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Book of Abstracts

3rd Interdisciplinary Annual PhD Conference on Material Science and Innovative Technologies

Krakow, 3-4 March 2025

General information

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Welcome to the 3rd InterMST 2025

Dear PhD Conference Participants,

On behalf of the Scientific Committee and the Organizing Committee we are pleased to welcome you on the InterMST 2025 conference – Interdisciplinary Annual PhD Conference on Material Science and Innovative Technologies hosted on-line by the Łukasiewicz Research Network – Krakow Institute of Technology, 03-04 March.

The conference is devoted to exploring the richness of approaches, methodologies, and themes of the discipline in order to showcase a wide range of studies and provide a picture of the current state of research in the field of material science and innovative technologies. The interdisciplinary approach of the conference highlight the trajectories of the various scientific disciplines which allow for a progress in material science and innovative technologies – from the engineering and exact sciences to the natural sciences and medical disciplines.

"Book of Abstracts" comprises 20 extended abstracts that have been carefully selected on the basis of a peer review process. It includes state of the art in scientific considerations related to innovative materials and material characterization, advances in casting technology, high temperature and high entropy materials, advances in coatings technologies and finally additive technologies and advances in biomedical and optical technologies.

On behalf of the conference hosts, we would like to express our gratitude to the members of the Scientific Committee, the members of the Organizing Committee, and all the Authors for their effort and willingness to take part in the InterMST 2025 conference – Interdisciplinary Annual PhD Conference on Material Science and Innovative Technologies.

Kraków, March 2025

General information

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The conference topic include:

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MACHINE LEARNING METHODS USED TO IDENTIFY FERRITE, PEARLITE AND GRAPHITE IN THE MICROSTRUCTURE OF CAST IRON

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The aim of the study was to develop and analyze machine learning methods for the identification of ferrite, pearlite and graphite in the microstructure of vermicular cast iron. The paper presents both supervised and unsupervised learning approaches, with particular emphasis on their effectiveness and limitations.

For unsupervised learning, algorithms such as KMeans and the Gaussian Mixture Model (GMM) were used to cluster microstructures based on extracted features such as color intensity, Sobel gradient, and local descriptors (LBPs). Results showed difficulties in precisely distinguishing between ferrite and pearlite and graphite, especially when it comes to similarities in colour and pixel textures.

For supervised learning, the Mask R-CNN neural network was used with the use of manual labeling of microstructures in COCO format. The model achieved high precision in phase detection and classification, and additional data augmentation operations allowed to increase the training set. The use of Mask R-CNN allowed for the automation of analysis and obtaining results similar to manual expert estimates.

The presented approaches show the potential of using machine learning methods in the analysis of cast iron microstructures, especially in the context of automation of control processes and design of materials with desired mechanical properties. These results can be widely used in materials science and the foundry industry.

Research carried out as part of the project POIR.04.01.04-00-027/18-00.

INFLUENCE OF LASER-RELATED PROCESS PARAMETERS ON AUSTENITIC STEEL MICROSTRUCTURE

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The microstructure and mechanical properties of additively manufactured metal parts are strongly influenced by the cooling rate and the temperature gradient direction during solidification. Traditionally, these characteristics have been controlled by adjusting the scanning strategy. This study investigates an alternative approach by varying laser speed and power while maintaining a consistent bidirectional meander scanning strategy, without rotating subsequent layers, in the fabrication of X30Mn22 austenitic steel with layer height of 50 µm. The objective was to determine whether these parameter adjustments could produce distinct crystallographic textures and to evaluate their impact on mechanical properties. The findings confirm that modifying laser parameters leads to significant variations in microstructure, including differences in grain shape, size, and orientation as can be seen in Fig. 1 (a) and Fig. 1 (b). Moreover, these structural changes correlate with notable variations in mechanical performance. The most significant difference was in achieved yield strength, which differed up to 20% and Young's modulus, which varied by up to 27% for the tested specimens. The main result of this study was the achievement of different microstructures and mechanical properties by using different laser-related process parameters highlighting the potential of this method for local fine-tuning material properties in additive manufacturing. These findings can lead to locally influencing the mechanical properties of additively manufactured components and increasing their resistance in critical areas. Alternatively, to define precisely where the component will fail safely if overloaded.

