in the measurement of the surface topography of components manufactured using FDM/FFF (Fused Filament Fabrication/Fused Deposition Modelling) and SLS (Selective Laser Sintering) technologies.

Automated In-Process Component Assembly During FFF: Design and Preliminary Validation of the AssemblePrint Hybrid Manufacturing System

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Keywords: fused filament fabrication, hybrid manufacturing, in-process assembly, automated component insertion, additive manufacturing.

The integration of additive manufacturing with in-process component insertion remains challenging due to the need for additional actuators, control systems, or external manipulators. This work presents AssemblePrint, a hybrid manufacturing concept combining FFF (Fused Filament Fabrication) with automated insertion of metal components during printing. The solution reuses the printer motion system for both material deposition and component manipulation. The assembly module employs permanent magnets, an interchangeable positioning pin, and a spring-loaded push-latch mechanism, enabling passive gripping and release of ferromagnetic components without additional actuators, control signals, or modifications to the printer controller electronics. The process, executed using standard G-code commands, includes printing to a predefined layer, component pickup, transport, controlled insertion into the printed structure, and automatic resumption of material deposition. A demonstrator integrated with a Voron 2.4 printer completed the full automated sequence, with tool-positioning deviations below 0.1 mm. The results demonstrate the feasibility of integrating additive manufacturing and automated assembly within a single machine and manufacturing cycle. The assembly module and manufacturing method are the subject of Polish patent application No. P.455872, filed on 27 May 2026.

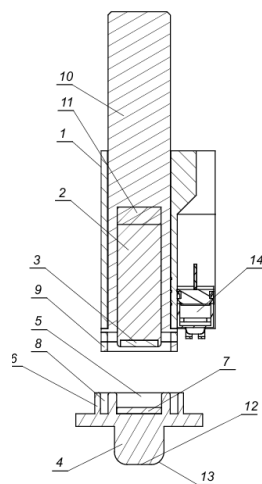


Fig.1

Patent Fig. 1. Assembly module cross-section and interchangeable positioning pin.

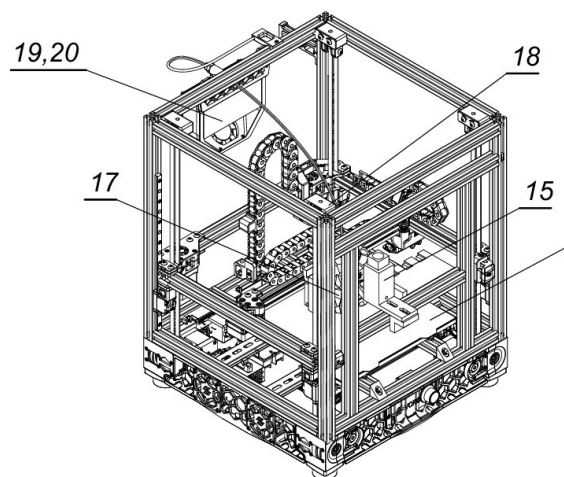


Fig.7

Patent Fig. 7. Isometric view of the 3D printer equipped with the assembly module.

Figure 1. Structural concept of the patent-pending AssemblePrint module and its integration with the 3D-printer motion system (Polish patent application No. P.455872).

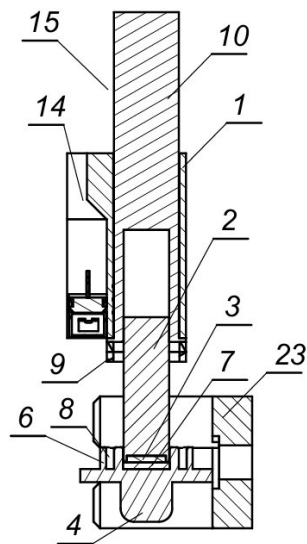


Fig.2

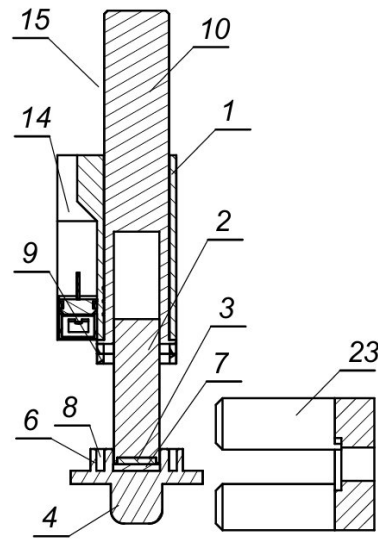


Fig.3

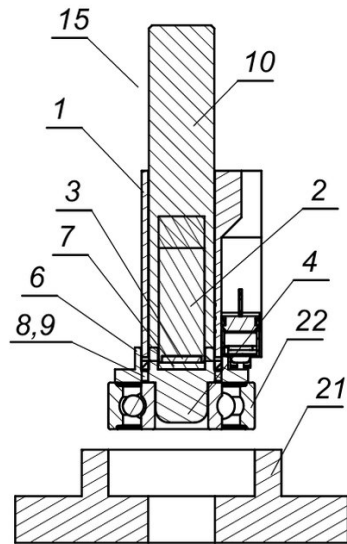


Fig.4

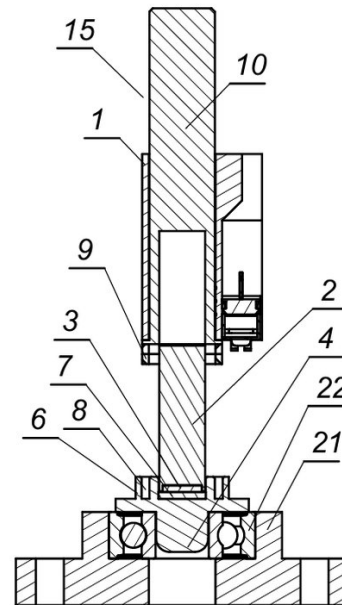


Fig.5

Figure 2. Operating sequence according to patent Figs. 2–5: Fig. 2 – the mounting pin is extended while the positioning pin is picked up from the positioning-pin container; Fig. 3 – the positioning pin is shown after pickup; Fig. 4 – the mounting pin is retracted while the mounted metal component is transported above the additively manufactured part; Fig. 5 – the mounting pin is extended after the metal component has been inserted into the additively manufactured part.

Reference numerals used in the patent drawings:

- | | | |
|---|---|---|
| 1 - body | 9 - permanent circumferential magnet | 17 - 3D-printing head |
| 2 - mounting pin | 10 - latching mechanism (push-latch) | 18 - printhead motion mechanism |
| 3 - permanent gripper magnet | 11 - elastic element / axial spring | 19 - controller |
| 4 - interchangeable positioning pin | 12 - contact end of the positioning pin | 20 - memory unit |
| 5 - central recess in the positioning pin | 13 - rounded positioning surfaces | 21 - additively manufactured part |
| 6 - positioning-pin flange | 14 - position sensor | 22 - mounted metal component |
| 7 - metal plate | 15 - assembly module | 23 - positioning-pin container |
| 8 - circumferential recess | 16 - build platform / working table | 24 - protruding element for actuating/resetting the latch |

Poster Session

1. **Małgorzata Zaborniak**, Katarzyna Grzywacz-Danielewicz, Janusz Kluczyński, Michał Bałuszyński, Przemysław Grzegorzewski, Bartłomiej Tołpa: *Analysis of the Impact of Sterilization on the Geometry and Dimensions of Polyetheretherketone (PEEK) Cranial Vault Implants*, Rzeszów University of Technology
2. **Tomasz Dyl**: *Analysis of additive manufacturing parameters to assess the impact of spare parts production capabilities in shipbuilding*, Gdynia Maritime University
3. **Mateusz Rudnik**, Paweł Szczygieł: *Influence of Local Shape Memory Polymer Application on the Mechanical Performance of 3D-Printed Orthoses*, Kielce University of Technology
4. **Paweł Szczygieł**: *Design and Fabrication of a Finger Prosthesis Using Multi-Material 3D Printing*, Kielce University of Technology
5. **Natalia Kowalska**, Sławomir Błasiak, Michał Skrzyniarz: *The Effect of Machining on the Surface Roughness of PLA Specimens Manufactured Using the Material Extrusion (MEX) Additive Manufacturing Process*, Kielce University of Technology
6. **Łukasz Przeszłowski**, Karolina Litak: *Testing selected mechanical properties of an elastic mechanism manufactured using FFF additive manufacturing technology*, Rzeszów University of Technology
7. **Vít Novák**, František Tatíček, Ondřej Stejskal, Břetislav Machka: *From Breaking Point to Production Line: FFF-Printed PLA Dies for Cold Sheet-Metal Forming*, Czech Technical University in Prague
8. **Julia Głowacka**, Natalia Kubiak, Magdalena Kustos, Jiri Kafka, Peter Scholz, Robert E. Przekop: *Material Selection and FGF Manufacturing of Future Mold Demonstrator for VAR*, Adam Mickiewicz University in Poznań
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Analysis of the Impact of Sterilization on the Geometry and Dimensions of Polyetheretherketone (PEEK) Cranial Vault Implants

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Keywords: additive manufacturing, medical sterilization, cranial vault implants, geometric accuracy, PEEK.

Does a 3D-printed implant retain its shape after the sterilization process? This question served as the starting point for research into personalized cranial implants made of PEEK, a material that combines high strength with biocompatibility. The implants were designed based on computed tomography (CT) and magnetic resonance imaging (MRI) scans and subsequently printed using the FDM/MEX method on an industrial 3D printer (3DGence Industry F42).

The design process began with the reconstruction of a 3D model of the patient's skull using data obtained from CT and MRI scans. Two model variants were prepared: a solid implant and an implant featuring holes designed to facilitate post-operative fluid drainage (Fig. 1a).

The implants were manufactured using a 3DGence Industry F42 printer operating on Material Extrusion (MEX) technology. PEEK was used as the construction material. The printing process was carried out with a nozzle temperature of 420°C, a chamber temperature of 110°C, and a layer thickness of 0.15 mm (Fig. 1b).

