

ENGINEERING MATERIALS AND PROCESS TECHNOLOGIES

2nd Conference of Programme Groups of the
Faculty of Mechanical Engineering University of Maribor

BOOK OF ABSTRACTS

edited by Tatjana Kreže, Lidija Fras Zemljič, Matej Bračič



University of Maribor

Faculty of Mechanical Engineering

Engineering Materials and Process Technologies

**2nd Conference of Programme Groups of the Faculty of Mechanical
Engineering University of Maribor**

Book of Abstracts

Editors

Tatjana Kreže

Lidija Fras Zemljič

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UVODNA BESEDA

Spoštovani,

z velikim veseljem vas pozdravljam na konferenci Inženirski materiali in procesne tehnologije, ki povezuje pet programskih skupin Fakultete za strojništvo Univerze v Mariboru. Fakulteta je s svojim dolgoletnim in uspešnim raziskovalnim delom uveljavljena kot ena izmed raziskovalno najmočnejših članic Univerze v Mariboru in širše.

Naši raziskovalni programi imajo nacionalni pomen, strateško usmerjenost in močno povezanost z gospodarstvom, kar nam omogoča, da s prebojnimi dosežki soustvarjamo razvoj Slovenije ter hkrati prispevamo k mednarodnemu raziskovalnemu prostoru. V zadnjem petletnem obdobju smo izvedli 42 ARIS in 13 drugih nacionalnih projektov, 13 projektov v okviru programov EU (H2020 in Horizon Europe), 6 Erasmus+ projektov, 10 drugih mednarodnih projektov ter 42 bilateralnih projektov. V program usposabljanja mladih raziskovalcev je bilo vključenih 48 doktorskih študentov, med katerimi jih je 26 uspešno zaključilo svoj doktorski študij.

Današnja konferenca združuje programske skupine **P2-0424 Dizajn novih lastnosti (nano)materialov & aplikacije**, **P2-0063 Konstruiranje celičnih struktur**, **P2-0120 Tehnologije metastabilnih materialov**, **P2-0118 Tekstilna kemija in napredni tekstilni materiali** ter **P2-0196 Raziskave v energetskem, procesnem in okoljskem inženirstvu**.

Ta dogodek je priložnost, da predstavimo najnovejše rezultate teh skupin, izmenjamo ideje in okrepimo sodelovanje med znanstveno-raziskovalno sfero ter gospodarstvom. Prepričana sem, da bo prav tovrstno povezovanje ključno za trajnostni tehnološki napredek in globalno prepoznavnost naših dosežkov.

Želim vam uspešno delo, navdihujoče razprave in veliko novih povezav.

prof. dr. Lidija Fras Zemljič
Prodekanja za raziskovalno delo
Fakulteta za strojništvo Univerze v Mariboru

PREFACE

Dear participants,

It is my great pleasure to welcome you to the conference Engineering Materials and Process Technologies, which brings together five programme groups of the Faculty of Mechanical Engineering, University of Maribor. With its long-standing and successful research activities, the Faculty has established itself as one of the most research-productive members of the University of Maribor and beyond.

Our research programmes are of national importance, oriented strategically, and connected strongly with industry, which enables us to achieve breakthrough results that contribute to the development of Slovenia, and, at the same time, to the international research space. In the past five years we have carried out 42 ARIS projects, 13 other national projects, 13 EU framework projects (H2020 and Horizon Europe), 6 Erasmus+ projects, 10 other international projects, and 42 bilateral projects. Within the programme for training young researchers, 48 Doctoral students have been included, of which 26 obtained their PhD degree successfully.

This year's conference brings together the programme groups **P2-0424** *Design of Novel Properties of (Nano)Materials & Applications*, **P2-0063** *Design of Cellular Structures*, **P2-0120** *Technologies of Metastable Materials*, **P2-0118** *Textile Chemistry and Advanced Textile Materials*, and **P2-0196** *Research in Power, Proces, and Environmental Engineering*. This event is an opportunity to present the latest results of these groups, to exchange ideas, and to strengthen cooperation between the scientific research community and industry. I am convinced that such collaboration will be crucial for sustainable technological progress and the global recognition of our achievements.

I wish you successful work, inspiring discussions, and many new connections.

Prof. Dr. Lidija Fras Zemljič

Vice-Dean for Research

Faculty of Mechanical Engineering, University of Maribor

INVITED LECTURES

From a Simple APM Sphere Thermal Acquisition to the AI Approach to Strain Evaluation by IR Thermography

Lovre Krstulović-Opara, Alen Grebo, Petra Bagavac, Željko Domazet

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“It started with a kiss, never thought it would come to this”, this is a short overview of a more than two decades of intensive collaboration between our group (listed authors) and LACE-X, FS, University of Maribor group. After a decade of joint development and testing of cellular structures, it started with using middle wave thermography, just to see if something can be acquired during dynamic compressive testing of APM spheres^{1,2}. The infrared images enabled us to understand what is happening with specimens during the dynamic loading process, where only a cooled InSb thermal detector of an MW thermal camera enabled acquisition of clear images. We tested mostly cellular energy absorption materials, where the IR approach was a valuable NDT tool. At a certain stage it was realised³ that the thermal pattern was similar to the Digital Image Correlation (DIC) strain distribution. As there was no relation for getting strain from thermal images, the AI approach has been used and developed to correlate images of thermal distribution to DIC strain distribution⁴. Two ML algorithms, Pix2Pix and CycleGAN were used to correlate IR to DIC, and, later, DIC to IR. This means that, after training, strain distribution can be obtained from IR images, and, vice versa, temperature distribution can be obtained from DIC. In the meantime, our equipment enabled us to test specimens on velocities more than 0,3 m/s (which was the maximum of our equipment until 2022), i.e., velocities up to 24 m/s, and the next big challenge is how to eliminate the rigid body motion of the whole testing system during DIC and IR acquisition.

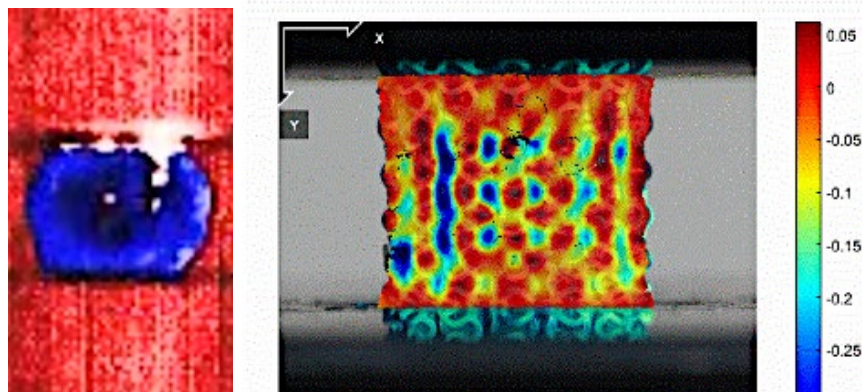


Figure 1: Infrared image^{1,2} of APM sphere during 0,3 m/s compression loading (left), and TPMS strain distribution obtained from IR images, a work in progress with the LACE-X group (right)

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INVITED LECTURES

Development of a Hot Work Tool Steel with High Thermal Conductivity

Peter Kirbiš

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The scope of this work is the development of a novel hot work tool steel which exhibits exceptionally high values of thermal conductivity, typically above 45W/mK at the commonly used range work hardness (44-51HRC). These steels are characterized by their tendency of largely retaining, or even increasing, their thermal conductivity at elevated temperatures, with a peak of thermal conductivity typically in the range between 400°C and 500°C. The impact toughness and other mechanical properties remain in compliance with the most common toughness requirements and Standard specifications for hot work tool steels (i.e., H13), while retaining sufficient hardenability to ensure homogeneous properties within thick sections. This steel, known under the commercial name SITHERM S140R, exhibits high tempering stability, low distortion during heat treatment and a very high resistance to heat checking. These characteristics make the newly developed steel especially suitable for production of die casting dies which operate between 400°C and 650°C, and tools for hot stamping of high strength steel and aluminium sheets. Generally, this steel is also suitable for applications of die forging and extrusion, as well as other tools for hot working and plastic molding which operate at temperatures above 200°C.

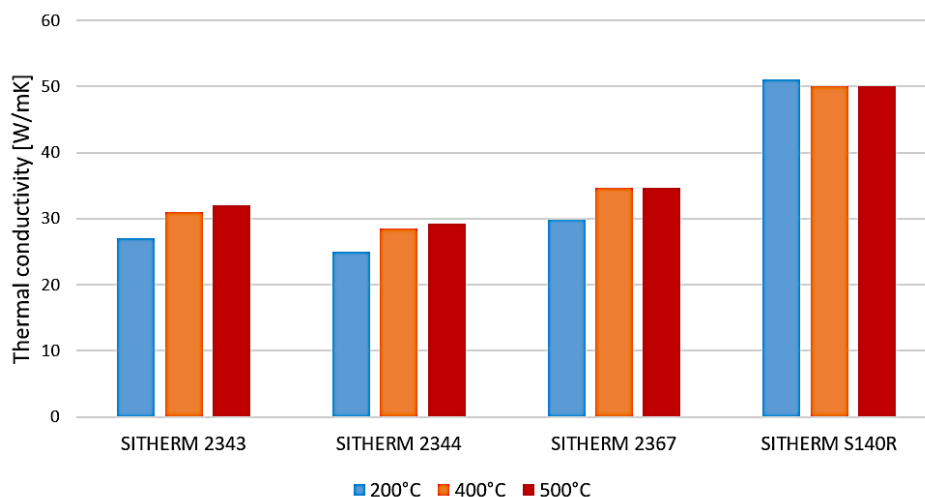


Figure 1: Thermal conductivity of different hot work tool steels compared to the newly developed steel ¹

Acknowledgment: The authors would like to thank the MARTINA project (materijali in tehnologije za nove aplikacije) for financing this research work.