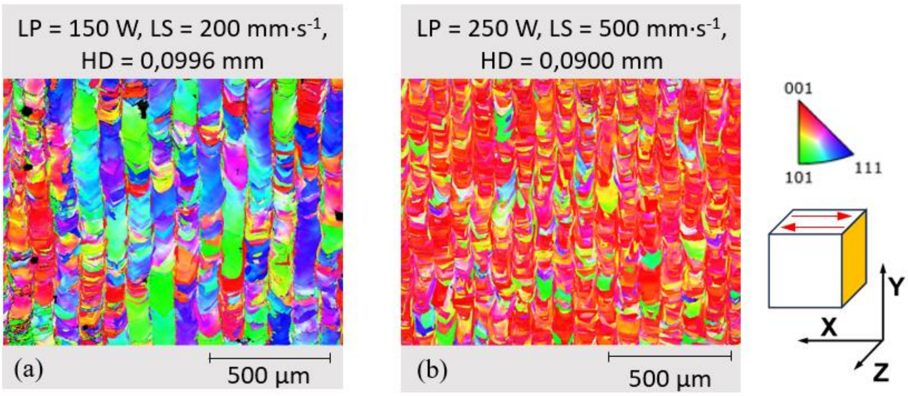

Fig 1. Comparison of achieved microstructures displayed by EBSD maps

ULTRA-HIGH HEATING RATE FAST/SPS OF WC-(Ti,W)C TOOL MATERIALS: PROCESS OPTIMIZATION AND SUSTAINABILITY CONSIDERATIONS

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Spark-plasma sintering (SPS) technology has garnered attention for its ability to perform the densification process at a lower temperature and shorter time compared to conventional sintering methods. Despite its status as a relatively novel sintering technology, its application to the synthesis and consolidation of engineering and functional materials is common and has been extensively documented in numerous studies worldwide. A particularly noteworthy aspect of SPS sintering is its capacity to operate at remarkably high heating rates. Typically, heating rates ranging from 50 to 400°C/min are employed, yielding satisfactory outcomes for a wide range of materials. This paper presents the findings of research conducted on SPS processes executed with heating rates reaching approximately 2300°C/min for carbide tool materials of the WC-(Ti,W)C type. The presentation outlines several approaches for implementing the aforementioned processes in the context of programming the sintering process, as well as designing a graphite tool set and modifying it by adding various elements, such as electrical insulators. The presented research results address not only the impact of sintering parameters on the sintered material, but also the economic and environmental aspects of SPS sintering. Researchers working on SPS sintering technology typically do not consider the analysis of electricity consumption, the duration of the various stages of sintering, and the possibility of industrial use. The research presented here considers the analysis of these values and the reasonability of classifying SPS sintering as a "green technology" method.

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INFLUENCE OF SPRAYING DISTANCE ON SELECTED PROPERTIES OF Fe-BASED NOVELTY PLASMA SPRAYED COATINGS

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The development of Fe-based amorphous and nanostructured coatings has gained significant attention due to their exceptional mechanical, thermal, and corrosion-resistant properties. These coatings, produced through thermal spray processes—particularly plasma spraying—exhibit remarkable performance characteristics, making them suitable for advanced engineering applications [1]. However, the glass-forming ability (GFA) and resulting properties of such coatings are highly dependent on processing parameters, with spraying distance playing a crucial role.Fe-Zr-Si-Cu is known as an amorphous alloy with soft magnetic characteristics and has primarily been used to produce ribbons via melt spinning [2,3]. However, no studies have reported the use of this material in thermal spraying technologies. Given the specific technological parameters of this method, it is possible to obtain a non-crystalline structure.

Powder for testing and coating was $Fe_{79}Ze_{6}Si_{14}Cu_{1}$ (at. %). It was manufactured by gas atomization (Nanoval GmbH & Co. KG, Berlin, Germany) then sieved to +15/-50 μm fraction. Particle size distribution analysis was done on PSA 1190 (Anton Paar, Graz, Austria). Atmospheric Plasma Spraying (APS) was chosen as a method to produce coatings. Spraying was done with SG-100 (Praxair, Indianapolis, USA). Argon was used as a gas for plasma formation. Electric power was 19,3 kW, plasma source was 39 V, and powder usage was 20 gpm. Spraying distance was 80 mm, 90 mm and 100 mm. Samples were tested on stereoscopic observations were done on SteREO Discovery (ZEISS, Germany). Magnifications for observations were x10, x50, and x100. Also, x10 and x25 magnification were done for the samples' edges. XRD was done on X'Pert Pro (Panalytical). Tribological testing was done on CSM Instruments in pin-on-disc mode with Al_2O_3 6 mm ball for following parameters: i) load: 0,5N, 1N, 10N, ii) linear velocity: 2 cm/s, iii) test duration: 300 s.

XRD testing showed that APS method did not allow to obtain fully amorphous structure of the samples, and mostly the spraying distance did not have an influence on it. The main identified phases were α-Fe(Si), $Fe_{23}Zr_{6}$, and $FeZr_{2}$. For microscopic images, they showed that APS was suitable method in the terms of quality and there were no deformations or cracks visible. Tribological tests showed that for low applied forces the Fe-Zr-Si-Cu coating may be suitable, but when the load is at 10 N, the coating exhibited rapid wear and could not withstand such conditions.

In conclusion, while APS was effective in producing Fe-Zr-Si-Cu coatings with good structural integrity, it did not achieve a fully amorphous state. Additionally, the coatings showed limited wear resistance under high applied loads, indicating that further optimization is needed for applications requiring high durability.

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HYBRID EPOXY COMPOSITES BASED ON BASALT FABRIC: A CASE STUDY OF LOW-TEMPERATURE PLASMA TREATMENT AND REDUCED GRAPHENE OXIDE FLAKES ADDITION

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The purpose of this study was to present a novel method for producing mechanically strong epoxy composite laminates of different compositions, reinforced with basalt fabric and reduced graphene oxide flakes. The laminates were prepared with basalt fabric, which is subjected to low-temperature plasma treatment. This approach was aimed to enhance the adhesion of fabric to resin filled with reduced graphene oxide flakes. Physical properties, adhesion, and mechanical properties of the obtained materials was determined.