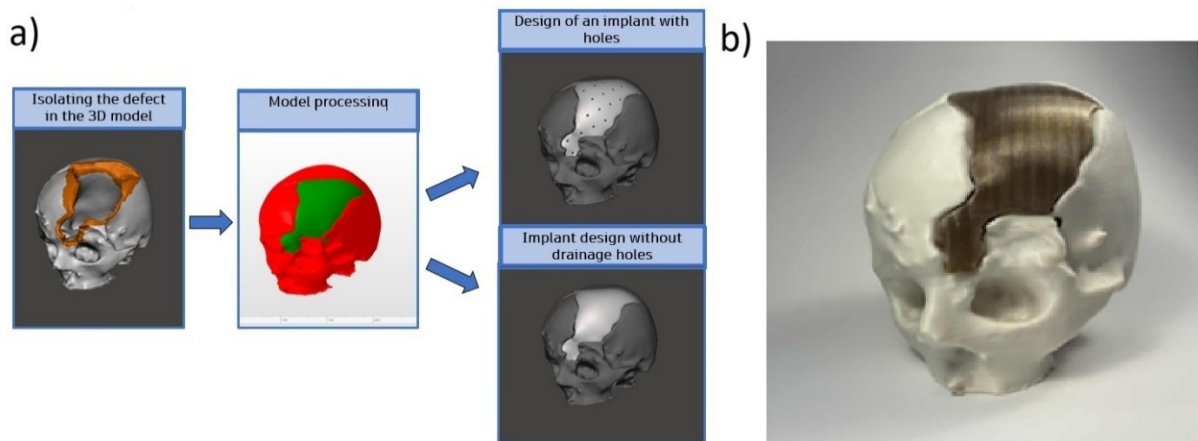
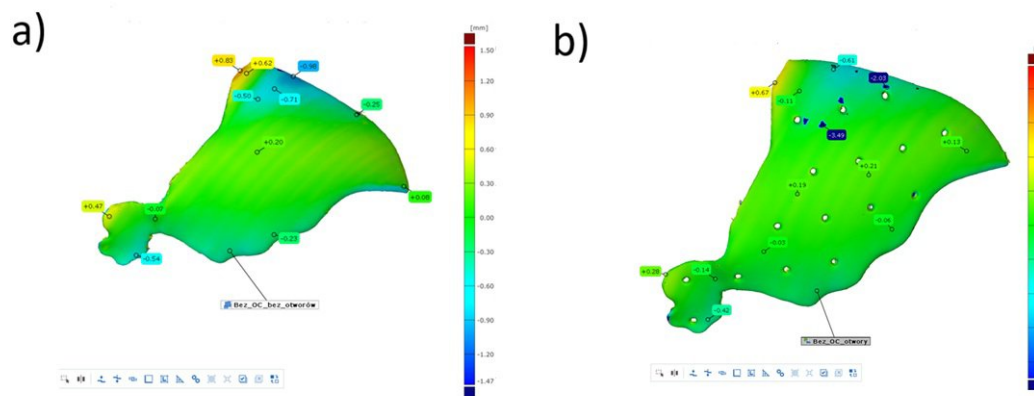
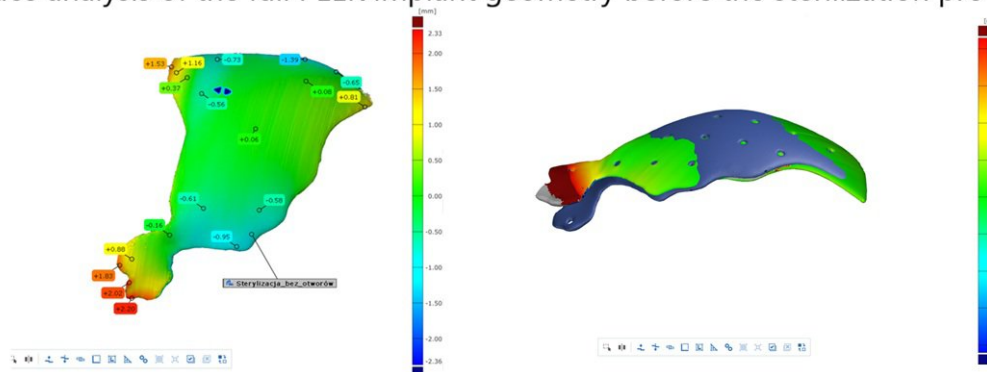


Figure 1. a) customized cranial implants – modeling, b) 3D-printed PEEK implant

The implants under investigation were sterilized at 134°C in accordance with the ISO 17665 standard and subsequently scanned using a 3D scanner. An ATOS II Triple Scan optical 3D scanner was used for the measurements. The obtained data were compared against reference CAD models using ZEISS INSPECT 2026 software. The analysis included surface deviation maps and an assessment of model conformity with a specified tolerance of ± 0.2 mm (Fig. 2).



Surface analysis of the full PEEK implant geometry before the sterilization process



Surface analysis of the full geometry of a PEEK implant following the sterilization process

Figure 2. a) solid implant b) implant with drainage holes

Analysis of additive manufacturing parameters to assess the impact of spare parts production capabilities in shipbuilding

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Keywords: additive manufacturing, Industry 4.0, manufacturing technology, parameters, shipbuilding.

Before implementing a new product into production, it is necessary to analyze the technological, production, and organizational parameters of the planned production. The choice of production method is influenced by numerous factors related to technological, organizational, economic, and increasingly ecological conditions. However, regardless of the component being manufactured, the goal is always to optimize production processes to ensure the most advantageous use of available technology. Among the available production methods, conventional and alternative (modern) production methods can be distinguished, characterized by parameters that align well with current market needs.

Modern manufacturing methods undoubtedly include additive manufacturing, which is groundbreaking in terms of achieving the final product shape. Additive manufacturing is one of the so-called Industry 4.0 technologies that can transform industry toward eco-efficient, high-performance, on-demand production of components, with increased digitalization of the entire process. In addition to cost savings and reduced waste, additive manufacturing enables rapid prototyping, immediate implementation of design changes, and the ability to produce components with highly complex geometric structures that would be impossible to achieve using conventional methods.

To implement modern manufacturing methods on an industrial scale, it is necessary to first guarantee the appropriate quality and safety of products manufactured using these methods. To this end, it is necessary to ensure industry-specific regulations that would allow for the implementation of certification of the manufacturing process and the final product for the technology used to produce this component, thus confirming the product's suitability for its intended use.

The intensive development of additive manufacturing technology recorded over the last few years and good forecasts for the coming years have contributed to the issuance by some Classification Societies of publications containing guidelines and recommendations relating

to additive production methods, the use of which will allow for obtaining certification of the final product.

This paper presents the topic of modern production methods, with a particular focus on technologies used in additive manufacturing processes. It also outlines the direction of development of production methods used in the shipbuilding industry, presents forecasts for the coming years, and identifies factors determining the development and implementation of new manufacturing technologies, taking into account historical perspectives. It also presents a classification of additive methods in accordance with applicable standards and identifies the characteristics and advantages of using these technologies in the production of shipbuilding components.

A properly conducted analysis should lead to the greatest possible reduction in production costs in subsequent stages. As shown in Figure 1, during the conceptual phase, the costs of subsequent production processes can be reduced by as much as 70-80%.

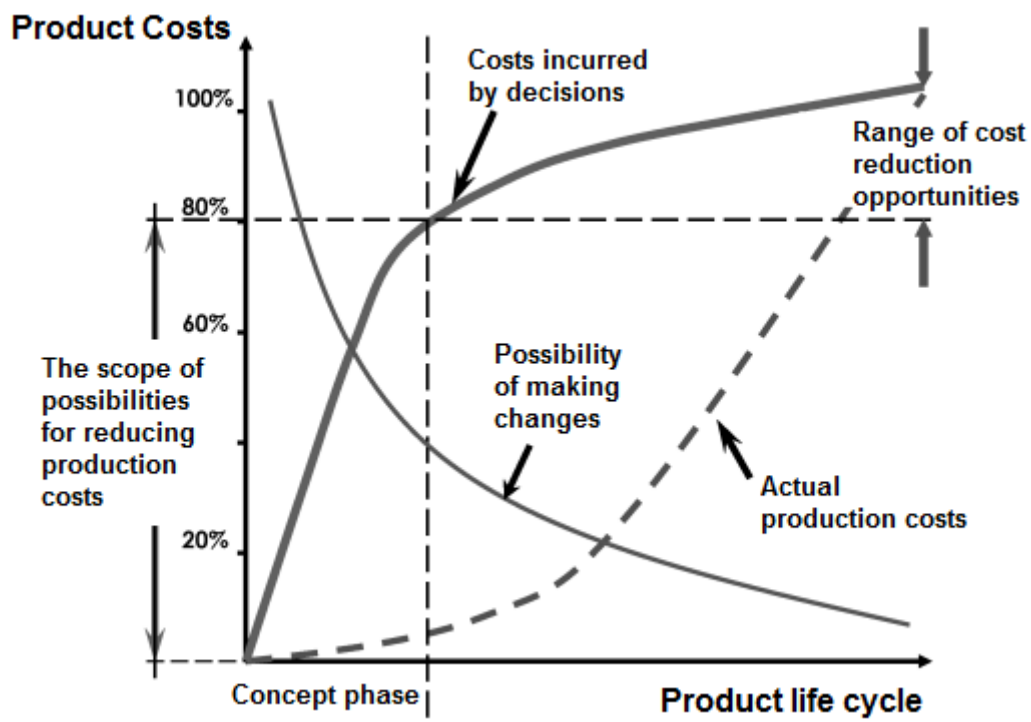


Figure 1. Possibilities of reducing production costs during the product life cycle

Influence of Local Shape Memory Polymer Application on the Mechanical Performance of 3D-Printed Orthoses

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Keywords: Shape Memory Polymer; Orthosis; Cellular Structure; Lattice Structure; 4D Printing; Smart Materials; Personalized Orthotics.

The study investigated the influence of the local application of a shape memory polymer (*SMP*) on the mechanical performance and shape recovery of 3D-printed orthotic structures. All specimens and orthosis models were manufactured using Material Extrusion (*MEX*) technology. In the first stage, specimens manufactured according to *ISO 178* were subjected to bending tests. Three series were investigated: specimens tested in the initial state, specimens thermally treated in a drying oven, and specimens treated in water at the same temperature. The bending angle and mechanical characteristics were determined and compared with conventional *PLA*. In the second stage, the *SMP* was locally incorporated into 3D-printed orthosis models. The orthosis was manufactured from a material whose geometry and mechanical properties were not affected by the applied temperature, while the locally incorporated *SMP* was responsible for the shape change. Three variants were examined: a reference model manufactured entirely from the base material and two models combining the base material with locally applied *SMP*. The models underwent bending tests to assess the effect of the *SMP* on their mechanical behaviour. Subsequently, the specimens and orthosis models were thermally treated in a drying oven and in water to evaluate their ability to recover their original shape. The results were used to assess the potential of locally applied *SMP* for controlled modification of the geometry and mechanical response of 3D-printed orthoses.