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INVITED LECTURES

Sustainability in the Aluminium Industry

Matej Steinacher

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The automotive industry requires that aluminium parts are produced with higher recycled content, or that their production produces as few kilograms of CO₂ per kilogram of product as possible. Other manufacturers specifically demand high levels of secondary content, the use of green primary aluminium and the sourcing of green electricity. Aluminium in cars is particularly interesting from a circular economy perspective, as more than 95 % of it can be recycled and reused. However, in the future, we will not be able to meet these customer requirements solely by the purchase of aluminium scrap. We will need to prepare and process the scrap aluminium ourselves, in the short term in collaboration with partners and in the long term with our own recycling centre. Throughout this process, we must ensure that the quality of aluminium car parts remains unchanged.

Development and Characterisation of Modern Metamaterials

Nejc Novak, Matej Vesenjajk, Zoran Ren

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The cellular metamaterials presented in this work are categorised into groups based on their topological structure and/or fabrication method in the following section. A selection of these metamaterials is shown in **Figure 1**, which illustrates the development from fundamental to advanced geometries over the last two decades. Recently developed auxetic and TPMS (Triply Periodic Minimal Surface) structures are a game-changer in Material Science.



Figure 1: Research of cellular metamaterials at the University of Maribor in recent years: from primitive to advanced cellular geometries

Auxetic metamaterials¹, with their fascinating negative Poisson's ratio, expand laterally when stretched and contract when compressed. This gives them superior energy absorption, indentation resistance, and fracture toughness. TPMS structures², on the other hand, offer an exceptional strength-to-weight ratio and vast surface area due to their intricate, interconnected surfaces. This makes them perfect for lightweight designs, biomedical implants and heat exchangers. Developing and characterising these modern cellular metamaterials relies on a powerful combination of approaches. Experimental testing, through methods like tensile, compression, shear and impact loading, provides vital real-world data on their mechanical performance, which will be discussed in detail in this presentation. These data are then used for the validation of computational models. These simulations enable detailed parametric studies and accurate predictions of complex behaviours under diverse loading scenarios. This integrated methodology is key to optimising designs, understanding failure mechanisms, and unleashing the potential of auxetic and TPMS metamaterials fully for a wide range of advanced engineering applications.

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Effects of Helium Ion Irradiation on the Microstructure and Properties of Aluminium Alloys

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Aluminium alloys are preferred in the aerospace industry due to their low density, high specific strength and corrosion resistance^{1, 2}. However, exposure to ionising radiation can affect their performance, resulting in a shorter lifespan and lower shielding efficacy^{1,2}. Our research investigates the influence of high-energy heavy ion irradiation on the microstructural development and mechanical properties of novel precipitation-hardening aluminium alloys in different initial states. By selecting alloys with complementary particle types, such as crystalline-quasicrystalline, stable-metastable and thermally stable-unstable³, we aim to study the impact of radiation damage on the microstructure of aluminium alloys. The primary focus of the research is to correlate the microstructural changes induced by ion irradiation with both the initial state and thermomechanically processed alloys with alterations in their mechanical properties. We studied a microalloyed Al-Mn-Cu alloy, referred to as VCr, and the aluminium alloy 6086 based on the Al-Mg-Si group system. The VCr samples were subjected to various thermal and thermomechanical treatments to develop different initial microstructures. Subsequently, all the samples were irradiated with high-energy helium ions. The microstructural changes were analysed using Scanning Electron Microscopy (SEM) with Energy Dispersive Spectroscopy (EDS) and Transmission Electron Microscopy (TEM). Nanoindentation testing was conducted to assess the mechanical properties. The results indicate that the heat treatment of the VCr alloy promotes the formation of spherical icosahedral and decagonal quasicrystals, $L1_2$ precipitates (Al_3Sc), and Al_2Cu needles³. The AA 6086 contains large dispersoids ($\alpha-AlMnSi$ and Al_3Zr) and various precipitates, mainly Mg_2Si (β') and $AlCuMgSi$ (Q'). The helium ion irradiation caused significant changes, namely, a reduction in dispersoids and precipitates in the VCr, as well as the formation of bubbles in both types of alloy (**Figure 1**).

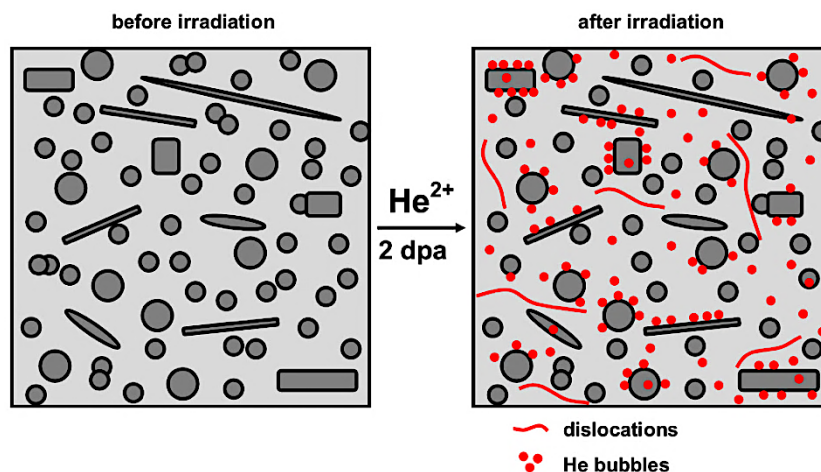


Figure 1: Schematic of the changes in microstructure and the formation of dislocations and helium bubbles after irradiation with He^{2+} ions.^{1, 2, 4}

In the AA 6086, helium bubbles were found along the needle-like β'' precipitates. These findings are essential for understanding how radiation affects specific microstructural phases.

This knowledge could help in designing the next generation of radiation-resistant aluminium alloys^{1, 2}. Such advancements could impact aerospace, nuclear, and space exploration sectors significantly, by extending the lifespan of components and improving safety in harsh radiation environments². The insights gained from this study are anticipated to apply to other metallic materials as well.

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Beyond Traditional Lyophilisation: Predictive Process Control with Digital Twins

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Lyophilisation (freeze drying) is a widely used preservation method in the pharmaceutical industry, where precise control of heat and mass transfer is essential. This work presents a novel multi-level modelling framework that integrates experimental drying kinetics, CFD-based simulation of ice deposition, and a system-level digital twin of the lyophilisation process. The main highlights include a refined simulation of vial-scale and chamber-scale interactions, an advanced model of condenser performance, and the development of a digital twin platform aimed at optimising drying cycles and improving scale-up. The methodology includes experimental determination of sublimation rates and pressure profiles, which serve as the foundation for model validation. A 1D time-dependent model for heat and mass transfer in vials is coupled with a 3D CFD simulation of vapour flow and pressure distribution in the drying chamber. The vial headspace and stopper are modelled using a mass flow rate-dependent resistance model, to capture local pressure and heat transfer conditions better, particularly in low-pressure environments. Additionally, a CFD model of ice deposition in the condenser will be presented, developed in ANSYS Fluent using user-defined functions (UDFs). This model treats ice formation as a volumetric sink of mass, momentum and energy, and is validated against experimental data. Parametric studies revealed the influence of condenser wall temperature, inert gas concentration and sublimate flow rate on the system pressure and energy consumption. The results demonstrate how accurate modelling of system interactions leads to improved prediction of process dynamics and enables the optimisation of cycle parameters. The developed digital twin framework lays the foundation for real-time simulation and control, supporting energy-efficient and robust freeze-drying operations.

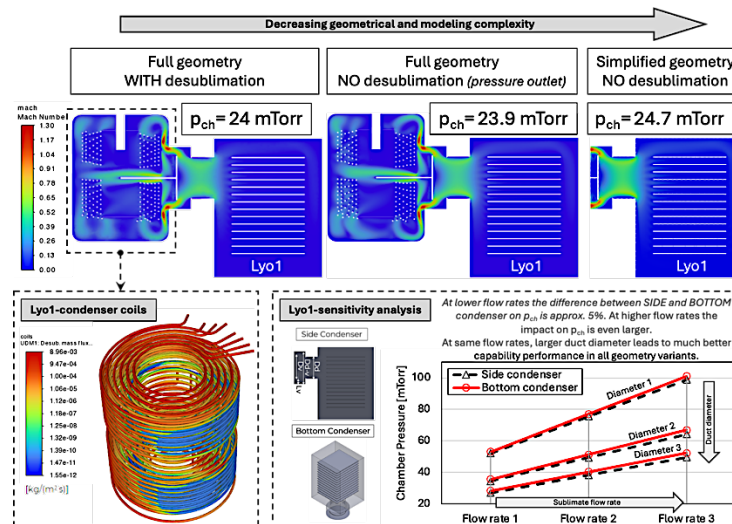


Figure 1: Coupled equipment CFD and vial scale 1D model flow fields, ice build up on condenser coils and equipment capability curves for large-scale freeze-dryers.

Acknowledgment: The authors wish to thank the Slovenian Research and Innovation Agency (ARIS) for the financial support in the framework of the Programme P2-0196: Research in Power, Process and Environmental Engineering.