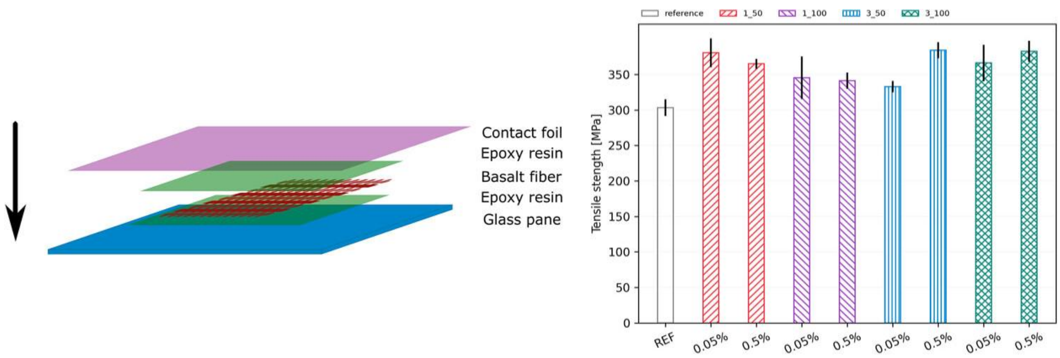

Fig 1. Scheme of the reinforced composites production (on the left) and tensile strength of basalt composites with the addition of graphene (X ax) in three concentrations for each fiber modified with low-temperature plasma under various conditions (on the right).

It was revealed that the addition of reduced graphene oxide in epoxy resin enhanced mechanical properties of the composite compared to reference sample. The greatest increase was observed for 0.05% rGO flakes concentration, which means that even a small addition of rGO has an impact on the mechanical properties of the composite (increase of tensile strength by 21%). Improvement was also achieved for plasma-treated basalt fabric reinforcement. Tensile strength increased up to 23% compared to non treated basalt fabric. After combining, both the previously mentioned modification synergistic effects of rGO and plasma etching was examined. The addition of rGO filler and etching in the oxygen plasma resulted in creation of composites with increased mechanical properties (up to 27% increment of tensile strength). Having this said, the conclusion of this study is that combination of two approaches proposed in this study, incorporation of carbonaceous nanomaterial and low-temperature plasma treatment, was successful and can be considered as an interesting alternative for currently used production protocols of composite materials. Based on the experiments, it is found that the highest improvement of tensile strength is obtained for epoxy composite with 0.5 wt% graphene-based filler and 3 min basalt fiber plasma treatment with 25 W plasma power.

CHALLENGES AND OPPORTUNITIES FOR THE USE OF MACHINE LEARNING, IMAGE SEGMENTATION AND IMAGE PROCESSING IN THE AUTOMATED IDENTIFICATION OF CARBIDES IN THE MICROSTRUCTURE OF GRAY CAST IRON

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Precise and automated microstructure analysis represents a significant challenge in materials engineering, particularly concerning identifying undesirable and potentially detrimental phases, such as carbides in the microstructure of gray cast iron. Traditional microscopic analysis procedures demand specialized expertise, are prone to errors, and incur significant time and cost. Consequently, there is growing interest in leveraging machine learning techniques and artificial neural networks for automated microstructure analysis.

One of the primary challenges in this context is data normalization and preprocessing of microscopic images. Photographs may exhibit variations in color and contrast due to different microscope parameters, etching times, staining agents, or illumination settings. During image acquisition, interference in the form of noise and artifacts can arise, adversely affecting the quality of microstructural analysis. Effective preprocessing techniques are essential to ensure high-quality input data for machine learning models.

An additional complication is the limited amount of data available for model training. Carbides are not as prevalent as other microstructural elements, restricting the number of samples accessible for analysis. This issue is particularly significant for smaller carbides, which are more challenging to detect and frequently blend into the background, complicating segmentation. In contrast, larger carbides are more conspicuous and thus pose less difficulty during segmentation. The lack of diverse, well-annotated training data can result in uneven model learning and diminished performance in detecting fine structures.

A crucial aspect of the segmentation process is the need for manual annotation of reference masks, which serve as the basis for training machine learning models. Generating such masks is both labor-intensive and time-consuming, requiring meticulous expert input. Inaccurate annotations can adversely affect algorithm performance, resulting in imprecise segmentation and classification of microstructures. Automating this stage—for instance, through applying semi-supervised learning methods—can substantially streamline the process; however, ensuring the high quality of annotations remains a significant challenge.

Microstructural image segmentation necessitates using advanced algorithms based on convolutional neural networks (CNNs). This study will employ models such as UNet and its variants, facilitating precise carbide localization by effectively capturing global context and local image details.

This study's objective is to discuss the key challenges associated with data normalization, preprocessing, and image segmentation in the context of carbide identification in gray cast iron microstructures. Effectively addressing these issues can contribute to enhanced automated quality control and increased precision in microstructural analysis within the foundry industry.

SYNTHESIS AND CHARACTERIZATION OF Cu-Zr-Al ALLOYS: ENHANCING MECHANICAL PROPERTIES THROUGH AMORPHOUS-CRYSTALLINE COMPOSITES

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This study explores the synthesis and characterization of Cu-Zr-Al alloys, focusing on enhancing their mechanical properties through the development of amorphous-crystalline composites. By investigating the factors that influence the formation of the B2 CuZr phase during solidification and its subsequent martensitic transformation, this research aims to unlock the commercial potential of these materials.

To achieve this, a comprehensive approach has been employed, beginning with alloy synthesis, casting, mechanical testing, and microstructural analysis. Metallic glasses offer exceptional properties, including high strength and corrosion resistance, making them attractive for engineering applications. However, their innate brittleness has hindered widespread adoption in load-bearing scenarios. To address this limitation, bulk metallic glass composites, particularly Cu-Zr-Al alloys, are explored. By embedding crystalline phases within the glassy matrix, these composites aim to merge the superior strength of metallic glasses with the ductility and toughness of crystalline materials [1,2].