Design and Fabrication of a Finger Prosthesis Using Multi-Material 3D Printing

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Keywords: Multi-material additive manufacturing, Finger prosthesis, PLA-Cu nanocomposite Thermoplastic polyurethane (TPU), Personalized prosthetics

The study focused on the design and fabrication of a personalized finger prosthesis using multi-material 3D printing. The prosthesis was developed based on the user's anatomical geometry and designed as a tendon-driven mechanical system, enabling finger movement through a cable-based actuation mechanism.

The main structural components of the prosthesis were manufactured from a rigid PLA-Cu nanocomposite, while flexible TPU was incorporated into the gripping surfaces. The combination of these materials within a single structure enabled the integration of mechanical stiffness with flexibility and improved the contact between the prosthesis and grasped objects. The device was subsequently provided to the user for everyday use and evaluated under real-life conditions over a period of one month.

The evaluation demonstrated satisfactory functionality and usability of the developed prosthesis. The user reported good comfort during use and effective gripping performance. The results confirm the applicability of multi-material 3D printing for manufacturing personalized finger prostheses with rigid and flexible components.

The Effect of Machining on the Surface Roughness of PLA Specimens Manufactured Using the Material Extrusion (MEX) Additive Manufacturing Process

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Keywords: additive manufacturing, PLA, surface roughness, surface metrology, machining

The aim of this study is to determine the effect of machining, performed on a DMG DMU 50 CNC machine tool, on the surface properties of specimens manufactured using an additive manufacturing process belonging to the Material Extrusion (MEX) group. The specimens were produced from PLA (polylactic acid).

Rectangular specimens with dimensions of 30 × 20 × 25 mm were prepared for the study. They were manufactured in nine series, with three specimens in each series. The controlled additive manufacturing parameters were the layer height (0.12, 0.20, and 0.28 mm) and the specimen orientation angle on the build platform (0°, 45°, and 90°). All other additive manufacturing parameters were kept constant in accordance with the material manufacturer's recommendations.

The specimens were machined on a CNC machine tool using a SECO milling cutter equipped with five cutting inserts. Identical machining parameters were applied to all specimens: a depth of cut of 0.5 mm, a spindle speed of 1995 rpm, and a feed rate of 798 mm/min.

Surface roughness was measured using a Taylor Hobson Form Talysurf PGI 1230 contact profilometer. Measurements were carried out both before and after the machining process. The evaluation length was 15 mm.

The objective of the study was to determine the change in surface roughness resulting from the machining process and to evaluate the influence of the specimen orientation angle and layer height on the obtained results.

Testing selected mechanical properties of an elastic mechanism manufactured using FFF additive manufacturing technology

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Keywords: Compliant Mechanisms, Rolling Contact Mechanism (RCM), FFF technology, 3D CAD design.

The study focuses on the design, fabrication, and research of selected mechanical properties of a compliant Rolling Contact Mechanism (RCM) manufactured using Fused Filament Fabrication (FFF). Based on a literature review, an original mechanism design was developed, its prototypes were fabricated, and a robotic gripper arm based on the proposed mechanism was designed. Experimental tests, including torsion, tensile, and gripping force measurements, were conducted to evaluate the mechanical performance and identify the limitations of the mechanism. The results confirmed the feasibility of manufacturing a functional compliant mechanism using FFF and demonstrated that its mechanical properties can be tailored through appropriate selection of geometry and materials.

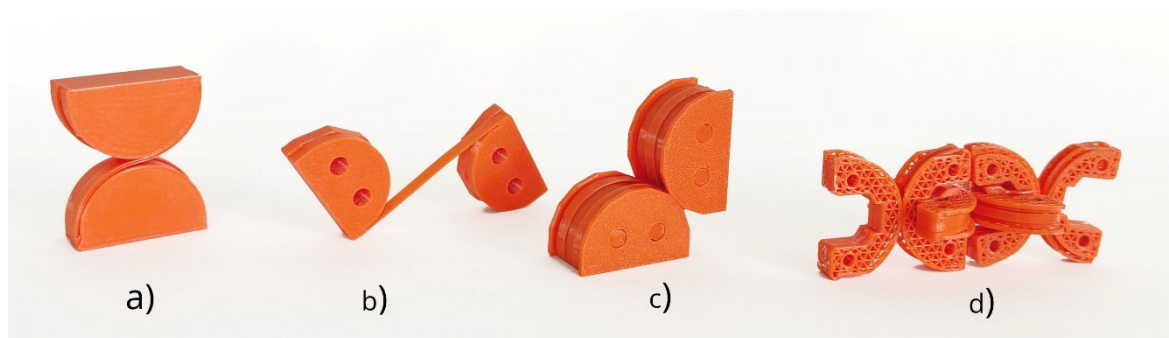


Figure 1. Flexible mechanisms developed in the first stage of the design process: a) a mechanism printed in a single process, b) a part of a mechanism with a printed straight link, c) a multistable mechanism, d) a combination of several mechanisms in a kinematic chain

From Breaking Point to Production Line: FFF-Printed PLA Dies for Cold Sheet-Metal Forming

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Keywords: fused filament fabrication, PLA, destructive testing, rapid tooling, sheet-metal forming.

Two case studies push FFF-printed PLA tooling for cold sheet-metal forming from characterisation to production. First, three V-bending die geometries — printed at 100% infill after a full tensile, compressive, three-point-bending and buckling characterisation of the PLA across build orientations and infill levels — were bent against six sheet grades of increasing strength. The dies stayed functionally intact, with only minor edge bruising, through 4 mm S235 steel and failed only at the final, most demanding 8 mm S235 test, mapping the real load ceiling of printed tooling instead of assuming one. Second, a press-die pair designed for prototype stabilizer-clamp production formed 275 aluminium inserts (250 at 1.5 mm, 25 at 2.5 mm) in a single validated run, at roughly 3% of the material cost and in hours rather than the six weeks a machined steel die requires; the same tooling, tested on higher-strength S420MC steel, could not withstand the required pressing force, marking the technology's present limit. Together the two studies show FFF PLA dies as mechanically characterised, destructively bounded and already validated at production scale for suitable materials — with tool-surface hardness, not simulation-predicted bulk stress, remaining the governing design constraint, consistent with reports elsewhere in the polymer-tooling literature.



Figure 1: A 3D-printed PLA V-bending die under load in a universal testing machine — one of six sheet grades used to map the die's real destructive limit.



Figure 2: The same rapid-tooling approach at production scale: 275 aluminium stabilizer-clamp inserts formed by a 3D-printed PLA die, at roughly 3% of the material cost of a machined steel tool.

Material Selection and FGF Manufacturing of FutureMold Demonstrator for VARI

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Keywords: FutureMold, PLA, FGF, composites, natural fillers.

Traditional mold fabrication methods dedicated to Fiber-Reinforced Plastic (FRP) composites production present significant challenges in terms of accommodating design changes reported during product development and production phases, high labor effort and material waste, significant energy demand, and low reusability. These challenges become significant in customized manufacturing and low-volume production, where tooling expenditure may account for a substantial proportion of the total production cost. To address these limitations, a sustainable hybrid plastic-metal tool concept is proposed.

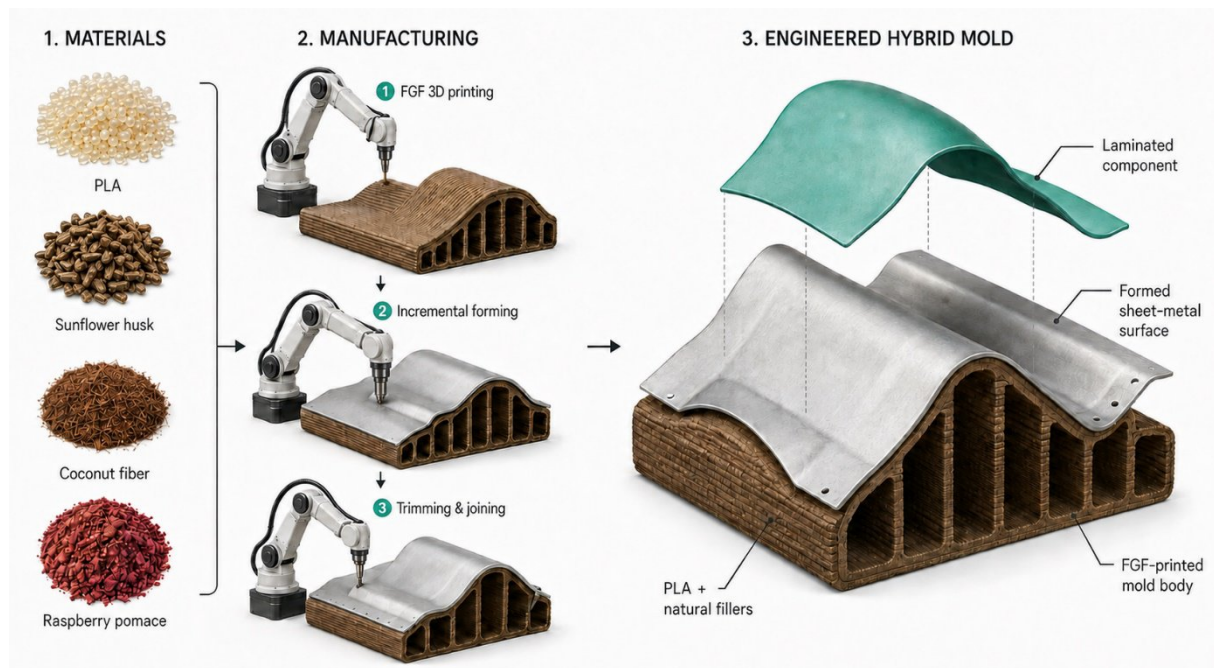


Figure 1. FutureMold fabrication concept.

The FutureMold idea combines a metal armor (working surface) fabricated by Incremental Sheet Forming (IFS) with a structural body manufactured by Large Scale Additive Manufacturing (LSAM) using direct pellet extrusion (Fused Granular Fabrication, FGF), both made by a robotic arm on a single work platform.

The main objective of this study was to evaluate the suitability of biocomposite materials for fabrication of an FGF 3D-printed body that ensures sufficient durability of the printed mold part and adequate processability during manufacturing. Polylactide (PLA) filled with natural fillers derived from agri-food industry waste streams was selected as the printing material to support the utilization of secondary raw materials and reduce the potential cost of mold production. The influence of material composition on the mechanical performance was evaluated with respect to its suitability for use in the FutureMolds concept.