Water Hammer Risk Assessment and Mitigation in Industrial Pipelines: 1D and 3D Numerical Approaches

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Water hammer events in pipelines can generate severe transient pressure surges, posing risks of structural damage and operational disruption. The presented case study focuses on a 3.4 km long DN400 pipeline undergoing a sudden pump failure, to assess pressure transients, cavitation and water column separation. This presentation explores a comparative simulation study of water hammer phenomena using two numerical approaches: a one-dimensional (1D) inviscid model based on the Euler equations with the method of characteristics, and a three-dimensional (3D) viscous model employing the Navier-Stokes equations in OpenFOAM. The 1D model proved effective for predicting pressure wave behavior and identifying cavitation risks quickly, while the 3D model offered a high-fidelity view of multiphase flow dynamics, including cavitation bubble formation and collapse. As a mitigation strategy, a pressure relief valve was incorporated into the system and evaluated through 3D simulations. The results demonstrate the valve's role in reducing extreme pressure spikes and limiting cavitation as an alternative to the traditional surge tank technologies¹. The conducted research also opens the potential to develop coupled 1D-3D solvers, that are able to simulate wave propagation on the whole pipeline, as well as the cavitation bubble collapse and the viscous effects at the pump area of the pipeline.

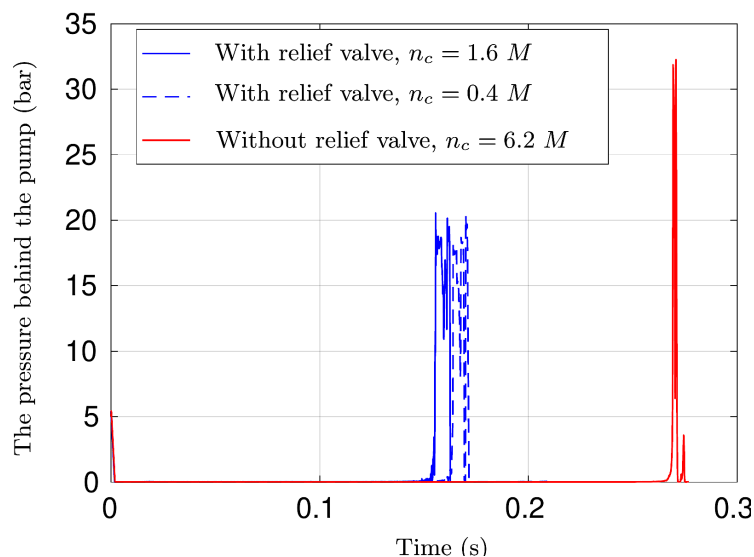


Figure 1: Comparison of the water hammer effect for a pipeline with and without relief valves.

Acknowledgment: The authors would like to acknowledge the support of their respective institutions and the company Rudis l.l.c. Trbovlje in conducting this research.

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Contamination Release from the Packaging Area to the Outside: Numerical Simulation with Particles

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This study applies Computational Fluid Dynamics (CFD) to investigate the dynamics of particle contamination in a tablet packaging area, addressing a critical issue in contamination control within pharmaceutical environments. The research evaluates the behaviour of particles of varying sizes - from microscopic viruses to larger contaminants-released during packaging operations. The CFD simulations provided a detailed understanding of particle trajectories and deposition patterns under controlled airflow conditions¹.

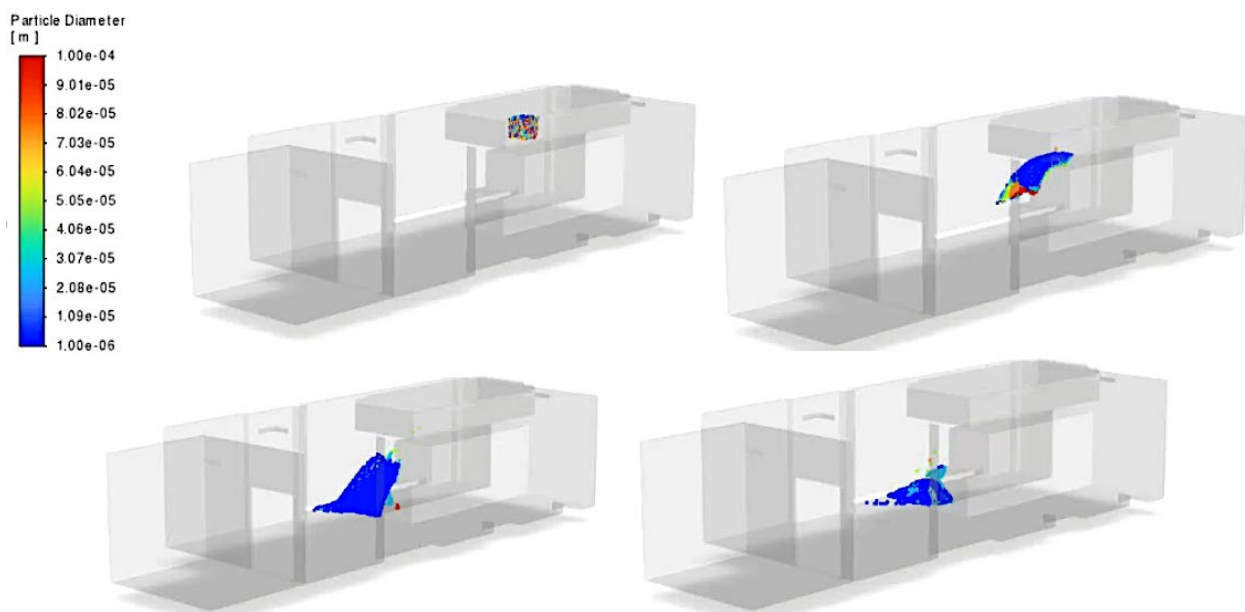


Figure 1: Contaminated particle flow simulation at different times ¹

Acknowledgment: The authors would like to thank Lek Lendava for financing this research work.

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Rheology in polymer and polymer composite processing

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Rheology offers more than just viscosity, it provides a detailed map of how polymers behave under stress, strain and temperature. This work highlights the role of rheology in optimising thermoplastic polymer and thermoplastic polymer composites processing methods such as extrusion¹, injection moulding¹ and fused filament fabrication². Key theoretical concepts, such as viscoelastic models and constitutive equations, are introduced, to describe the viscous and elastic responses in polymer melts. These concepts provide the basis for evaluating measurement techniques like rotational testing, dynamic oscillatory testing, amplitude and frequency sweeps and creep experiments, each offering insights into different deformation mechanisms relevant to processing. Rotational and oscillatory rheology are then applied to practical cases using polymers and polymer composites³. For injection moulding, we will demonstrate how shear-thinning behaviour and temperature-dependent viscosity affect mould filling and defect formation. In extrusion, the rheological data predict pressure drops, flow stability and die swell. For fused filament fabrication, melt elasticity and layer adhesion are linked to complex modulus data and time-temperature behaviour. The rheological data serve as a powerful foundation for tailoring material properties and fine-tuning process parameters across different manufacturing methods. By translating complex measurements into actionable insights, this approach positions rheology as an integral part of process innovation in polymer engineering.

Acknowledgment: The authors would like to thank the Slovenian Research Agency for financing this research work.

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Polysaccharides in Biomedical Applications

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The use of polysaccharides in biomedical applications is researched extensively, and holds great potential. Their main advantages are their biocompatibility, biodegradability, hydrophilicity, and ability to form bioactive, modifiable hydrogels from renewable sources. However, they often suffer from poor mechanical strength, rapid degradation, batch variability, and limited processability, making them less suitable for load-bearing or long-term applications without modification. Despite these challenges, their versatility makes them particularly valuable in drug delivery, wound healing, and tissue engineering. Polysaccharides are utilised in biomedicine as hydrogels, e.g., drug delivery systems, wound dressings, injectable systems, as coatings or surface modifiers, e.g., bioactivation of implants, biosensoric surfaces, as films and membranes, e.g., dialysis and barrier membranes, transdermal patches, as scaffolds for tissue engineering, e.g., 3D printed cartilage or bone scaffolds, or drug delivery carriers, e.g., nano- and microparticles. This work focuses on the fabrication of three-dimensional and porous scaffolds made from nanocellulosic materials, which hold significant potential in tissue engineering to replicate the complex architecture and functionality of natural tissues¹. Among the various materials explored for this purpose, (nano)cellulose has emerged as a promising candidate, due to its biocompatibility, biodegradability and exceptional mechanical properties².

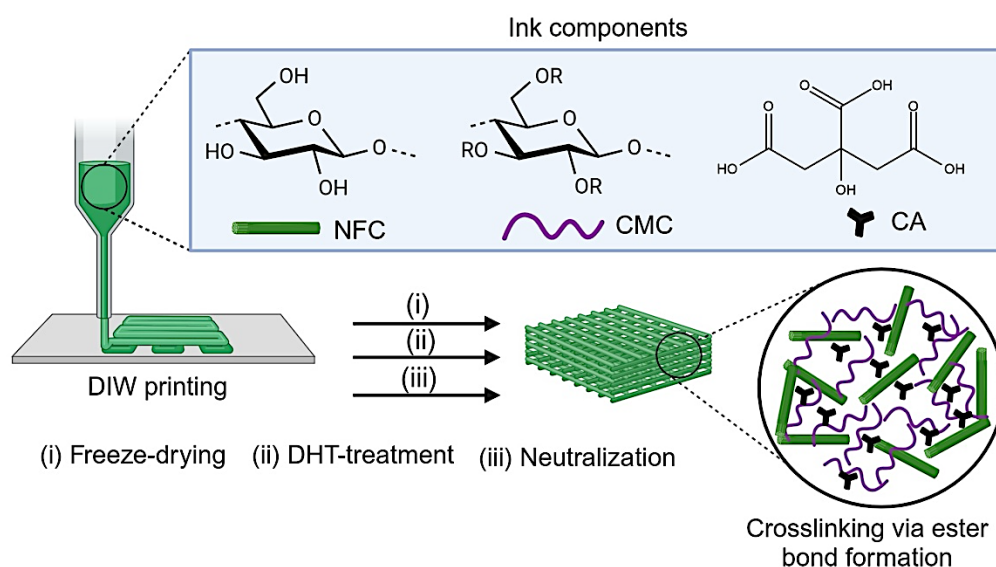


Figure 1: Illustration of the DIW printing of scaffolds, post-treatment procedures, and the cross-linking mechanism among the scaffold components (NFC, CMC, and CA)

This work provides a comprehensive methodology for fabricating self-standing (nano)cellulose-based 3D-scaffolds designed specifically for in-vitro testing of cells from skin and cartilage tissues. By leveraging the unique characteristics of (nano)cellulose, this work provides a comprehensive

guide to creating scaffolds with tunable porosity, structural integrity and mechanical stability, all essential for supporting cell growth and tissue regeneration³. It details the preparation of nanocellulose ink for direct-ink-writing (DIW) 3D printing and the stepwise procedural method to prepare mechanically and dimensionally stable scaffolds by subsequently combining DIW 3D printing, freeze-drying and dehydrothermal heat-assisted crosslinking techniques (**Figure 1**). It offers researchers a reliable framework for developing versatile and sustainable biomaterials for regenerative medicine.