In this work, we investigate a specific group of Cu-Zr-Al alloys with a composition of $Cu_{48}Zr_{45}Al_7$, cast in an arc furnace under a protective argon atmosphere. The samples, with diameters ranging from 5 mm to 10 mm, are designed to facilitate the formation of the B2 CuZr phase during solidification, which subsequently transforms into the B19′ phase under deformation. Additionally, the influence of cooling rate on the composite's microstructure and mechanical properties is examined in detail.

The structural characteristics of the samples were analyzed using X-ray diffraction (XRD), while light microscopy was employed to quantify crystalline precipitations. Uniaxial compression tests were conducted to determine the compressive yield strength and fracture strength. Furthermore, fracture analysis using scanning electron microscopy (SEM-SE) provided insights into the failure mechanisms of the alloys. To further understand the thermal behavior of these materials, differential thermal analysis (DTA) was performed, assessing glass transition behavior, crystallization, and melting temperatures. These findings offer valuable insights into the glass-forming ability of the alloy and its tendency to form the B2 phase during solidification.

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THERMAL SHOCK RESISTANCE OF ADDITIVELY PRODUCED MARAGING STEEL MATERIAL

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The presented study investigates the thermal shock resistance of 3d printed maraging steel, a high-strength, precipitation-hardened alloy. The material is widely used in aerospace, tooling, and high-performance engineering applications. The material was subjected to rapid cyclic heating and cooling to evaluate the thermal fatigue behavior. The microstructural evolution, phase transformations, and residual stress development were analyzed using scanning electron microscopy (SEM), X-ray diffraction (XRD). Results indicate that the additively manufactured maraging steel exhibits a unique combination of thermal shock resistance and mechanical stability, influenced by process-induced microstructural features and post-processing heat treatments. The findings provide insights into optimizing the additive manufacturing process for enhanced durability in high-temperature environments.

MXENES APPLICATION FOR LEAD DETERMINATION IN AQUATIC ENVIRONMENTS

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2D nanostructures, known as MXenes, have garnered significant attention in recent years due to their exceptional properties. These include excellent conductivity, the ability to modify and functionalize surfaces through termination groups, biocompatibility, flexibility, and mechanical strength. As a result, MXenes have made an impact in fields such as electronics, biomedicine, catalysis, and energy storage. One area where MXenes are being extensively studied is sensing. Numerous studies highlight MXenes' potential as a material for designing strain, pressure, optical, humidity, temperature, and electrochemical environmental monitoring sensors [1]. The electrochemical sensors are particularly valuable, given the rapid industrialization and urbanization, which have led to the release of harmful contaminants into various environmental systems, such as air, water, and soil. One such contaminant is lead and its ions, as both can cause significant damage to both human health and the environment. Consequently, finding methods for lead contamination monitoring are crucial. MXene-based electrochemical sensors offer a promising solution to this issue [2]. In this study, we explore the properties of MXenes and develop an electrochemical sensor for detecting lead ions in water, based on their specific interaction with MXenes.

A glassy carbon electrode (GCE) was modified with a Nafion-MXenes mixture to create the sensor. Differential pulse voltammetry (DPV) was used to determine key sensor characteristics, such as the limit of detection (LOD), selectivity, and sensitivity. Experiments were conducted in an acetic buffer solution (ACB) at pH 3.5 to 5.5.

Lead ion sensing was influenced by the pH of the solution, with the best performance observed at pH 3.5 and 4.5. The selectivity tests demonstrated a strong affinity of MXenes for lead ions compared to other ions. Cadmium ions were the only ones producing a signal near the lead peak, but the cadmium signal was about half the intensity of the lead signal. The sensor exhibited a sensitivity of 7.29 μA/(μM·cm^2) and a LOD of 0.68 μM (P=0.95) within a concentration range of 4–10 μM. A potential sensing mechanism involves a reversible transformation between lead ions and lead oxide. The stability of the sensor was also assessed, with relatively stable sensing for up to 12 weeks [Fig. 1].

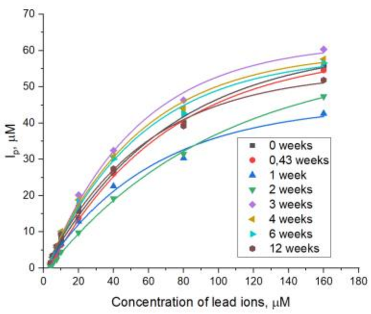

Fig 1. Stability testing results of the sensor

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AU SENSITIZED FUNCTIONALIZED MXene FOR THE COLORIMETRIC SENSING OF GLYCOLIC ACID AND ITS DERIVATIVES

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Colorimetric sensors are increasingly being used in environmental and biological fields due to their high sensitivity, selectivity, cost-effectiveness, simplicity, and visibility to the naked eye. They can detect organic species like proteins, amino acids, DNA/RNA, microorganisms, water quality, reactive oxygen species, acidity/base, and heavy metal ions, and can serve as biomarkers in clinical diagnostics [1][2]. The basic principle of colorimetric sensors is to record color changes in the system due to the presence of the target analyte, providing real-time detection and direct identification. However, existing technology is limited due to low extinction coefficients and low accuracy [3]. Advanced nanomaterials, such as 2D materials, metal and metal oxide nanoparticles and quantum dots, have significantly aided the development of colorimetric sensors [4]. Herein we demonstrate the Au nanocluster-decorated, functionalized MXene-based colorimetric sensor prepared at room temperature for colorimetric detection of trace amounts of glycolic acid and thiol glycolic acid. In this study, L-Cystine functionalized MXene shows the prominent Au nanocluster growth evident in the 375 nm Au plasmonic peak. It also shows significant detection sensitivity and selectivity for glycolic acid and thioglycolic acid in water. Overall, this work not only expands the application of MXene in colorimetric sensors but also provides a general sensing principle to construct highly sensitive sensors.