Design of Metal–Polymer Interfaces for Adhesive Bonding of Steel Sheets and Thermoplastic Materials

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Keywords: metal–polymer interface, adhesive interface, pull-off test, additive manufacturing

Bonding polymeric materials to metals remains a significant challenge in materials engineering. The metal–polymer interface plays a key role in determining the mechanical properties and durability of the resulting connection. Achieving reliable and durable adhesion at metal–polymer interface is difficult due to differences in physicochemical properties, including surface energy, elastic modulus, and thermal expansion. Bonding using structural adhesives, such as epoxy, polyurethane, or acrylic, is commonly used. One of the factors influencing the durability of an adhesive bond between metal and polymer is proper surface preparation, including mechanical or chemical treatment, to increase roughness and surface energy, thereby improving adhesion.

The mechanical strength of the interface can be evaluated using a pull-off test, in which a metal dolly is bonded to the surface and subjected to a perpendicular tensile load until failure occurs. The force or stress required to detach the dolly provides a quantitative measure of the bond strength, while analysis of the failure mode provides additional insight into the adhesion mechanisms and the quality of the bonded interface.

The aim of this study is to develop an effective bonding system between a steel metal sheet and a 3D-printed (Fused Granulate Fabrication) polymer structure for potential application in a hybrid mold construction dedicated for composite part lamination. The proposed interface combines an additively manufactured polymer structure with a thin metallic layer produced using incremental sheet forming. The study focuses on the selection of suitable thermoplastic materials, optimization of adhesive application methods, and evaluation of different bonding approaches.

Acknowledgment

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Processing-Route-Dependent Performance of Modified Recycled PA6/GF30 Composites for Large-Format Additive Manufacturing

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Keywords: recycled PA6; glass fiber; large-format additive manufacturing; injection molding; functional additives;

Large-format fused granulate fabrication (FGF) offers a promising route for the high-value reuse of fiber-reinforced thermoplastic waste in the production of large-scale tooling. This study evaluated recycled PA6 containing nominally 30 wt.% glass fibers (PA6/GF30), recovered from public-transport seating, as a feedstock for large-format additive manufacturing. An unmodified reference material and three formulations containing SF315/F6008M, SF315/U15, or MIX-OH were investigated. The materials were compounded and subsequently processed by injection molding and FGF to determine whether the effects of modification were retained after changing the manufacturing route. The granulates were characterized by melt mass-flow rate measurements, thermogravimetric analysis, and differential scanning calorimetry. Tensile, flexural, and Charpy impact properties were determined for both processing routes. In addition, preliminary pull-off tests were conducted for polymer–steel joints produced using thermoplastic polyurethane adhesives.

The SF315/F6008M and SF315/U15 formulations exhibited the best mechanical performance after FGF processing. Their tensile strengths reached 117.3 and 118.7 MPa, respectively, compared with 56.8 MPa for the unmodified FGF-processed reference. Their flexural strengths reached 158.8 and 152.4 MPa, respectively, versus 88.0 MPa for the reference. Both formulations also showed increases in impact strength exceeding 50% relative to the printed reference material. In contrast, the mechanical improvements produced by MIX-OH after injection molding were not retained following FGF processing, demonstrating a pronounced processing-route dependence. Pull-off strengths of the TPU-bonded polymer–steel joints ranged from 0.29 to 0.63 MPa, with failure occurring predominantly at the adhesive–steel interface.

The results demonstrate that appropriately selected functional additives can substantially improve the performance of recycled PA6/GF30 after large-format FGF. The SF315/F6008M and SF315/U15 formulations are particularly promising for further development of large-scale, recyclable composite tooling.

This research was funded by the National Centre for Research and Development under the project M-ERA.NET 3 Call 2023 (M-ERA.NET3/2023/6/FutureMold/2025) “Flexible manufacturing approach for recyclable biobased high performance composite molds”.

State of Knowledge on the Tailoring of Microstructure and Mechanical Properties of Polymer Materials in 4D Additive Manufacturing Processes

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Keywords: 4D additive manufacturing; polymer materials; microstructure and anisotropy; mechanical properties; technologies for the Polish Armed Forces.

Additive manufacturing of polymer materials is a dynamically developing field of research, whose importance results from the possibility of rapidly and individually manufacturing components with complex geometries. A particularly promising approach is 4D printing, which represents an extension of conventional 3D printing technologies and enables the fabrication of structures capable of changing their geometry or properties in response to external stimuli. This technology may also enable the reduction of anisotropy characteristic of conventional layer-by-layer additive manufacturing, as well as the tailoring of the microstructure and mechanical properties of manufactured components.

The research presented, conducted as part of my doctoral studies, focuses on determining the relationships between 4D manufacturing process parameters, post-processing, microstructure, and the mechanical properties of polymer materials. The 4D Fusion technology is investigated, including the BFG head, which enables the use of various material deposition techniques and the incorporation of significant amounts of additives into a polymer matrix. The research includes the analysis of material porosity and homogenization, the effects of manufacturing orientation and heat treatment, as well as tensile, flexural, hardness, impact, and fatigue tests. The results will be compared with components manufactured using conventional 3D printing methods.

The scientific objective is to determine the mechanisms influencing the microstructure, isotropy, and functional properties of materials manufactured using 4D printing, as well as to establish relationships enabling the controlled tailoring of their properties. An important outcome will also be the development of a basis for selecting technological parameters that allow the production of repeatable and functional components.

The obtained results may provide a basis for the further development and implementation of additive manufacturing technologies within the Polish Ministry of National Defence. Of particular importance is the possibility of rapidly manufacturing individual and replacement components, reducing procedures associated with the procurement of spare parts, and potentially enabling the use of additive manufacturing directly within military units. The development of 4D printing technology may therefore contribute to increasing technological autonomy, flexibility of material supply, and the capability of the Polish Armed Forces to utilize advanced functional materials.

Analysis of the development of competences in the field of science and education in the field of 3D printing and artificial intelligence

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Keywords: 3D printing, artificial intelligence, scientific competences, competences in education.

This publication analyzes the potential for developing competencies in 3D printing as a tool for research and educational processes, including those using algorithms based on artificial intelligence and generative modeling. The authors' extensive experience in research and educational programs based on additive technologies informs the publication. The publication summarizes the results of research aimed at assessing the effectiveness of 3D printing in both in-school and out-of-school education. The experiences of students, teachers, parents, and guardians were analyzed. This broad approach allows for a diverse perspective and a better understanding of the technology's real impact on the learning process and students' preparation for higher education based on 3D modeling and printing technologies. The research included, among other things, levels of satisfaction with classes, assessment of the achievement of educational objectives, student engagement, and concerns about safety and work organization. The presented results are part of the work carried out as part of a collaboration between Rzeszów University of Technology, the Rzeszów City Hall, and the Urban Innovation Center - Urban Lab.

Human–Artificial Intelligence Collaboration in Additive Manufacturing: An Immersive VR/AR/MR Approach for Industry 5.0

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Keywords: Artificial Intelligence, Additive Manufacturing, Virtual Reality, Augmented Reality, Mixed Reality, Industry 5.0, Human–AI Collaboration, Cyber-Physical Systems.

The increasing integration of artificial intelligence into industrial processes requires the development of new models of human–AI collaboration aligned with the human-centric approach of Industry 5.0. This paper presents the concept of using an immersive XR environment as a research testbed for investigating human–AI interaction in additive manufacturing. The proposed approach integrates immersive technologies, AI agents, and elements of cyber-physical environments, enabling the investigation of different forms of communication, control, and collaboration between humans and intelligent systems. Particular attention is given to task allocation between humans and AI, remote operation within immersive environments, and the identification of areas where automation can be complemented by uniquely human competencies. The proposed concept provides a foundation for the development of laboratory testbeds and further experimental evaluation of human–AI collaboration models in manufacturing environments.

Reverse engineering and additive manufacturing techniques in the process of reconstructing machine parts

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Keywords: reverse engineering, additive manufacturing, machine parts, connecting rod.

The subject of this paper is the process of developing a methodology for inspecting damage and reconstructing a selected machine component – the connecting rod of an internal combustion engine – using reverse engineering and additive manufacturing. A non-contact measurement of the damaged part was performed using an optical scanner that utilizes structured blue light, which is characterized by high accuracy in 3D geometry mapping. In the next step, the acquired data was analyzed and processed using dedicated software tools. Based on the processed 3D data regarding the dimensional and geometric characteristics of the damaged connecting rod, a complex repair process was carried out using CAD tools, followed by the development and verification of an STL model necessary for manufacturing the part using additive manufacturing. The final stage of the research involved the precise 3D printing of the connecting rod using the PolyJet method with UV light-curable resin. The prototype of the reconstructed machine part, in accordance with the methodology presented in this article, can be used to design and manufacture a silicone mold and a casting of the part from a dedicated wax, followed by the production of a fully functional part through metal alloy casting, using the standard lost-wax method to construct the ceramic mold.

Standardization in 3D Printing - Metrological Aspects Of AI

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Keywords: 3D printing, Standardization, Artificial Intelligence, Metrology

The quality problems of models manufactured by 3D printing is a key issue when making decisions, both for 3D printers and for ordering printed objects from companies. Due to the layered nature of the manufacturing process, additive technologies are extremely specific and require an individual approach to adapt procedures to their specific nature – especially in responsible application like medicine, aerospace or military.

This paper concisely presents information on the current state of standardization and the inconsistencies between current standards and the requirements typical of analysis models manufactured using 3D printing. Particular attention is also paid to the development of standards and the need to develop new ones. Moreover, the work indicates areas of potential application of artificial intelligence in already implemented 3D printing systems requiring standardization and presents the concept of using artificial intelligence in new areas of 3D printing.

Drawing on international databases such as Web of Science, Scopus, etc., the development of standardization in selected scientific sectors over recent years is presented.

Regarding the practical industrial applications of 3D printing, the role standardization plays in the financial aspects of industrial enterprises' operations is emphasized, as well as how deficiencies in the use of international standards expose companies to both financial and reputational losses. This is especially important in metal 3D printing and materials like aluminum, copper or titanium.

Application of reverse engineering and 3D printing in the creation of a thin-walled solid model of a 3-blade propeller

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Keywords: Thin-walled element, Fan blade, 3D printing, 3D Scanning.