Acknowledgment: The authors acknowledge the financial support received from the Slovenian Research Agency (G. No: P2-0118 and J4-1764).

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Biopolymer-based Membranes for Fuel Cell Applications

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Fuel cells are innovative power generation devices that have the potential to replace conventional combustion engines and batteries in a variety of applications. Our group's research focuses on the development of materials (**Figure 1**) for different types of polymer electrolyte fuel cells (PEFCs), with an emphasis on the development of solid polyelectrolyte materials that act as ion exchange membranes, mainly biopolymer-based membranes for the alkaline subtype (AFC) of PEFCs and for microbial fuel cells (MFC).

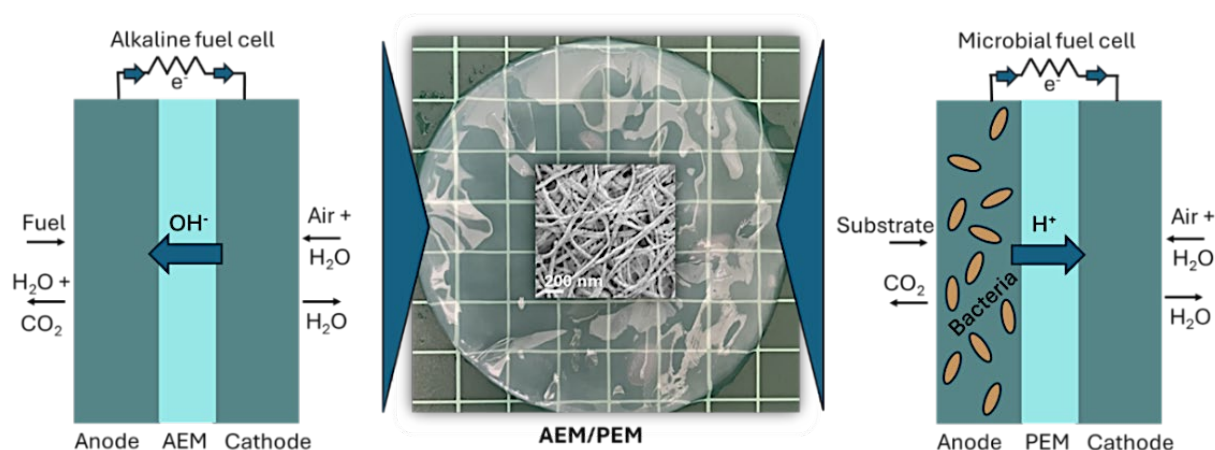


Figure 1: SEM image of bacterial cellulose membrane (photographed by Sara Zdovc, SEM image obtained by Urška Jančič) (centre) and schematic representation of an AFC (left) and MFC (right).

AFCs with anion exchange membranes (AEMs) are a cost-effective option, as they allow the use of non-precious metal catalysts. However, current AEMs are not very efficient, so new, efficient and environmentally friendly alternatives are being sought. Naturally derived materials such as chitosan, cellulose nanofibrils and bacterial cellulose are promising, but their limitations in ionic conductivity and barrier properties need to be addressed by functionalisation and the incorporation of functional fillers. Our research on AEMs for AFC applications includes the development of chitosan (CS)-based biopolymer AEMs with nanofibrillated cellulose (CNF), functionalised CNF, and N-doped graphene oxide^{1,2,3,4} and, more recently, biopolymeric AEMs based on nanocellulose (NC)⁵. A lab-scale fuel cell test of our CS-based membranes exhibited a higher maximum power density than the commercial Fumatech membrane, highlighting their potential for use in AFCs. In addition, NC's low cost, biodegradability, non-toxicity and excellent mechanical and chemical stability, as well as its functionalisation potential, make it an interesting material for FC components, as the introduction of fixed charges or combination with ion-conducting phases should transform them into excellent ionic conductors. MFCs are another application niche for our biopolymeric membranes. They can treat wastewater while simultaneously generating electricity and recovering hydrogen, valuable chemicals and metals.

Proton exchange membranes (PEMs), particularly Nafion, the currently available reference material, have a critical impact on the performance and cost of MFCs, although they are synthetic, expensive (~40% of MFC cost), prone to biofouling and environmentally unsustainable, demonstrating the need to develop efficient and environmentally friendly alternatives. Our research focuses on the development of NC-based membranes and their introduction into a pilot concept for the scale-up of completely new and high-performance MFCs.

Acknowledgment: The financial support from the Slovenian Research and Innovation Agency was received in the frame of the project “Efficient bacterial cellulose-based anion exchange membranes for alkaline fuel cell applications” (Z2-60175), “Nanofibrillar cellulose membranes in microbial fuel cells: material development for sustainable, high value-added applications” (J2-50086) and the Textile Chemistry and Advanced Textile Materials Programme (P2-0118).

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Green Colloidal Coatings Based on Pullulan and Bio-Extracts from Chestnut Wood for Active Food Packaging

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The growing environmental concerns associated with conventional plastic packaging, alongside increasing consumer demand for clean-label and functional food protection, have accelerated the search for sustainable alternatives. Traditional packaging materials often lack bioactivity and rely on non-renewable resources, contributing to both food spoilage and environmental concerns. To address these challenges, in this study, we explore the development of active, biodegradable coatings based on pullulan, a water-soluble, film-forming polysaccharide incorporated with natural bio-extracts from chestnut wood (WE).

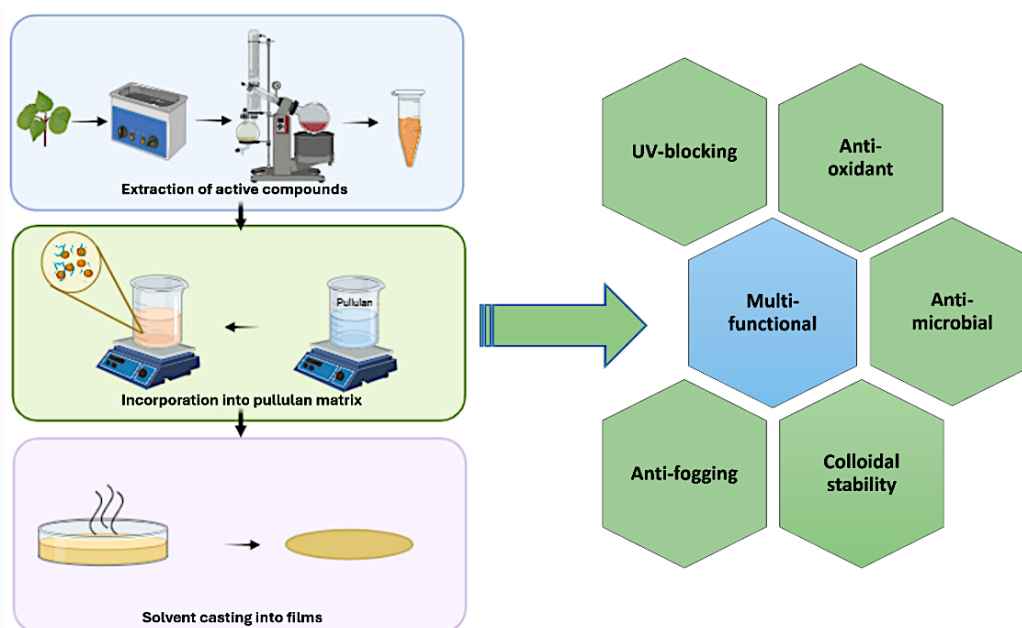


Figure 1: Green Colloidal Coatings Based on Pullulan and Bio-Extracts for Active Food Packaging

The chestnut wood extract was obtained using ultrasound-assisted extraction with water as a green solvent, ensuring both eco-friendly processing and effective recovery of phenolic compounds. The minimal inhibitory concentration (MIC) of the extract was first determined, and these bioactive components, known for their antioxidant and antimicrobial properties, was incorporated into a pullulan matrix, at 8 times the MIC value, to create stable colloidal formulation - pullulan + WE. A rheological and particle size analysis confirmed the suitability for industrial coating methods, exhibiting stable viscosity (190.18 mPa·s), a hydrodynamic diameter of 964 ± 85 nm, and improved

colloidal stability (PDI ~17%). The colloidal formulation was cast further into free-standing film, to study its potential for film formation on food packaging in comparison with neat pullulan. The resultant film was uniform, defect-free, and demonstrated enhanced surface functionality. The pullulan + WE cast film exhibited improved wettability, with a contact angle of 56.11° and a total surface free energy of 45.18 mN/m, with a polar component of 20.54 mN/m and 24.64 mN/m dispersive part, facilitating strong adhesion and potential anti-fogging behaviour. A UV–Vis analysis showed significant UV-blocking capability, attributed to the aromatic and phenolic structures present in the wood extract. Antimicrobial testing by agar diffusion assay (the zone of inhibition method) demonstrated selective inhibition against *S. aureus* (10 mm) and a moderate inhibition against *E. coli* (5mm), consistent with the extract's higher efficacy against gram-positive bacteria. Antioxidant assays - both DPPH and ABTS assays confirmed high radical scavenging capacity, with 100% inhibition observed within 30 minutes. Overall, this study demonstrates a green and scalable approach for developing multifunctional pullulan-based coatings using chestnut wood extracts. The coatings provide enhanced bioactivity, surface interaction and optical performance, offering a promising solution for sustainable active food packaging.