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3D-PRINTES CONDUCTIVE MATERIALS – RESEARCH AND APPLICATIONS IN BIOMEDICAL ENGINEERING

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3D printing is an additive manufacturing technology in which three-dimensional objects are produced by successively layering material based on a pre-prepared digital model developed in CAD software. In recent years, this technology has gained popularity and has been increasingly applied across various fields, such as mechanical engineering, automotive, entertainment industry, architecture, as well as medicine and healthcare. One of the key advantages of 3D printing is its ability to rapidly prototype, that leads to shorter project times and lower production costs. This technology enables the creation and testing of many variants of a given solution, thus facilitating the selection of the optimal concept. As a result, potential design errors can be identified at an early stage, minimizing the risk of costly modifications in later phases of production implementation. Additionally, 3D printing enables the production of components with complex geometry that is difficult to achieve using traditional production methods. With ongoing advancements in technology, various types of filaments with specialized properties have been developed, including materials that conduct electricity, thereby opening up new possibilities for applications in biomedical engineering [1].

The purpose of the paper was to analyze the electrical properties of conductive materials produced using 3D printing technology. Firstly, CAD model of a typical ECG electrode was developed in the Autodesk Inventor 2025 software, incorporating appropriate parameters to accurately reflect the physical properties of the analyzed component. Then, pre-prepared parts were printed using filaments provided by five different manufacturers, including those made of *polylactic acid* (PLA) and *acrylonitrile-butadiene-styrene* (ABS). Subsequently, measurements were taken of electrical conductivity and its stability under various conditions depending on production time. The final phase of the project involved data collection and analysis.

The results obtained allow us to conclude that 3D-printed electrodes have practical potential in healthcare applications, including ECG examination. Electrocardiography is a non-invasive diagnostic method used to detect cardiac rhythm disorders and myocardial ischemia. During this examination, electrodes are placed on patient's chest and limbs to record the electrical potential variations associated with heart muscle contractions. Based on the recorded data, it is possible to determine whether the heart is functioning normally or abnormally, as well as to assess the risk of surgery for patients with certain conditions. The electrodes used for ECG examinations should be of high quality to minimize the likelihood of interference and signal distortion. Their most important parameters include high electrical conductivity of the material and low contact resistance between the electrode and patient's skin [2]. Electrodes manufactured using additive method have potential to meet assumptions that been previously mentioned. Additionally, due to the easy adaptability of the shape and size of electrodes to the patient's anatomy, it is possible to develop dedicated electrode sets, for example in the form of matrices, which could be used for monitoring pregnant women.

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EXPLORING THE IMPACT OF TEMPERATURES ON PHOTOTHERMAL SIGNAL USING OPTICAL PHOTOTHERMAL INFRARED SPECTROSCOPY (O-PTIR)

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Spectroscopy allows for studying the interaction between light and matter. Especially, mid-infrared (IR) wavelengths enable the detection of molecular vibrations allowing characterization and identification of materials based on absorption spectra. However, conventional infrared microspectroscopy with Fourier transform (FT-IR) suffers from the diffraction limit, which restricts spectral resolution due to the long wavelengths of IR light.

The appearance of Optical Photothermal Infrared Spectroscopy (O-PTIR) has revolutionized this field, surpassing the diffraction limit of traditional infrared microscopes and positioning itself at the forefront of cutting-edge technologies. By illuminating a sample with a pulsed IR beam, O-PTIR excites molecular bonds and absorbs IR leading to localized heating and thermal expansion which change the optical properties of the sample. A visible probe beam detects these alterations, generating spectra in which the system's diffraction limit is defined by the wavelength of the visible laser (532 nm), ensuring a constant submicron spatial resolution across the entire IR range. Moreover, this far-field microscopic technique effectively addresses key limitations of conventional IR microspectroscopy, such as sample thickness, properties of the sample substrate, and the presence of water during measurements.

So far, photothermal expansion has been studied at room temperature. However, certain materials, such as those with low crystallization temperatures, exhibit changes in morphology or polymorphism that can only be detected at subzero temperatures. To enable these investigations, the temperature-controlled stage was integrated into the O-PTIR microscope to assess and monitor the O-PTIR signal of triglycerides and polymers under a controlled cooling environment reaching the temperature of -100 °C. The non-destructive nature of O-PTIR makes it suitable for analyzing sensitive samples, enabling comprehensive spectroscopic characterization. This study highlights the potential of O-PTIR in advancing the understanding of molecular structures and demonstrating the effectiveness of a precisely controlled temperature stage for low-temperature spectroscopic analysis.