This paper describes the fabrication of a fan blade using 3D printing technology. The blade belongs to a group of thin-walled elements, the production of which by 3D printing poses many challenges. The aim of this paper is to investigate the feasibility of 3D printing thin-walled elements of the propeller class. Reverse engineering and a commercial object were used to obtain the .stl format of the blade model. The scanning procedure and point cloud processing are presented, as well as dimensional inspection using the ATOS II scanner and GOM software. Discontinuities in the triangle mesh after polygonization, occurring at sharp edges, are highlighted, and methods for removing these discontinuities are discussed. To select optimal process conditions that ensure a balance between high mechanical strength, surface quality, and dimensional stability of the final product, 40 test samples were 3D printed for static tensile testing. MEX (FFF) technology and a Bambu Lab P1S 3D printer were used to fabricate the samples and the blade model. After the propeller model was completed, its visual, dimensional, and strength assessments were performed. The wall thicknesses of the propeller blades and hub were measured. A bending test was performed on individual blades of the printed propeller model and the commercial object. The imperfections of the printed model were identified, and how they could be improved to achieve the required quality were discussed.



Figure 1. a) 3-blade propeller during scanning, b) 3-blade propeller model during printing

Challenges of Reverse Engineering Micro-Mechanical Watch Parts for 3D Printing

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Keywords: reverse engineering, additive manufacturing, optical microscopy, X-ray computed tomography, horology.

Reverse engineering of micro-mechanical watch components for additive manufacturing is constrained by a mismatch between the micron-level tolerances of horological parts and the accuracy of the methods available to capture them. The paper is divided into a theoretical and a practical part.

The theoretical part reviews the two families of measurement relevant to horological reverse engineering and delimits the accuracy each delivers on miniature parts: optical microscopy, covering the profile projector, measuring and video microscopes, chromatic-confocal sensing, confocal and focus-variation areal microscopy and interferometry; and 3D scanning, covering structured light, laser triangulation and X-ray micro-computed tomography, the last treated in detail as the only technique that reaches horological accuracy while also capturing internal and assembled geometry.



Figure 1: Overall picture of disassembled components of calibre K25

The practical part applies this toolkit to the movement of the 1954 Prim Spartak, the first Czechoslovak mechanical wristwatch, itself historically reverse-engineered from the French

LIP R25. A digitisation workflow combining microscopy, computed tomography and 3D scanning is proposed and carried out, the difficulties specific to a seventy-year-old, worn, reflective and partly transparent object are discussed, and the resulting parametric CAD model is used to make a scale model of a watch movement by additive manufacturing.



Figure 2: 3D scan of calibre Prim K25

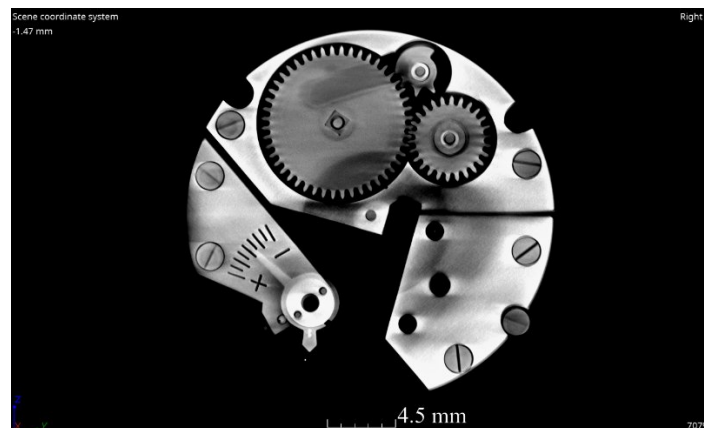


Figure 3: CT scan of calibre K25 from the front

Microstructural characterization and microhardness of LMD-Deposited NiCrBSi–W₂C–PDC composite coatings

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Keywords: laser material deposition, metal matrix composite layers, microhardness

Metal matrix composite (MMC) layers combine advantageous mechanical and tribological properties and are widely used to protect engineering components against wear. Their performance can be enhanced by incorporating ceramic reinforcements, such as TiB₂, TiC, Al₂O₃, and WC. However, their application remains limited by reinforcement agglomeration, microstructural defects, and insufficient interfacial bonding between the ceramic phase and metallic matrix. Among the available fabrication techniques, laser material deposition (LMD) is particularly suitable for producing wear-resistant layers and repairing high-value components.

In this study, multilayer **layers** were produced by laser material deposition (LMD) on 4715H low-alloy steel and P550 non-magnetic steel substrates. The layer system comprised a NiCrBSi buffer layer and a composite layer consisting of a NiCrBSi matrix reinforced with spherical W₂C particles and PDC material. The microhardness and microstructural homogeneity of the deposited layers were subsequently evaluated. To characterize the deposited layers, their microstructures were examined using optical microscopy and scanning electron microscopy. Mechanical properties were assessed through microhardness measurements. The results revealed differences in both the microstructure and mechanical properties of the investigated layers.

The work was carried out as part of an implementation PhD conducted in collaboration with Glinik Drilling Tools and the Warsaw University of Technology.

Comparative Study of Spent Sand Reclamation from Binder Jetting and Conventional Foundry Technologies

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Keywords: binder jetting, additive manufacturing, spent foundry sand, sand reclamation, mechanical reclamation, thermal reclamation.

Binder jetting (BJ) is increasingly used in foundry practice for the rapid manufacture of geometrically complex sand molds and cores. In comparison with conventional molding technologies, BJ generally uses a substantially finer silica matrix and a selectively deposited binder, which may change the behavior of the spent sand during recycling. Effective reclamation of this material is therefore important both for reducing the consumption of fresh silica sand and for limiting the quantity of foundry waste. The aim of this study was to compare the reclaimability of spent furfuryl-resin sands originating from additively manufactured molds and from conventionally prepared molds under mechanical and thermal treatment.

The experimental material consisted of two spent sands obtained after pouring identical ASTM A 536-84 wedge molds with ductile iron EN-GJS-500-7 and shaking the castings out after 30 min. US-1 originated from molds produced by binder jetting on a KOCEL AJS 300A system, whereas US-2 originated from conventional furfuryl-resin mold production. The sands differed markedly in granulometry: the geometric mean grain diameter was 0.125 mm for US-1 and 0.287 mm for US-2. Before secondary reclamation, the LOI values were 2.70% and 2.85%, respectively, while the initial pH was 3.96 for US-1 and 3.67 for US-2.

Mechanical reclamation was performed in an AT-2 rotary impact–abrasive apparatus using 2 kg batches. Rotor speeds of 280, 420 and 560 rpm and treatment times of 10, 20 and 30 min were applied. After treatment, the reclaim was dedusted and pneumatically classified. Because of the finer BJ matrix, an air velocity of 0.75 m/s was used for US-1, compared with 1.0 m/s for US-2. Thermal reclamation was carried out in an experimental batch reclaimer at nominal temperatures of 600, 800 and 1000 °C for 10–30 min. Reclaim quality was assessed using LOI, pH, dust generation, dust LOI and bending strength of molding sands prepared with reclaimed matrices.

Table 1. Selected properties of spent sands and maximum reclamation performance.

Material	d_s [mm]	Initial LOI [%]	Max. mechanical WRK [%]	Max. thermal WRK [%]
US-1 (BJ)	0.125	2.70	31.5	94.8
US-2 (conventional)	0.287	2.85	41.1	89.8

Mechanical reclamation progressively reduced residual organic binder as rotor speed and treatment time increased. Under the most intensive conditions, LOI decreased from 2.70% to 1.85% for US-1 and from 2.85% to 1.68% for US-2. The corresponding maximum reclamation efficiency indices, WRK, were 31.5% and 41.1%. Thus, despite its higher initial LOI, conventional spent sand was more susceptible to impact–abrasive cleaning. The lower mechanical reclaimability of US-1 is associated with its finer matrix, larger specific surface area and binder distribution between closely packed grains.

Increasing mechanical-treatment intensity also increased dust generation. The dust fraction rose from 1.46% to 5.58% for US-1 and from 2.01% to 7.56% for US-2, while dust LOI decreased from 35.1% to 22.1% and from 37.1% to 27.1%, respectively. This indicates a growing contribution of mineral particles produced by abrasion and crushing of silica grains. Consequently, excessive mechanical reclamation may reduce the yield of useful matrix, particularly for fine-grained BJ sand. Thermal reclamation was markedly more effective. At the highest temperature after 30 min, LOI decreased to 0.14% for US-1 and 0.29% for US-2, corresponding to WRK values of 94.8% and 89.8%. Simultaneously, pH increased to 4.86 and 5.06, confirming effective removal of acidic binder and catalyst residues. The binder-jetted material responded particularly well to high-temperature reclamation, enabling nearly complete removal of organic binder residues.

The technological usefulness of the reclaimed matrices was verified by bending-strength tests. With 100% mechanically reclaimed sand, strength remained below that of fresh silica sand mixtures. Better results were obtained with 50% mechanically reclaimed matrix: maximum bending strengths reached 4.69 MPa for US-1 and 3.45 MPa for US-2, corresponding to approximately 84% and 89% of the respective reference values. With 100% thermally reclaimed matrix, maximum strengths were 4.43 MPa for US-1 and 3.34 MPa for US-2, equivalent to approximately 79% and 86% of fresh-sand values.

Overall, conventional spent sand showed greater susceptibility to mechanical reclamation, whereas high-temperature thermal reclamation was preferred for fine-grained binder-jetted sand. Mechanical treatment can serve as a preliminary or partial reclamation stage, but its intensity should be controlled to limit grain degradation and dust formation. Pneumatic classification and fluidization should also be adapted to the finer BJ matrix. Reclamation systems for additive manufacturing should therefore be optimized with respect to granulometry, binder chemistry and the intended reclaim proportion..

Funding: This research was funded by the National Science Centre, Poland (NCN), under OPUS project no. 2021/41/B/ST5/02632, “Control of the Microstructure of the Skin Layer of High-Quality Cast Iron Castings in Sand Molds Made Using the Incremental Method with Conformal Cooling Channels”, and by AGH University of Krakow through the “Excellence Initiative—Research University” program (application no. 3726).

Virucidal and fungicidal GALVI system based on Zn/Bi and Cu electrodes deposited on acrylonitrile butadiene styrene (ABS) surface

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Keywords: Biopolymer; surface property; antimicrobial properties; coating; wear; anti-microbial additive; coating testing; coefficient of friction.

Galvanic Cu and Zn electrodes on a polymer substrate were found to prevent the development of fungal and viral structures on surfaces exposed to changing climatic conditions, which can be applied in air circulation systems. The work presents an analysis of methods for the fabrication of microcells by adhesion metallic powder coatings and the polymer surfaces, which were realised by two powder bed fusion methods, laser sintering and hot pressing.