Acknowledgment:

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Thermal and Catalytic Pyrolysis of Waste for the Recovery of Secondary Materials and Energy Source Production

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Modern materials are replacing traditional materials like wood and metals increasingly, due to their low weight, design flexibility and efficient manufacturing processes. In 2022, global production exceeded 400 million tonnes of plastic and 12.7 million tonnes of composites.^{1,2} The challenge arises when these materials become waste, as conventional recycling methods are often inefficient in their utilisation. Plastic waste typically contains mixed fractions, while composite materials consist of polymer matrices reinforced with fibres. Pyrolysis provides a solution by decomposing these complex materials thermally to yield useful products. The pyrolysis process was carried out in a batch laboratory reactor at temperatures up to 450°C, with and without the use of a catalyst. Plastic Waste: Thermal and catalytic pyrolysis converted plastic waste successfully into liquid and gaseous products, along with solid residue. The liquid products, or pyrolysis oils, exhibit properties (density, viscosity, elemental composition, calorific value, etc.) similar to those of fossil fuels. Catalysts improve the product quality and yield further, and reduce processing time.³ Composite Waste: Pyrolysis enabled the removal of the polymer matrix, allowing recovery of the reinforcing fibres. The process was effective on both single-layer and multi-layer composite waste. Post-pyrolysis oxidation was used to clean the residual decomposition by-products from the fibre surfaces. The recovered glass and carbon fibres were clean and suitable for reuse.⁴ The study demonstrates that thermal and catalytic pyrolysis is a suitable method for processing various types of plastic and composite waste. The resulting oils can serve as alternative fuels, and the recovered fibres reduce the demand for the production of new fibres. Pyrolysis thus presents an effective strategy for unlocking the energy potential of waste that would otherwise remain unused.

Acknowledgment: The authors wish to thank the Slovenian Research Agency (ARRS) for the financial support in the framework of the Research Programme P2-0196 in Power, Process and Environmental Engineering.

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Personalised intelligent wearable system for freezing of gait detection and active stimulation for patients with Parkinson's disease

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Parkinson's disease is the second most common neurodegenerative disorder after Alzheimer's dementia. As the disease progresses, patients may experience freezing of gait - a condition in which they are suddenly unable to move their legs even though they actually want to walk, which can lead to falls and injuries. These episodes typically occur when patients lose their subconscious focus on walking and last between 1 and 20 seconds. Research shows that additional sensory stimulation can improve patients' focus and thus significantly increase motor function. The most common therapeutic approach at present is continuous stimulation. However, this method has one major disadvantage: the patients adapt gradually to constant stimulation, which reduces its effectiveness over time. This limitation prompted the development of a personalised wearable system capable of analysing the patient's movements, detecting motor disturbances such as freezing of gait and delivering stimulation in real-time automatically. **Figure 1** shows a graphical overview of the developed system.

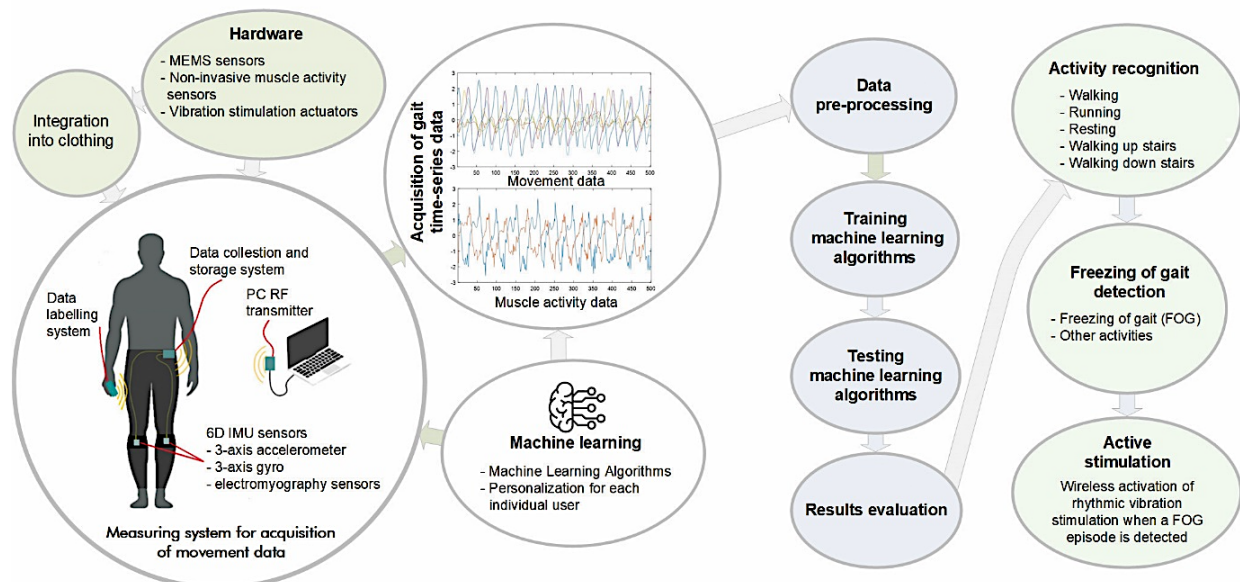


Figure 1: Graphical overview of the developed system

The movement data are collected using accelerometers, gyroscopes and electromyography sensors integrated into form-fitting trousers below the knee on both trouser legs. These multimodal sensor data serve as the input for training and testing machine learning algorithms that recognise and react to pathological movement patterns in real-time¹.

The personalised, intelligent wearable system developed uses artificial intelligence to analyse the patient's movements and detect motor disorders automatically, particularly freezing of gait, enabling real-time therapeutic stimulation upon detection. Initial offline testing demonstrated robust performance, achieving 95.1% accuracy in recognising freezing episodes with an average detection latency of only 261 milliseconds. Clinical evaluation of active rhythmic vibration stimulation showed promising therapeutic potential, as the duration of freezing episodes could be reduced by approximately 45% on average ². This personalised wearable system represents a significant interdisciplinary achievement, integrating artificial intelligence techniques successfully into practical medical applications. The system provides active, responsive stimulation triggered by real-time detection of freezing of gait in Parkinson's patients. In addition, the collected movement data can be shared with healthcare providers along with analysis and classification results, enabling more objective and data-driven assessments of patients' health status and disease progression. This comprehensive approach combines immediate therapeutic intervention with long-term clinical monitoring capabilities.

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Thermally Conductive Cellulose-based Substrates for Flexible Electronics

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Green renewable biopolymers have attained extensive attention recently in advanced electronics and wearable sensing devices, to decrease the cost, and, above all, to replace nonbiodegradable dielectric thermoplastic polymers (e.g. BOPP and PVDF) while retaining the devices' flexibility and boosting their recyclability. Nanocellulose/NC has gained particular attention, due to its inherent biocompatibility, biodegradability and cost-effectiveness¹. A dielectric substrate with attached electronics should also possess good thermal transport capability to dissipate the heat produced by the Joule (resistivity) effect during its operation, thus not affecting its function adversely. The thermal diffusivity of NC films can be obtained by reducing the thermal resistance at the interface between the fibrils/crystals with an increased interaction through their highly aligned anisotropic structure and/or introduced thermally conductive 2D nanofillers². In this frame, the films have been prepared from semi-crystalline NC with the addition of 2D hexagonal boron nitrides / hBNs (lateral size 5 to 150 μm) by pressure-filtration, to examine their impact on the films' morphological (**Figure 1**) and thermal dissipation (through-plane, in-plane) properties.

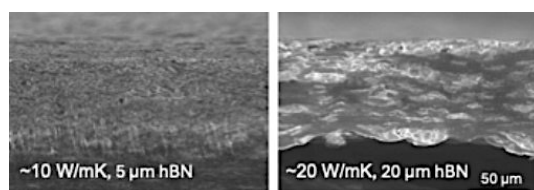


Figure 1: Morphology and in-plane thermal conductivity of NC-based composite films.