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MAGNESIUM-BASED BIOMATERIAL FOR MEDICAL APPLICATIONS

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Magnesium-based biomaterials have garnered significant attention in the field of biomedical applications, particularly for orthopedic implants and bone regeneration. These materials offer a unique combination of biodegradability, biocompatibility, and mechanical properties similar to natural bone, which makes them suitable for temporary implants that naturally degrade as the tissue heals. Magnesium alloys without aluminum content, such as WE43, LAE442, and magnesium-calcium (Mg-Ca) alloys, have gained prominence as safe and effective alternatives for medical use.

Key properties of magnesium-based biomaterials include their favorable mechanical strength, which is similar to that of cortical bone, and their ability to degrade in vivo in a controlled manner. This degradation, when properly managed, eliminates the need for surgical removal of the implant [2,3]. Additionally, these materials are highly biocompatible and support the healing process by promoting bone growth. However, challenges such as rapid degradation rates in physiological environments, which can lead to hydrogen gas release and localized pH changes, still need to be addressed.

The main requirements for magnesium-based biomaterials include good mechanical properties to support the load during healing, adequate corrosion resistance to prevent premature degradation, and favorable biocompatibility to avoid adverse biological reactions. Ongoing research aims to modify the surface of the samples to meet these requirements and enhance the performance of magnesium-based biomaterials in medical applications.

This paper is based on the research results obtained as part of the 6th edition of the Implementation Doctorate project funded by the Ministry of Education and Science within the research results developed as part of the grand number 5020/50 funded by the Ministry of Education and Science.

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IN SEACH OF BIOMATERIALS SUPPORTING BONE TISSUE REGENERATION AND VASCULARIZATION

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Tissue engineering has undoubtedly advanced therapeutic approaches in the treatment of bone defects, though bone regeneration remains a significant challenge in this field. An ideal biomaterial should not only exhibit osteoconductive and osteoinductive properties but also support angiogenesis, as proper vascularization is crucial for successful tissue repair. Therefore, developing biomaterials that integrate all these characteristics is a priority in regenerative medicine [1]. Hydrogels are promising materials in bone tissue engineering due to their high water content, which facilitates the incorporation of bioactive molecules such as proteins, cells, or growth factors [2]. In our previous work (currently under review), we developed hydrogels from whey protein isolate (WPI), a cost-effective and sterilizable biomaterial known to promote osteogenic differentiation [3]. These were further enriched with various concentrations of heparin (HP) and tinzaparin (TP). Our findings demonstrated that these hydrogels enhanced the cytocompatibility and angiogenic potential of human dental pulp stem cells (hDPSCs), suggesting their potential to support angiogenic differentiation. In addition to hydrogels, another promising approach to enhancing vascularization is the incorporation of angiogenic metal ions into biomaterial scaffolds. Elements such as cobalt, zinc, and magnesium have been shown to stimulate neovascularization [4]. Our current research focuses on the fabrication of calcium carbonate microcapsules modified with magnesium (Fig.1), additionally modified with HP and TP at different concentrations. Calcium carbonate-based biomaterials are highly biocompatible, bioactive, and osteoconductive, making them attractive for bone tissue engineering applications [5]. To assess the physicochemical properties of these materials, we conducted structural and microstructural analyses using scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), and X-ray diffraction (XRD). The preliminary results showed that the chemical composition strongly affects morphology and structural properties. These can further influence biological activity of the materials. Ongoing biological evaluations aim to further elucidate the potential of these biomaterials in promoting angiogenesis and bone regeneration.

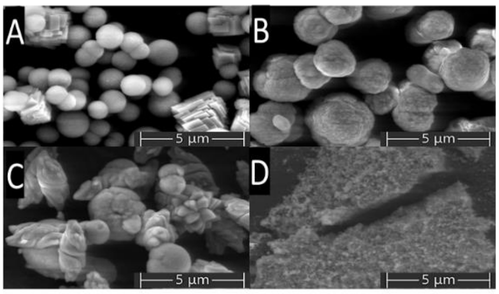

Fig. 1. SEM pictures of A)$CaCO_3$; B)$CaCO_3$+10%Mg; C)$CaCO_3$+20%Mg; D)$CaCO_3$+50%Mg.

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SUSTAINABLE LEACHING OF LITHIUM-ION BATTERY BLACK MASS: EVALUATING LEVULINIC ACID AS A GREEN ALTERNATIVE

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The increasing demand for lithium-ion batteries (LIBs) necessitates efficient recycling methods for recovering valuable metals like Co, Ni, or Li. Despite the increasing awareness and growth of the battery recycling industry, some processes require significant improvements in terms of sustainability. Levulinic acid as a leaching agent offers a more sustainable alternative to widely used sulfuric acid, as it can be derived from biomass, aligning with the principles of green chemistry. This study investigates the leaching efficiency of levulinic acid (6.86 M) at 90°C, over various time intervals (0.5, 1, 3, 6, 8, 14, 16, 24, and 48 hours) for the extraction of critical metals. Samples were taken from the black mass obtained from an industrial recycling process of lithium-ion batteries. Additionally, the effect of hydrogen peroxide (30%) in levulinic acid system was examined over a similar range of leaching durations. The results were compared with conventional leaching method using sulfuric acid(VI). The efficiency and insight into reaction mechanisms of the leaching processes were confirmed using X-ray diffraction (XRD), scanning electron microscopy (SEM), thermogravimetric analysis (TG), nuclear magnetic resonance (NMR), and inductively coupled plasma (ICP) spectroscopy. While levulinic acid successfully leached valuable metals, its efficiency required extended reaction times and temperature compared to leaching in sulfuric acid(VI). This research highlights the potential of bio-based organic acids for LIB recycling, contributing to more environmentally friendly metal recovery processes.