The final product was polymer plates with a pattern of electrodes forming galvanic microcells, activated by the humidity in the air. Mechanical tests showed the adhesion strength of the copper powders to a substrate at a level of 2.6 MPa and good wear resistance after tribology tests. A model describing the wear mechanism of a metallic layer deposited on a polymer substrate was proposed and next used to the analysis of lifetime the galvanic microcells.

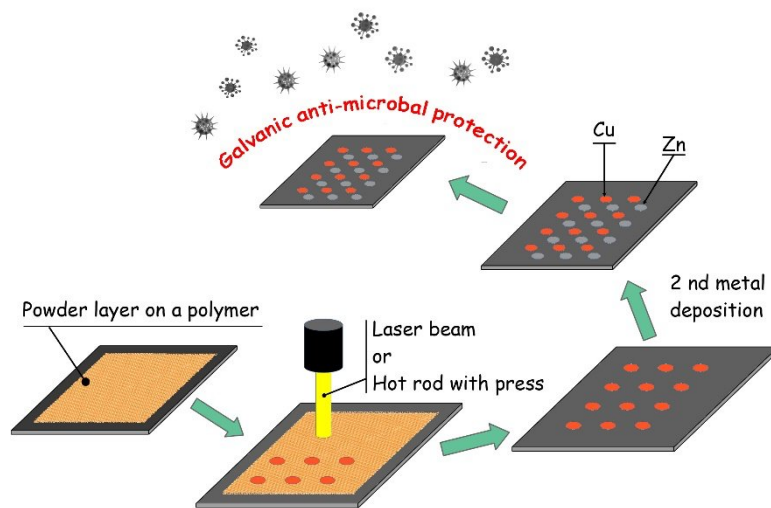


Figure 1. Deposition of metallic electrodes on ABS surface by hot pressing method.

A noise-reducing 3D internal structure of a hydraulic pump body manufactured with the PBF-LB/M technique

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Keywords: additive manufacturing, powder bed fusion, noise reduction, 3d structure

Noise emission is a significant issue in modern machine design. One of the loudest machines are hydraulic systems. Excessive noise emission may limit the use of hydraulic systems in noise sensitive applications, but also requires personnel to use hearing protectors. One possible improvement in terms of noise level may be a 3-dimensional internal lattice structure in the body of the part.

The idea of a 3-dimensional structure is based on frustum pyramids. Pyramids are placed on top and bottom walls of the element body, and there is no connection between them. Empty spaces are filled with metallic powder to reduce the vibrations and noise generation. Manufacturing of this type of structure inside is possible only with additive manufacturing.

For the purpose of testing the hydraulic pump (Hydronit EK1PD2G-G1,3), the body has been manufactured. The pump geometry was prepared with the inverse engineering methodology, and the obtained model was improved with an internal 3d structure. The pump has been made from AlSi10Mg alloy on the NIKON SLM 125 HL device (Fig. 1).



Figure 1. Manufactured hydraulic pump body with internal noise-reducing structure.

or the purpose of the proposed solution's assessment, a noise test was conducted for both versions: original pump and pump with replaced body. The measurements were done with the noise sensor Abatronik AB-8850, according to the DIN45635 standard. The revealed level of acoustic power is lower (10dB), but a significant decrease in flow rate and pressure was recorded, which is associated with the dimensional accuracy of the body.

The presented solution is a subject of a patent application (issue number: P.448663).

Sintering Behaviour of Zn–Bi Materials during Spark Plasma Sintering: Effects on Microstructure and Properties

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Keywords: Zn–Bi; monotectic system; spark plasma sintering; densification; microstructure.

The sintering behaviour of Zn–Bi materials produced from elemental Zn and Bi powders was investigated. The Zn–Bi system exhibits monotectic behaviour and limited mutual solid solubility. Published studies on the powder-metallurgy processing of Zn–Bi materials are limited. The influence of Bi-rich liquid formation on densification during pressure-assisted sintering has received little attention.

Powder mixtures containing 2 and 4 wt.% Bi were consolidated by SPS at 220, 250 and 280 °C under a constant pressure of 50 MPa. For each composition, sintering temperature was varied while the remaining processing parameters were kept constant. The selected temperatures covered conditions below, near and above Bi-rich liquid formation. Densification was evaluated from SPS process data and density measurements. Phase composition was examined by X-ray diffraction (XRD), while microstructure and the spatial distribution of Bi were analysed by scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy (SEM/EDS). Vickers microhardness was measured to evaluate the mechanical response of the consolidated materials.

Homogeneous microstructures were obtained for all materials. Density increased with sintering temperature for both compositions. A greater increase was observed for the material containing 4 wt.% Bi. At 280 °C, both compositions reached approximately 93% of their theoretical density, consistent with enhanced densification in the presence of a Bi-rich liquid phase.

This research was funded by the Excellence Initiative – Research University (IDUB) programme at AGH University of Krakow.

Selection of L-PBF Process Parameters for 42CrMo4 Steel Based on Multi-Method Porosity Assessment

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Keywords: additive manufacturing, Laser Powder Bed Fusion, L-PBF, 42CrMo4 steel, porosity, computed tomography, Archimedes method

Laser Powder Bed Fusion (L-PBF) enables the manufacture of complex steel components, but their internal quality strongly depends on the applied process parameters. This study investigates the influence of laser power, scanning speed and hatch spacing on the porosity of 42CrMo4 steel manufactured by L-PBF. Twenty-seven parameter combinations were analysed. Porosity was evaluated using quantitative metallographic analysis of polished cross-sections and X-ray computed tomography, while density measurements based on the Archimedes principle are used as an additional verification method. Considerable differences in porosity were observed between the investigated parameter sets. The most favourable combined result was obtained for a laser power of 302.5 W, scanning speed of 810 mm/s and hatch spacing of 0.108 mm, corresponding to a volumetric energy density of 115.26 J/mm³. For this variant, the porosity determined from metallographic cross-sections and CT was approximately 0.30% and 0.17%, respectively. The results confirm the strong influence of L-PBF process parameters on defect formation and support the selection of a processing window for manufacturing low-porosity 42CrMo4 steel.

Theoretical and experimental analysis of the effect of extrusion parameters for 17-4 PH steel processed by the MEX technique

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Keywords: Material Extrusion (MEX); 17-4 PH stainless steel; Porosity; Statistical analysis; Machine learning, Decision tree regressor, Random forest regressor, Extreme gradient boosting

This study investigates the influence of printing path geometry parameters: extrusion multiplier (EM), outline overlap (OO), and extrusion width (EW) on the porosity of 17-4 PH stainless steel components manufactured using Material Extrusion (MEX) Additive Manufacturing (AM) technique, both in the as-printed state (green part) and after sintering (metal part). While these parameters govern filament packing and inter-track bonding during printing, their combined effect on porosity evolution across the full MEX process chain remains insufficiently quantified, limiting reliable process parameter selection at the green-part stage. To address this, porosity prediction models were developed using both a statistical Design of Experiments (DoE) approach and machine learning algorithms based on decision trees (Decision Tree Regressor (DTR), Random Forest Regressor (RFR), and Extreme Gradient Boosting (XGB)). The porosity of green parts ranged from 0.14% to 4.76% (mean: 1.39%), whereas the porosity of metal parts ranged from 0.36% to 5.19% (mean: 1.56%). The EM was identified as the dominant process parameter. Increasing EM from 0.95 to 1.15 reduced porosity by more than 83% in both manufacturing stages, with EM = 1.10 determined as the optimal process setting. The DoE model achieved coefficients of determination of $R^2 = 0.918$ for green parts and $R^2 = 0.783$ for metal parts. Machine learning models provided higher predictive accuracy, with the RFR yielding the best performance for green part porosity prediction ($R^2 = 0.913$, Max Error = 0.456), while XGB achieved the highest accuracy for metal part porosity prediction ($R^2 = 0.962$, Max Error = 0.347), representing a 75% improvement over the DoE model. A novel model was also developed incorporating measured green part porosity as a fourth input feature for predicting metal part porosity, the first attempt, to the authors' knowledge, to forecast post-sintering porosity from green-part measurements without destructive postprocessing characterization. This

approach reduced the Mean Absolute Percentage Error (MAPE) by 38.1%, from 28.2% to 17.5%. Both modeling approaches consistently identified EM as the most influential factor, confirming the complementary strengths of DoE (interpretability and process optimization) and machine learning (predictive accuracy).

To the authors' knowledge, this is the first study comparing statistical DoE and tree-based machine learning approaches for predicting porosity evolution between green and sintered MEX-manufactured 17-4 PH stainless steel components.

Mechanical Properties and Stress Corrosion Performance of WAAM-CMT Fabricated Inconel 718

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Keywords: Inconel, Cold Metal Transfer, Heat treatment, Mechanical properties, SCC

The increasing adoption of Wire Arc Additive Manufacturing (WAAM) for large metallic structures requires a comprehensive assessment of the mechanical and environmental durability of additively manufactured materials. This study investigates Inconel 718 produced by a Cold Metal Transfer (CMT)-based WAAM process and compares its performance with conventionally manufactured material.

Mechanical properties and susceptibility to stress corrosion cracking (SCC) in simulated seawater were evaluated for the reference material and WAAM-CMT specimens subjected to different post-processing routes, including Hot Isostatic Pressing (HIP) and followed by heat treatment (HT). The results show that HIP alone does not fully restore the material performance, resulting in lower strength (~ 330 HV0.2, $R_m \approx 825$ MPa) while corrosion resistance was maintained. However, the combined HIP + HT treatment significantly improves mechanical strength (~ 470 HV0.2, $R_m \approx 1170$ MPa) comparable to those of conventional Inconel 718 (~ 420 HV0.2, $R_m \approx 1190$ MPa) while corrosion resistance was maintained.

The study demonstrates that appropriate post-processing is essential for maximizing the performance of WAAM-CMT fabricated Inconel 718 and supports its application in marine and corrosion-demanding environments.

The presented work was carried out within the framework of the PhD research project “Development of Technological Guidelines for Additive Manufacturing of Components of Subsea Oil & Gas Production Equipment”

Effect of Heat Treatment on the Mechanical Behavior of LPBF Ti-6242: Towards High-Strain-Rate Characterization

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Keywords: Ti-6242, LPBF, heat treatment, high-strain-rate behavior, Split Hopkinson Pressure Bar.