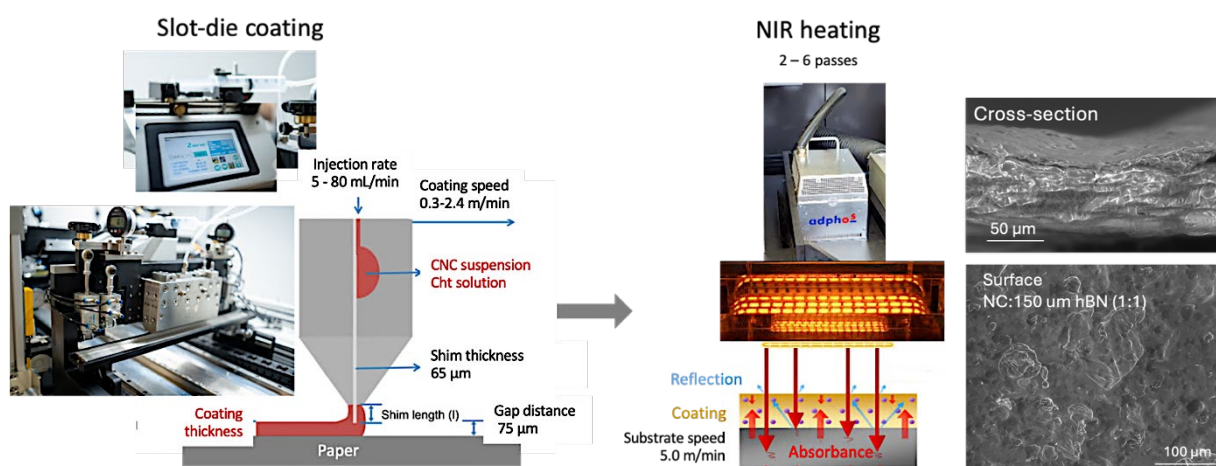


Figure 2: Schematic presentation of the slot-die coating deposition (supported by a high energy-density near-infrared / NIR drying as an advanced alternative to conventional convective heating), and the settings used for the coating deposition experiments. The morphology and thickness of the NC-hBN coated paper.

The up-scalable slot-die coating technology was used (**Figure 2**) In the next stage, to study the coatability of the most promising formulations onto the flexible paper substrate ³. A uniform and relatively high coat weight (>10 g/m²) at high coating speeds (>10 m/min) was achieved, being comparable to conventional industrially used blade coating, leading to complete coverage of the paper's surface and an improved thermal conductivity.

Acknowledgment: The authors would like to thank the Slovenian Research and Innovation Agency (J2-60048, P2-0424), and the Ministry of High Education, Science and Innovation (Flag-Era 2D-PAPER) for financing this research work.

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Gold Nanoparticle Dispersions for Plasma Jet Printing of Printed Circuit Boards: Characterisation of Stability, Printability and High Frequency Signal Performance

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The increasing demand for reliable, high-frequency signal transmission in extreme environments, such as space applications, has driven the development of novel materials and additive manufacturing techniques for printed circuit boards (PCBs).¹ Traditional PCB fabrication methods often fall short in terms of material compatibility, miniaturisation, and performance under harsh conditions.^{2,3} Gold nanoparticles (AuNPs) offer high electrical conductivity, excellent chemical stability, and strong resistance to oxidation, making them ideal for long-term performance in demanding environments.^{4,5} This work addresses these challenges by developing AuNPs based dispersions tailored for plasma jet printing - a contactless, flexible and scalable deposition method. The novelty of the study lies in the synthesis of stable, printable dispersions optimised for direct deposition onto Al₂O₃ substrates, enabling the fabrication of patterns on the substrate. The methodology includes the optimisation of an ultrasonic spray pyrolysis (USP) process for the synthesis of AuNPs, followed by the formulation of dispersions tailored for plasma jet printing. Key characterisation techniques, such as scanning electron microscopy (SEM), transmission electron microscopy (TEM), dynamic light scattering (DLS), zeta potential, thermogravimetric analysis (TGA) and profilometry were employed to assess the properties of the AuNPs, the dispersions and the PCBs. Additionally, high-frequency transmission line measurements were conducted, to evaluate signal losses and validate performance. The USP process produced mostly spherical AuNPs successfully. The smallest measured AuNPs were around 10 nm in diameter, while the largest recorded were around 300 nm, with an average diameter of approximately 70 nm. The formulated dispersions exhibited colloidal stability, confirmed by zeta potential measurements, and were compatible with plasma jet printing onto Al₂O₃ substrates. The printed lines were visually uniform with a distinct purple colour, and exhibited low surface roughness ($\leq 2.8 \mu\text{m}$). The results confirmed that the AuNP-based dispersions are compatible with plasma jet printing, and can be used to fabricate PCB traces. This work contributes to the advancement of nanomaterial-enabled additive manufacturing, offering a foundation for future developments in printed electronics.

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Preserving the Cultural Heritage of Clothing: Sleeping Beauties

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The preservation of the cultural heritage of clothing in the context of "Sleeping Beauties" consists of reanimating and reawakening historical garments that are too fragile to be exhibited traditionally in museums, thus preserving their cultural and social significance for the public. As historic garments age, the textile materials embedded within them also age, and their degradation sooner or later reaches the point where they can no longer be conserved or restored. Efforts to preserve these garments are directed towards their digitisation in the form of virtual replicas that reactivate the context of the garment's history, the knowledge of the construction of the garment patterns and the textile materials. The behaviour of the textile material in garments depends on the physical and low-stress mechanical properties of the textiles. The low-stress mechanical properties are determined with a FAST or KES measurement system, or with measurement systems developed on a similar principle by CAD software providers for garment simulations (e.g. CLO3D, Browzwear, Lectra, OptiTex 3D, etc.). Since these properties cannot be measured on original historical garments, our research focuses on predicting the physical and low-stress mechanical properties of textiles based on the known properties of historical textiles taken from historical garments. For this purpose, small samples (approx. 1 x 1 cm) were taken from historical silk garments from the Maribor Regional Museum (N.5259 - mid-19th century, N.6847 - early 20th century).

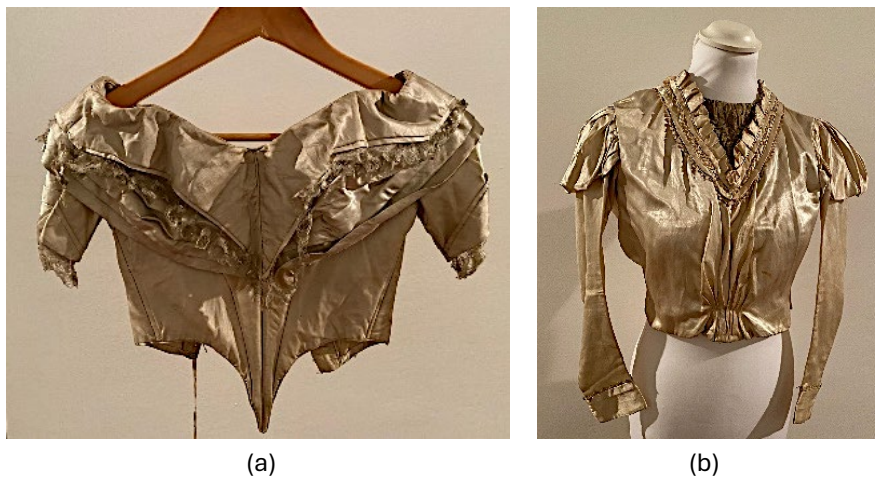


Figure 1: Historical silk garments from the collection of the Maribor Regional Museum, Slovenia: (a) silk blouse N.5259 - mid-19th century, (b) silk blouse N.6847 - early 20th century¹

The first phase of the study consisted of analysing the construction parameters of the silk fabrics. For the study we used standard test methods, that we adapted to the sample sizes and measuring devices such as FTIR, micro-FTIR, nano-CT and spectrophotometer. The results of the study provided information on the raw material, weave, surface mass and thickness of the fabrics, fabric count, linear yarn density and colour of the historical silk textiles.

The second part of the research, which is currently underway, focuses on the artificially accelerated ageing of silk fabrics, to determine the ageing mechanism of silk by monitoring some structural and constructional parameters, drape parameters, and physical and low-stress mechanical properties of silk fabrics. The results of this part of the research will be presented in this contribution. The ageing mechanism will be the key to the third part of the research, in which artificial intelligence will be used to predict the low-stress mechanical properties of silk fabrics, to create virtual replicas that reproduce the properties of the original fabric. Preserving the "Sleeping Beauties" as virtual cultural heritage enables education, inspiration and connecting people with the past in a multi-sensory and respectful way.

Acknowledgment: *The authors would like to thank the Funding body for financing this research work, the Slovenian Research Agency (Research Programme P2-0118: Textile Chemistry and Advanced Textile Materials) and project Advocating the Role of silk Art and Cultural heritage at National and European scale – Aracne (European union's Horizon Europe Research and Innovation programme: Ga.N. 101095188).*

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Assessment of Microplastic Fibre Emissions During Tumble of Fabrics

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A protocol for evaluating microfibre (MiF) emissions during the machine drying of textiles was developed based on a laser particle counting method. Textile samples of three different fibre compositions and varying moisture contents were tested according to the IEST-RP-CC003 recommendation, which relates to the evaluation of particulate emissions from textiles intended for use in cleanroom environments. A modified tumble dryer (drum volume 35 L) was used, into which either dry or moistened textile samples were placed. A Particle Plus RP-7301 laser particle counter was employed (measurement range 0.3–25 µm, airflow 2.83 L/min via a membrane pump, a 12/4.8 mm sampling probe, and a 6.35/3.18 mm antistatic sampling tube). The results showed that microfibre emissions are influenced strongly by fabric type and moisture content. Cotton released the highest mass of microfibres in its dry state, with emissions decreasing as the moisture content increased. A similar trend was observed in PES/Cotton blends, although with overall lower emissions. Notably, at certain moisture thresholds, the emissions began to rise again, likely due to fibre saturation and increased mechanical stress. Pure PES samples showed unexpectedly high emissions when dry, dominated by larger particle sizes (PM₁₀), which decreased significantly with added moisture before increasing again at higher humidity levels. Overall, the moisture content was found to play a key role in suppressing or enhancing microfibre release. A statistical analysis confirmed a strong negative correlation between moisture content and the emission of smaller particles (PM₁₀ and below), especially in cotton samples.