CORROSION BEHAVIOUR OF HEA ALLOYS BASED ON AlCoCuFeNi SYSTEM

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Three high entropy alloys based on AlCoCuFeNi system, were prepared by induction melting with using inert gas blow on metal bath to protect components before oxidation. Were prepared three types of alloys, with different concentration of Al and Cu (chemical composition in Table 1).

Alloy sign	Element concentration (at %)				
	Al	Co	Cu	Fe	Ni
D1	7,14	7,14	28,57	28,57	28,57
D3	13,33	6,66	26,66	26,66	26,66
D5	20,00	20,00	20,00	20,00	20,00

When alloys were melted, casting were conducted into ceramic mold, to assure good surface quality. Before casting process molds were heated up to 900ºC.
From prepared materials, were prepared samples for microstructure and mechanical tests. First results, showed that changes in Al and Cu concentration have large impact on microstructure, phase composition and mechanical properties(1). Equiatomic D5 alloy is very brittle material, and have complex microstructure, consisting of at least 3 phases and have the highest hardness from testing group. Other alloys have much less hardness, but they are characterized by good ductility and impact strength, and in microstructure visible are less phase than in D5 alloy (which is confirmed by XRD tests).
Based on currently available results, some alloys from tested groups, have good corrosion resistance. For this purpose, corrosion tests where carried out to check impact of Al and Cu concentration on corrosion resistance. Tests were carried out in water vapor atmosphere in 760ºC. The entire test lasted 1000 hours, with breaks after 250, 500 and 750 hours to checking differences in mass of samples.
Results shows that occur large differences between tested variants. The best corrosion resistance in described conditions have equiatomic D5 alloy (0,018 mg/cm^2 after 1000 hours), and mass differences are similar to nickel alloys (2) tested in similar conditions. Corrosion test will be continued, to checking corrosion resistance in differ conditions.

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APPLICATION OF DISCRETE WAVELET TRANSFORM IN IMPEDANCE CARDIOGRAPHY SIGNAL DENOISING

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Impedance cardiography (ICG) is a non-invasive method for assessing cardiovascular function by analyzing changes in electrical impedance in response to blood flow. This technology is increasingly significant in cardiac diagnostics, particularly for evaluating hemodynamic parameters and detecting heart disease. The complexity of ICG signals arises from their high sensitivity to motion, respiratory noise, and biological variability, complicating analysis. Signal filtering techniques may reduce events associated with heart rate variability, further hindering analysis. The discrete wavelet transform (DWT) is often used for signal reconstruction due to its low computational complexity. DWT coefficients are obtained by decomposing the signal with high-pass (detail) and low-pass (scale) filters, effectively extracting key signal features while minimizing noise that could interfere with accurate analysis, as in ICG.

This work compares methods of denoising the impedance cardiography signal using the Daubechie, Symlet, and Coiflet wavelets with different orders. 24 recordings of ICG from the ReBeatICG database [1] were analysed using MATLABR2024a. First, a comparison was made between different orders from the same family. Next, the chosen order from each family was evaluated, and the most suitable one is selected. Evaluation of the denoising method was made by determining the signal-to-noise ratio (SNR), the root mean square error (RMSE), and the percent difference root mean square (PRD).

The number of decomposition levels was set at 4. The wavelets used in this study are Daubechies (db2, db4, db6, db8), Symlet (sym2, sym4, sym6, sym8) and Coiflet (coif2, coif3, coif4, coif5).

The results indicate that db8, sym8, and coif5 had the highest SNR and the lowest RMSE and PRD in their families, so they were selected for further testing. These wavelets were compared in the next step, showing that the wavelet coif5 achieved the best performance.

In conclusion, the Coiflet wavelet of order 5 (coif5) is the most efficient denoising method suitable for ICG signal filtering, with no significant impact on signal shape degradation. The de-noised signal is more straightforward to interpret by specialists, allowing better determination of hemodynamic parameters and diagnosis of cardiovascular diseases.

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COMBINATION ANTIMICROBIAL THERAPY FOR THE TREATMEANT OF DIABETIC FOOT INFECTIONS

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Diabetic foot infections (DFIs) are a serious health problem that affects many people with diabetes around the world. Diabetes affects about 537 million people worldwide, and it is estimated that about 19-34% of them will experience problems resulting from the DIFs, which, through an untreatable infection bacterial infection leads to foot amputation and even death [1].

DFIs are defined by the invasion and multiplication of microorganisms in diabetic non-healing wounds and are associated with tissue destruction and/or alterations in the host's inflammatory response [2]. They are commonly polymicrobial and involve antibiotic-resistant strains of organisms. These infections can be difficult to treat, and despite the administration of multiple rounds of antibiotics, prospects of clinical resolution of infection can still be poor and repeated courses of antibiotics risks selecting for antimicrobial resistance [3].

In light of these pressing challenges, the demand for effective treatment for DFIs solutions has never been more critical. It drives researchers to turn their attention to advanced nanotechnology to address it. Our research focuses on developing a series of novel biocompatible antimicrobial nanoparticles specifically designed to combat antimicrobial resistance in DFIs.
By harnessing state-of-the-art techniques such as artificial intelligence in drug development, employing green chemistry principles for nanoparticle creation, and utilizing a diverse array of sophisticated biological models—including advanced human skin organoids infected with clinical DFI isolates—we aim to transform the treatment landscape for these debilitating infections. Together, we can strive toward a future where DFIs no longer pose a threat to the health and well-being of individuals with diabetes.