This work investigates the effect of heat treatment on the mechanical response of Ti-6242 alloy produced by Laser Powder Bed Fusion (LPBF), with particular emphasis on its behavior under high strain rates. Four material conditions are considered: as-built (AB) and three heat-treated conditions, HT0, HT1 and HT2. Quasi-static tensile tests revealed a pronounced strength–ductility trade-off induced by heat treatment. The AB condition exhibited the highest tensile strength (1430 MPa) but the lowest elongation (4.7%), whereas HT2 showed the highest elongation (13.5%) while retaining a tensile strength of 1264 MPa. Microhardness remained within a relatively narrow range of 360–380 HV. The resulting changes in quasi-static mechanical properties are summarized in Fig. 1. These results provide a baseline for an ongoing high-strain-rate characterization program involving Split Hopkinson Pressure Bar and Taylor impact testing. The experimental data are intended to support constitutive model identification and subsequent numerical simulations in LS-DYNA. The overall objective is to assess how post-processing heat treatment influences the mechanical response of LPBF Ti-6242 under dynamic loading conditions. This work forms part of the doctoral dissertation of Piotr Piwowski, entitled “Development of a Method for Manufacturing 3D Composite Structures for the Design of Ballistic Protection Systems with Enhanced Performance Characteristics.”

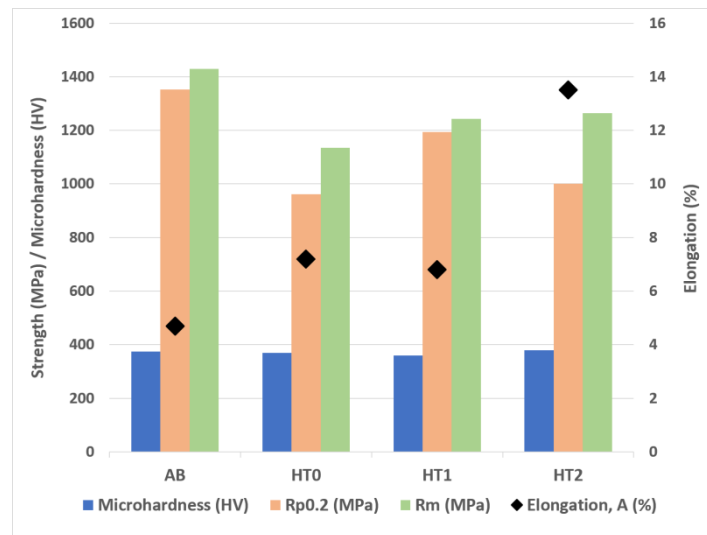


Figure 1. Effect of heat treatment on the quasi-static mechanical properties and microhardness of LPBF Ti-6242.

Investigation of effects of SLM process parameters on the microstructure and mechanical properties for CuSn10 alloy

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Keywords: Selective Laser Melting, CuSn10, mechanical properties, microstructure, process parameters.

Selective Laser Melting (SLM) enables the fabrication of complex bronze components using Selective Laser Melting enables the fabrication of complex bronze components using an AL3D-METAL 200 metal 3D printer, although final performance strongly depends on processing conditions. This study investigates the combined impact of key technological variables, with particular focus on laser power and scan speed alongside scan strategy and sample orientation across vertical, horizontal, and angular positions on the mechanical behavior of CuSn10 alloy. The fabrication employed a layer thickness of $d = 20 \mu\text{m}$ and a hatch distance of $hd = 68 \mu\text{m}$. Microstructural analysis was examined using an optical microscope, while tensile tests were conducted to determine ultimate tensile strength, yield strength, and elongation. The tests proved that appropriate selection of laser power and scan speed governs energy input and structural formation. Increasing power to 140 W while reducing scan speed to 730 mm/s allowed achieving a maximum ultimate tensile strength reaching $549 \pm 4 \text{ MPa}$ and elongation of $10 \pm 1\%$ for angularly oriented samples under a unidirectional scan strategy. Meanwhile, standard parameters utilizing 120 W and 930 mm/s secured peak strength in the vertical orientation at $513 \pm 4 \text{ MPa}$. The results confirm that precise coordination of power, speed, and orientation geometry remains essential for optimizing CuSn10 elements due to the strong influence of the obtained microstructure.

Table 1. Selected mechanical properties of CuSn10 alloy depending on laser power, scan speed, and samples orientation

Path	Power [W]	Speed [mm/s]	Orientation	UTS [MPa]	YS [MPa]	UE [%]
Unidirectional	120	930	Vertical	513 ± 4	405 ± 5	$7,9 \pm 0,8$
Unidirectional	120	930	Horizontal	421 ± 6	330 ± 14	$3,7 \pm 0,7$
Unidirectional	140	730	Angular	549 ± 4	398 ± 4	$10 \pm 1,0$
Snake	120	930	Horizontal	482 ± 7	366 ± 16	$5 \pm 1,1$

Acknowledgements:

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Processing Window for Laser Powder Bed Fusion of $\text{Zr}_{50}\text{Cu}_{40}\text{Al}_{10}$ Bulk Metallic Glass

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Keywords: metallic glass, glass forming ability, atomization, laser powder bed fusion.

Bulk metallic glasses (BMG) exhibit exceptional strength, a high elastic limit, relatively low Young's modulus, and excellent corrosion resistance owing to their amorphous structure. Their application is limited by the need for rapid solidification, high-purity constituent elements, strict oxygen control. Moreover, the maximum fully amorphous casting thickness rarely exceeds 10 mm. Additive manufacturing may overcome these limitations by melting only small powder volumes, enabling high cooling rates and fabrication of larger components. However, repeated reheating during layer-by-layer fabrication can induce devitrification.

$\text{Zr}_{50}\text{Cu}_{40}\text{Al}_{10}$ BMG was prepared from high-purity elements ($\geq 99.95\%$), suction cast into $\varnothing 5$ mm rods, ultrasonically atomized, and processed by PBF-LB/M using different laser powers and scan speeds, corresponding to VED values of 8.3–37.5 J/mm³. At VED ≤ 16.7 J/mm³, samples remained fully amorphous but were highly porous because of incomplete melting (Fig. 1a). VED of 20.8–25.0 J/mm³ produced dense, fully amorphous specimens (Fig. 1b). Higher VED caused crystallization owing to excessive heat input (Fig. 1c). These results define the processing window for fully amorphous Zr-based BMGs fabricated by PBF-LB/M.

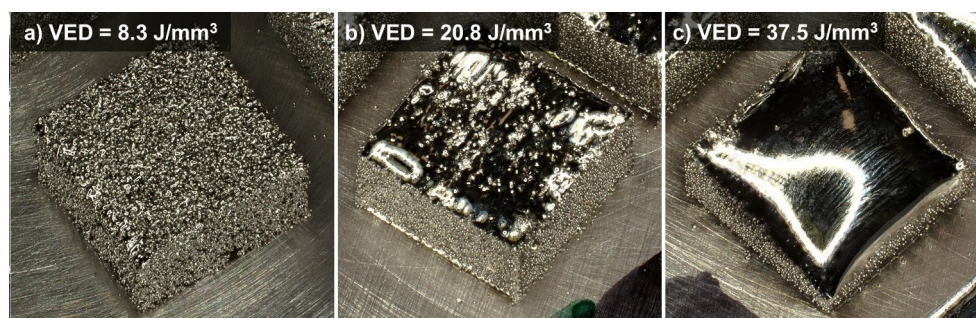


Figure 1. $\text{Zr}_{50}\text{Cu}_{40}\text{Al}_{10}$ BMG cubes fabricated at different VED: (a) 8.3 J/mm³ (porous), (b) 20.8 J/mm³ (dense, amorphous), (c) 37.5 J/mm³ (dense, partially crystallized).

Analysis of the properties of 3D printed components from 316L metal

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Abstract

This paper presents an analysis of the properties of samples 3D printed from 316L metal. The paper aims to conduct an in-depth analysis of 3D printing, verify the complexity of the process, and examine the properties of the finished product. The most commonly used 3D printing techniques are presented and the additive printing process is characterized. The 3D printing technology for 316L steel products is also presented.

Keywords: 3D printing, additive methods, metal structure testing, hardness testing

Metal 3D printing is a relatively new technology that has been developing over the past few decades. Initially, metal printing was only possible on a limited scale, primarily due to the cost and complexity of the process. However, over the past few years, the development of metal printing technology has become much faster, allowing for a significant increase in its efficiency and popularity.

Initially, metal 3D printing was limited to applications in the aerospace and medical industries, where high precision and durability were required. However, thanks to advances in technology, metal printers are becoming increasingly popular in other industries, such as automotive, electronics, architecture, and jewelry.

Cuboidal samples measuring 20x20x10 mm were printed on a Raise 3D PRO 3D printer.

3D printing parameters:

- nozzle diameter: 0.4 mm,
- layer height: 0.2 mm,
- printing speed: 15 mm/s,
- infill: 100%,
- filament temperature: 190°C,
- platform temperature: 40°C

After printing, the samples were rinsed in acetone at 40°C for 24 hours. This was to clean and degrease the samples after the printing process. The samples were then fired in an inert gas atmosphere (argon). Figure 1 shows the sample firing scheme used.

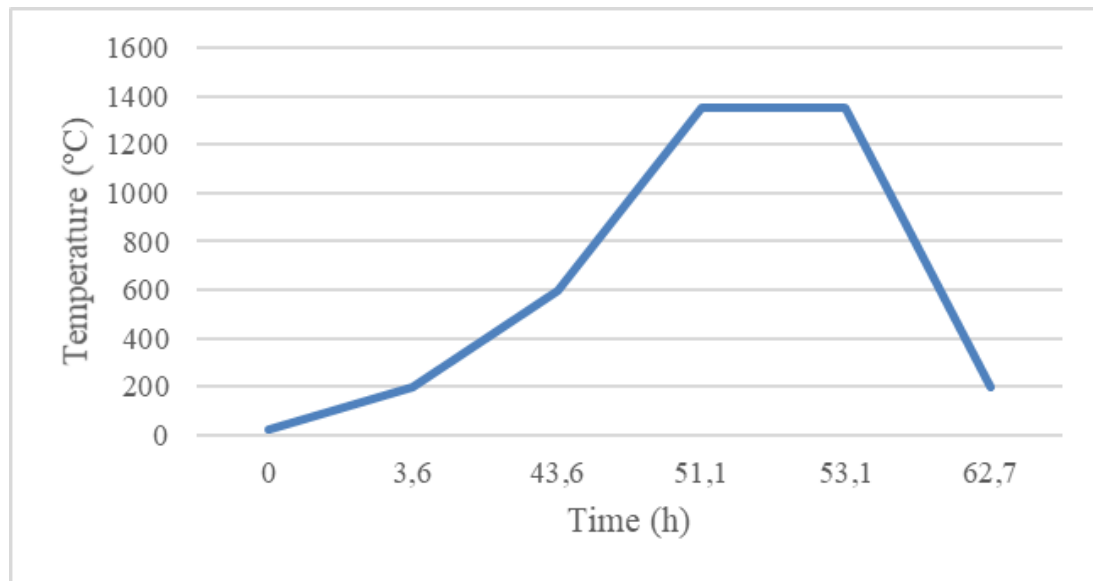


Figure 1. Graphical representation of the temperature-time relationship during sample firing.