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Development of Mycelium-PLA Composites for Improved Mechanical Properties and Radiation Shielding Performance

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Traditional mycelium-based composites, formed by fungal colonisation of lignocellulosic substrates, offer sustainable and biodegradable alternatives to synthetic materials. However, these materials suffer from low mechanical performance, due primarily to their highly porous and heterogeneous structure. The modulus of elasticity typically remains below 2 MPa, with compressive strengths rarely exceeding 4 MPa, limiting their applicability in structural or load-bearing contexts severely.^{1,2} To overcome these limitations, we developed biocomposites in which a dried fungal biomass is repurposed as a reinforcing phase in a polylactic acid (PLA) matrix, reversing the conventional mycelium-matrix concept. This approach controls the mechanical robustness of PLA, while incorporating bio-based functionality from the fungal components. Various fungal species, including *Trametes gibbosa* (TG) and *Ganoderma lucidum* (GL), were integrated into the PLA through extrusion. The specimens were prepared using an injection moulding process for evaluation of the mechanical properties. The results indicated that, while most fungal additions increased the stiffness (modulus of elasticity), only TG improved the ductility. Fractographic analysis revealed a fibrillar dispersion of TG, shown in **Figure 1**, correlating with enhanced crystallinity confirmed by differential scanning calorimetry (DSC). To assess radiation shielding potential, the composite specimens were exposed to UVC light for 24 hours, simulating high-energy UV radiation conditions. A post-exposure colorimetric analysis showed lower degradation in the PLA–TG and PLA–GL samples compared to neat PLA, with GL providing superior protection. While GL is known to contain melanin, TG may possess other compounds which can enhance UV resistance in PLA composites. This aligns with previous findings on melanin's role in protecting fungal cells from ionising radiation.^{3,4} This work demonstrates that integrating fungal biomass into thermoplastic matrices like PLA not only mitigates the mechanical shortcomings of conventional mycelium composites, but also introduces functional benefits such as radiation resistance, making such materials promising for advanced sustainable applications.

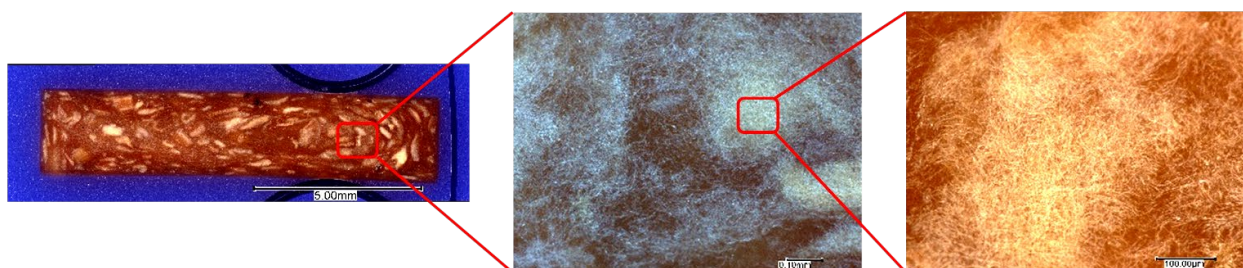


Figure 1: Macro and microstructure of PLA - TG composite.

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Enhancing Endovascular Treatment of Aortic Dissections through Advanced Computational Modelling

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Minimally invasive endovascular procedures have become increasingly important in the treatment of complex aortic diseases, such as dissections and aneurysms. In this study, we present a patient-specific finite element simulation framework aimed at improving the understanding and planning of endovascular stent deployment in the aorta. The novelty of our work lies in the integration of detailed anatomical reconstruction, and multi-phase simulation of the stent delivery process, enabling precise evaluation of device behaviour in challenging vascular anatomies. Computed Tomography imaging was used to reconstruct three-dimensional models of dissected aortas. The computational model of the stent was created, based on a clinically used bare-metal stent design. Simulations were performed using LS-DYNA covering the stent deployment stages: crimping, navigation through the vascular path and release within the target region. Interactions and mechanical properties for the stent, aorta, and catheter system were defined to mimic in vivo conditions closely. The simulations reproduced key aspects of stent deployment successfully, including deformation, wall apposition and true lumen expansion, and showed good agreement with intraoperative fluoroscopic images. The stent achieved stable positioning and restored blood flow without compromising branch vessels. These findings confirm the reliability of the computational model, and demonstrate its potential in predicting clinical outcomes. Our results highlight the growing role of numerical simulations in endovascular surgery, particularly for treatment planning, device design and risk assessment in patient-specific scenarios ^{1, 2}. The proposed methodology contributes to the development of safer, more effective, and personalised minimally invasive therapies for aortic pathologies.

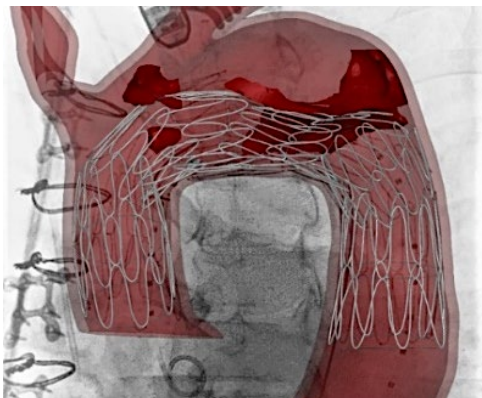


Figure 1: Virtually deployed bare-metal stent obtained from patient-specific finite element simulation. The simulation results are aligned with an intraoperative fluoroscopy image manually to validate stent deformation and positioning within the aortic arch visually. Anatomical structures such as the true and false lumens are shown in red to enhance the spatial context

Acknowledgment: The authors acknowledge the financial support of the Research Core Funding (No. P2-0063).

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Development of Flexible 3D Printed Auxetic Structures

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Metamaterials are artificially engineered materials whose macroscopic properties arise primarily from their internal architecture rather than their intrinsic chemical composition.¹ Within this broad category, auxetic structures represent a particularly intriguing subclass, characterised by a negative Poisson's ratio – a counterintuitive mechanical response resulting from their unique geometric configurations.² This study presents a novel approach to the design and fabrication of flexible auxetic structures based on rotating unit geometries^{3,4,5}, leveraging the versatility of additive manufacturing with thermoplastic elastomers. The aim is to provide a viable alternative to traditional auxetic textile manufacturing techniques, which are often complex or resource intensive.⁶ The research methodology involves a systematic literature review of auxetic materials, with a focus on structures employing rotational deformation mechanisms. Based on this review, three distinct auxetic geometries – each reflecting a different level of structural complexity - were selected for experimental investigation. These geometries were modelled parametrically in Autodesk Fusion 360 using motif-based subdivision (motif α), and subsequently fabricated using fused filament fabrication (FFF) with flexible thermoplastic elastomer filaments. Mechanical characterisation was performed using a Tinius Olsen H10 KT universal testing machine, to evaluate the key tensile properties and deformation behaviour. High-resolution imaging facilitated precise tracking of the strain fields, enabling accurate determination of the Poisson's ratio and identification of stress concentration zones.

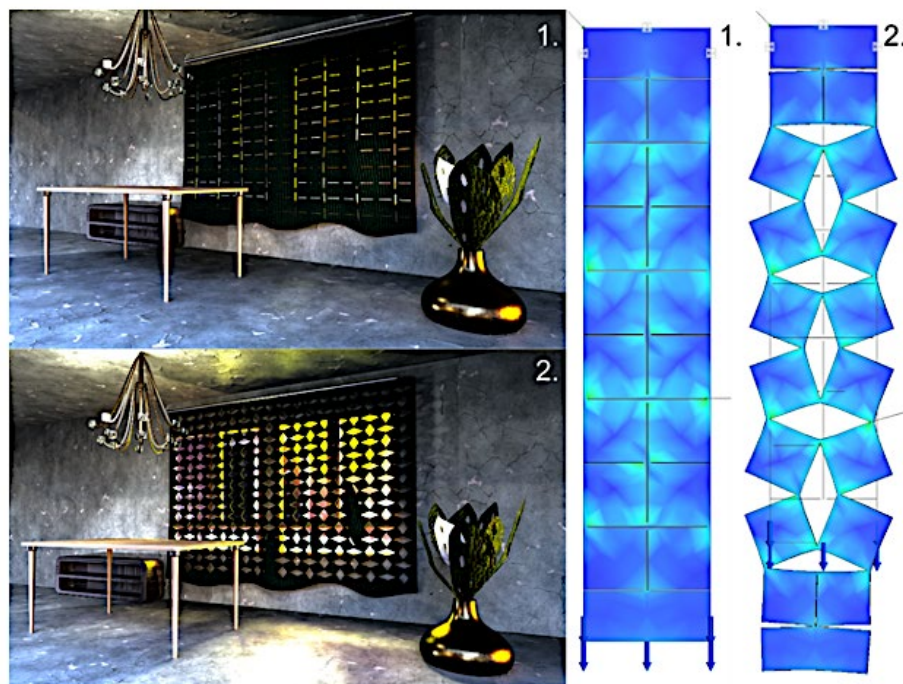


Figure 1: Possibility of using the developed flexible auxetic structure to regulate the light entering the room

The results confirmed that 3D-printed auxetic structures can replicate the essential mechanical behaviours of conventionally produced auxetic textiles effectively – most notably their flexibility and volumetric adaptability under load. Additionally, the study demonstrated that cell geometry influences tensile strength, elongation at break and auxetic response significantly. Among the tested configurations, rotating square units offered the most favourable balance between mechanical performance and design tunability. This work advances the field of Textile and Materials Engineering by showing that 3D printing provides a sustainable, customisable and scalable platform for the development of auxetic materials. The proposed approach holds promise for broadening the application scope of auxetic structures, particularly in wearable technology, medical textiles and adaptive functional materials.