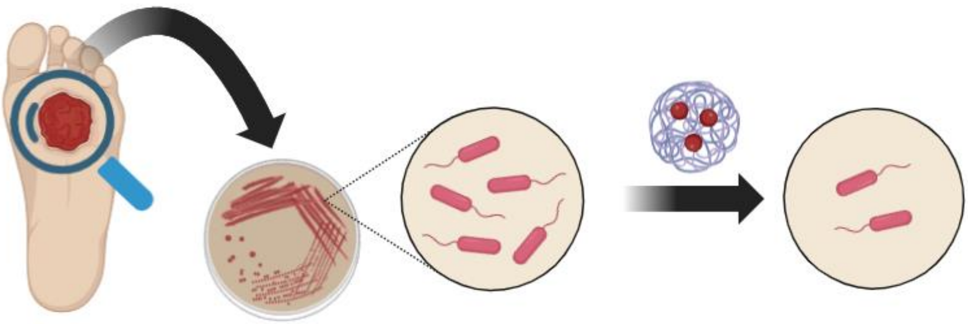

Figure 1. Bacteria responsible for diabetic foot infections (DIFs) will be treated with antimicrobial agents encapsulated in nanoparticles designed to combat antimicrobial resistance in DFIs. The figure was created in BioRender.com

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PROTEIN-BASED DRUG DELIVERY SYSTEMS FOR THE TREATMENT OF PERITONEAL CANCER

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Peritoneal malignancies represent a heterogeneous group of neoplasms. Diagnosis is ofen delayed, as many patients remain asymptomatic during the early stages or present with non-specific symptoms such as abdominal distension and discomfort due to ascites [1]. The aim of the project is to develop novel protein-based drug carriers that can enhance targeted chemotherapy, reduce side effects, and improve treatment efficacy. The drug encapsulated within these carriers is cabazitaxel (CAB), a semi-synthetic taxane analogue designed to overcome anticancer drug resistance. Preclinical studies have demonstrated that cabazitaxel is as potent as docetaxel in cellular models, and more effective against variants resistant to taxanes. CAB was approved by the FDA in 2010, in combination with prednisone/prednisolone, for the treatment of metastatic hormone-refractory prostate cancer in patients previously treated with docetaxel [2].

Proteins, being both natural and polymeric, offer several advantages as drug nanocarriers. Thus, this study focuses on developing a method for producing stable, protein-based, drug-loaded particles and characterizing their physicochemical properties. In this process, lysozyme (1 g/l) was mixed with hydrophobic drugs (CAB) to obtain lysozyme-based drug particles. Following preparation and purification via dialysis, the resulting nanoparticles were characterized using techniques such as dynamic light scattering (DLS), spectrofluorimetry, atomic force microscopy (AFM), Fourier transform infrared (FT-IR) and in vitro studies on HT-29 colon adenocarcinoma cells. The DLS analysis revealed that the nanoparticles have an average size of approximately 250 nm with a zeta potential of -17 mV, indicating good stability. Spectrofluorimetry was used to assess the encapsulation efficiency (EE) of CAB within the protein-based carrier, yielding the high EE of approx. 99%. FT-IR spectroscopy identified characteristic absorption bands for samples with varying compositions, enabling the evaluation of interactions between CAB and lysozyme. *In vitro* experiments on HT-29 cells confirmed the anticancer activity of prepared drug-loaded nanoparticles and non-toxicity of the lysozyme-based carrier.

In conclusion, protein-based drug carriers exhibit significant potential for the delivery of anticancer drugs in the treatment of peritoneal cancer, owing to their high encapsulation efficiency, stability, and promising *in vitro* performance.

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DESIGN OF A SAFE AND INSULATED APPLICATOR HANDLE FOR TISSUE ABLATION BY IRREVERSIBLE ELECTROPORATION METHOD IN ONCOLOGY APPLICATIONS

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Cancer represents one of the greatest challenges of modern medicine, being the second most common cause of death worldwide. The increase in the number of cases is forcing the development of modern treatment methods, among which irreversible electroporation (IRE) is a promising technique for ablating cancerous tissues. The procedure involves the application of short-lasting high-voltage pulses that create pores in the cell membrane. Depending on the intensity of the pulses, the cell can regenerate or initiate apoptosis, allowing the selective removal of pathological structures with minimal damage to healthy tissue.

The basic components of the IRE system are applicators that transmit electrical pulses directly to the tissues. To ensure the safety of the operator and the effectiveness of the treatment, it is crucial to meet international standards for electrical insulation, in particular the requirements set forth in IEC 60601-1, which defines minimum insulation distances (creepage distances). Figure 1 shows the designed applicator handle for tissue ablation by irreversible electroporation, taking into account key safety parameters.

Fig 1. The concept of a safe and insulated applicator handle

The design of the applicator handle was based on an analysis of normative requirements for electrical insulation and ergonomics for use in clinical settings. Material properties, surface insulation clearances and environmental factors that can affect the applicator's effectiveness and safety were taken into account. The appropriate design of the handle minimizes the risk of electric shock, increases user comfort and ensures precise application of electrical pulses.

The developed solution contributes to the reliability of applicators used in IRE, which is crucial for the implementation of this method into standard clinical practice and its further development as an effective alternative in cancer treatment.

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