In table 2 presents the density test results for metal prints made of 316L steel using the 3D printing technology proposed by Zetamix.

Table 2. Sample mass and density comparison

No	Weight after printing [g]	Weight after acetone [g]	Weight loss [%]	Weight after firing	Density [g/cm ³]	Weight loss after firing [%]	Weight loss from initial weight [%]
1	24.4	23.65	3.07	22.497	6.6203	4.88	7.80
2	24.17	23.4	3.19	22.292	6.7767	4.74	7.77
3	24.63	23.86	3.13	22.677	6.6137	4.96	7.93

After printing the test samples and firing them to remove the binder, structural, hardness, and corrosion resistance tests were performed. The results confirm the possibility of obtaining metal products with uniform properties throughout their entire volume. The presented research is part of a larger study and is being continued.

PBF-LB of Mg alloys containing LPSO structures

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Keywords: magnesium, LPSO, atomization, additive manufacturing, corrosion

Long-period stacking ordered (LPSO) phases are of particular interest in Mg- alloys due to their ability to significantly enhance mechanical performance while providing distinctive microstructural features associated with their complex, highly ordered crystal structure. However, the high cooling rates and repeated thermal cycles inherent to additive manufacturing may strongly affect their stability, morphology, and distribution. Therefore, understanding the response of LPSO phases to powder atomization and subsequent laser-based processing is essential for assessing the feasibility of additive manufacturing of LPSO-containing Mg alloys.

In this study, an Mg–Zn–Y–Al–Yb alloy containing LPSO phases was initially produced by conventional casting at Kumamoto University and subsequently processed into powder by atomization. The obtained powder was used as feedstock for laser powder bed fusion (PBF-LB). The primary objective was to determine whether the LPSO phases present in the initial alloy can survive successive rapid solidification events associated with powder atomization and PBF-LB processing.

The evolution of the microstructure throughout the processing route was investigated using scanning electron microscopy (SEM) and transmission electron microscopy (TEM), with particular emphasis on the presence, morphology, and distribution of LPSO-related structures. The microstructural observations were complemented by corrosion studies to evaluate how the microstructure developed during additive manufacturing affects the degradation behavior of the investigated alloys.

The study demonstrates the potential of combining LPSO-strengthened Mg alloys with additive manufacturing and establishes a basis for tailoring their microstructure through control of the processing route.

From 3D Printing Powder to Bulk Material: Can SPS Compete with Additive Manufacturing?

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Keywords: high-entropy alloy, CoCrFeMnNi, spark plasma sintering, additive manufacturing, powder metallurgy.

The study explores an alternative use of gas-atomized CoCrFeMnNi (Cantor) alloy powder originally intended for additive manufacturing. This high-entropy alloy (HEA) is of particular interest for advanced manufacturing due to its complex composition and unique combination of structural and mechanical properties. Instead of layer-by-layer processing, the same powder was consolidated into dense bulk material using spark plasma sintering (SPS). The aim was to investigate whether SPS can provide an efficient alternative route for processing powders selected for 3D printing. The alloy was sintered at 1050 °C under 50 MPa for 7.5 and 30 min. Relative densities of 99.12–99.62% were obtained, while the addition of 5 wt.% Ti increased the density to 99.75–99.87%. The graphite tooling strongly affected the near-surface region through carbon diffusion. Surface hardness reached about 400 HV1 for the reference alloy and 505 HV1 for the Ti-containing material after 30 min, while the core hardness remained close to 180 HV1. Microstructural and EDS analyses revealed chromium carbide formation near the surface. The addition of Ti promoted TiC formation and reduced chromium depletion, resulting in a modified composite surface layer. The results demonstrate that SPS can transform an AM-grade powder into a nearly fully dense bulk material within minutes, highlighting its potential as an alternative processing route for powders originally intended for additive manufacturing.

Acknowledgements

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Numerical analysis of the SLM process of AlSi10Mg alloy considering melt pool geometry, porosity and microstructure and its experimental validation

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Keywords: Laser-based powder bed fusion, AlSi10Mg alloy, Microstructure, Simulation, Mechanical properties

Laser powder bed fusion (L-PBF) enables the fabrication of AlSi10Mg components, while numerical simulation provides an effective method for predicting process characteristics. ANSYS Additive simulations were performed to investigate single-bead geometry, porosity, and microstructure. 270 simulations were conducted for laser powers of 100–200 W, scanning speeds of 750–2000 mm/s, layer thicknesses of 20–40 μm , and hatch distances of 80–160 μm . AlSi10Mg powder was processed using an AL3D-METAL 200 machine equipped with a 200 W IPG laser under high-purity argon. Experimental validation was performed using 155 W laser power, 1350 mm/s scanning speed, 30 μm layer thickness, and 100 μm hatch distance, corresponding to 38.3 J/mm³ volumetric energy density (VED) selected based on the simulations. Samples were produced in three building orientations (0°, 30°, and 90° to the Z-axis) and characterized by optical microscopy, density measurements, and tensile tests. The results showed that low porosity was associated with high laser power, high scanning speed, low hatch distance, and low layer thickness, with an energy density around 38 J/mm³ recommended for obtained relative density above 99.0%. Simulated single-bead geometry showed good agreement with experiments, while the predicted microstructure indicated no features associated with structural defects. Typical as-built microstructures with approximately 0.75% porosity were observed. The highest UTS, 378 $\pm$ 8 MPa, was obtained for horizontal orientation.

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Surface Modification of PBF-LB/M AlSi10Mg Alloy Using Laser Shot Peening,

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Keywords: PBF-LB/M, AlSi10Mg alloy, shot peening, roughness, microhardness, SEM

Improving the surface quality of components produced by Powder Bed Fusion of Metals using PBF-LB/M technology remains a critical research challenge. While conventional shot peening using glass, steel, or ceramic beads has demonstrated effectiveness in reducing roughness, closing surface-connected porosity, and enhancing fatigue resistance, this study explores the application of Laser Shot Peening (LSP) operating in both air and water environments to modify the surface characteristics of additive-manufactured AlSi10Mg alloy. The LSP treatment was conducted using a Nd:YAG laser ($\lambda=1064$ nm) generating 20 ns pulses at a frequency of 1 Hz. Surface topography and roughness parameters (R_a and R_z) were evaluated before and after processing using a Wyko NT9300 optical profilometer. The initial, as-built 3D-printed surface exhibited typical features of selective laser melting, dominated by un-melted powder particle adhesion and balling effects, resulting in high baseline roughness values. Upon applying LSP in both air and water, the generated shockwave mechanism induced dynamic plastic displacement of the surface profile peaks. This led to a significant surface smoothing effect, reducing the R_a parameter by over 50% down to 14.12 μm . The results confirm that Laser Shot Peening is a highly effective post-processing method for additive-manufactured metallic parts, successfully combining mechanical surface strengthening with substantial geometric quality improvement.

Influence of post-processing techniques on the microstructure and mechanical behavior of PBF-LB/M-Fabricated 18Ni300 Maraging Steel

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Keywords: PBF-LB/M, 18Ni300 tool steel, microstructure, porosity, mechanical properties, wear resistance, laser processing, heat treatment.

This study investigates the effect of post-processing methods—specifically heat treatment (HT consisting of solution treatment and aging), hot isostatic pressing (HIP), laser shot peening (LSP), and laser surface remelting (LSR)—on the geometric accuracy, microstructural evolution, porosity, mechanical properties, and surface characteristics of 18Ni300 maraging tool steel fabricated via Powder Bed Fusion of Metals using Laser (PBF-LB/M). Cubical samples were evaluated using 3D scanning, X-ray computed tomography, uniaxial tensile testing, Vickers microhardness mapping, confocal optical profilometry, scanning electron microscopy (SEM), and X-ray diffraction (XRD) phase analysis to determine optimal post-processing parameters. Dimensional deviations of the as-built parts ranged within -0.10 to +0.07 mm. As-printed specimens exhibited a maximum porosity of 0.45% with maximum pore volumes below 0.02 mm, whereas complete densification (0% porosity) was achieved following the HIP process. The initial hardness of the as-built 18Ni300 steel was 36 HRC. Volumetric heat treatment (solutionizing and aging) significantly increased the hardness to a maximum of 57 HRC through precipitation hardening. Surface modification treatments also induced notable surface-layer hardening and structural refinement: LSP resulted in a maximum hardness of 39 HRC over an affected layer thickness of 98–127 µm, while LSR increased surface hardness up to 41 HRC across a remelted depth of 65–155 µm. The findings demonstrate that combining volumetric and surface post-processing treatments effectively optimizes the mechanical performance, wear resistance, and surface integrity of additive-manufactured 18Ni300 maraging steel for demanding tool and mold applications.

Optimizing M350 Maraging Steel: The Role of PBF-LB/M Parameters

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Keywords: PBF-LB/M, M350 maraging steel, process parameter optimization, computer tomography

This study explores the optimization of process parameters during laser powder bed fusion (PBF-LB/M) and subsequent post-processing treatments to enhance the structural and mechanical performance of M350 maraging tool steel. Specimens were initially fabricated using an XactMetal XM200C system by systematically varying key printing parameters, including laser power, hatch spacing, layer thickness, scanning speed, and scanning strategy. To further refine material properties, the as-built samples underwent volumetric post-processing-consisting of solution annealing followed by age hardening, alongside hot isostatic pressing (HIP) across various parameter regimes-as well as surface post-treatment via laser burnishing and laser surface remelting. The effects of these combined processing steps were evaluated through dimensional accuracy inspection via 3D scanning, porosity analysis using X-ray computed tomography, uniaxial tensile testing, Vickers hardness testing, confocal optical profilometry, scanning electron microscopy (SEM) microstructural characterization, and X-ray diffraction (XRD) phase identification. The comprehensive testing framework successfully identified optimal additive manufacturing, heat treatment, and surface modification parameters required to achieve minimal internal porosity, superior hardness, and maximized wear resistance in M350 tool steel components.

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