Acknowledgement: The authors acknowledge the financial support from the Public Agency for Scientific Research and Innovation of the Republic of Slovenia (Research Core Funding No. P2-0063).

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Effect of Natural Fillers on the Surface Composition of Recycled Polymer Composites

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The growing demand for sustainable solutions in polymer recycling has sparked interest in natural bio-based fillers that could enhance the functionality of thermoplastic recyclates.^{1, 2} This work investigates the influence of natural nanofillers, namely, nanocellulose and chitosan - on the surface characteristics of recycled polymer composites derived from post-consumer polypropylene (PP) waste containing minor fractions of polyamide 6 (PA 6) and polyethylene terephthalate (PET).³ This study provides an in-depth ATR-FTIR mapping analysis of the surface distribution of natural fillers in the final material obtained by thermomechanical recycling. Nanofillers were added to the recycled polymer blend during melt-compounding using a twin-screw extruder. The resulting granulate was then injection moulded into test specimens. Surface chemical characterisation was conducted using micro-FTIR imaging, allowing the spatial mapping of characteristic functional groups linked to nanocellulose and chitosan. The detection of individual filler domains was based on tracking the correspondence between the recorded spectra during mapping and the reference spectra of each specific filler. The image data were analysed, to assess the intensity and homogeneity of filler distribution. The results demonstrated that both types of natural fillers are present on the surface of the material, which is highly relevant for potential functionalisation (e.g. antimicrobial or hydrophilic surface modification). In conclusion, the study confirms that micro-FTIR is a powerful method for assessing the surface activity and distribution of natural nanofillers in recycled thermoplastics. The findings highlight the potential of such fillers to impart additional surface functionalities (e.g. antimicrobial or hydrophilic surface modification) to otherwise inert recycled polymers. Future work may focus on evaluating the mechanical and antimicrobial performance of such composites, offering a path towards smart, sustainable materials for packaging or technical applications.

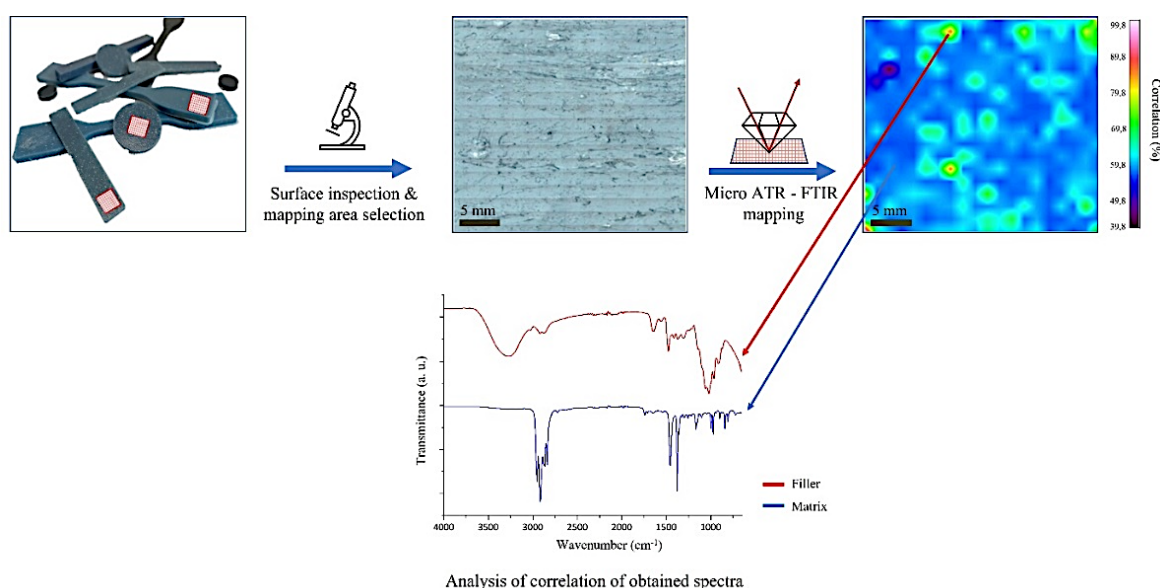


Figure 1: Micro ATR-FTIR analysis of the surface distribution of fillers in a polymer matrix

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Identification and Classification of Sources for the Research and Reconstruction of Historical Clothing from the Second Half of the 19th Century

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This research focuses on the identification, analysis and interpretation of historical sources relevant to the study and reconstruction of clothing from the second half of the 19th century. This period, which was characterised by significant socio-cultural changes and technological and industrial advances, poses a challenge to the accurate reconstruction of historical clothing. The study focuses on the systematic classification of historical sources, and proposes methodological guidelines developed to evaluate the authenticity, accuracy and relevance of these sources critically, with the aim of enabling accurate historical reconstruction and virtual prototyping of replicas of historical garments. A combined methodological approach was applied, comprising a qualitative source analysis, a comparative study and a historiographical overview. The material was categorised into three main groups: written, visual and material sources. The written sources included fashion magazines, tailoring manuals and archival records. The visual sources included portraits, photographs and fashion illustrations.



Figure 1: Page from the 19th-century magazine *Der Bazar* with detailed fashion illustrations and descriptive text. Serving as a visual and written record of women's dress of the period ¹

Material sources refer to authentic garments preserved in museums and private collections, while their reproductions, such as photographs or drawings, can be accessed through digital archives. Each type of source was analysed critically for authenticity, reliability and representativeness. The main findings show that, although written and visual references are essential for understanding trends, styles and materials typical of the period, they need to be examined critically due to inherent idealisations or contextual influences. Material sources are more objective and generally more reliable, but they are rare and often incomplete or damaged. In conclusion, this paper presents an integrated methodological approach suitable for clothing engineers and historians engaged in the research, reconstruction or digital replication of historical garments. By defining a methodological framework clearly and evaluating different source materials critically, the study facilitates more accurate reconstructions, and preserves historically significant clothing artefacts through advanced digitisation and prototyping techniques. This research contributes to the conservation and digital replication of historical clothing, supporting 3D prototyping and the preservation of cultural heritage.

Acknowledgment: *The authors would like to thank the Funding body for financing this research work, the Slovenian Research Agency (Research Programme P2-0118: Textile Chemistry and Advanced Textile Materials).*

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Structural and Functional Modification of Bacterial Nanocellulose into Bioactive Burn Dressings

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Bacterial nanocellulose (BnC) is a nanomaterial synthesised as an extracellular polysaccharide by various non-pathogenic bacteria. It has unique properties, including high water-holding capacity, biocompatibility, exceptional purity, non-toxicity and mechanical stability¹, making it highly useful for burn wound care. Nonetheless, a primary limitation of native BnC is its lack of bioactivity, which can be addressed by incorporating bioactive agents into the BnC matrix^{2,3}. While previous studies have explored BnC as a burn wound dressing, investigating real-time interactions using QCM-D and the toxicity of BnC in conjunction with bioactive agents in ex vivo human skin explants remains an unexplored area in Material Science⁴. In this study, BnC was modified in situ by carboxymethyl cellulose (**Figure 1a**) and ex-situ modified further using natural bioactive agents – bromelain and nisin, to enhance the membranes with proteolytic and antimicrobial properties. The BnC-CMC nanocrystals were synthesised from BnC-CMC membranes, and were subsequently utilised to investigate the surface interactions with bromelain and nisin using the QCM-D methodology (**Figure 1b**).

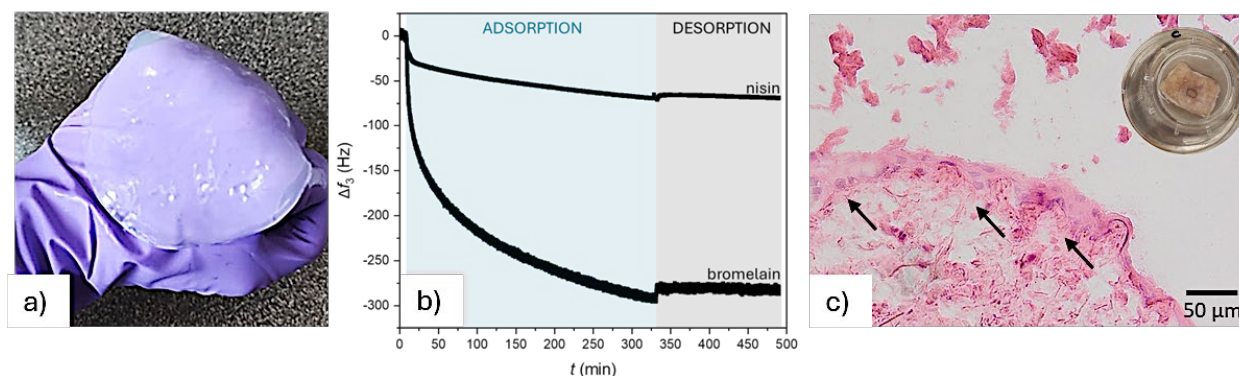


Figure 1: **a)** In situ modified BnC membrane produced under static fermentation conditions; **b)** Adsorption and desorption of bioactive agents onto modified BnC thin films; **c)** Micrograph of a histologically stained human skin section after a 12-day incubation with the bioactive BnC membrane. (Photographed by Urška Jančič; part of the Figure was published previously⁴.)

The membranes were characterised according to physical-chemical, morphological, mechanical and bioactive properties. The biological activity of the membranes was evaluated through antimicrobial activity and various in vitro and ex vivo methods, including the in vitro cell viability and morphology of an HaCaT cell line, in vitro wound healing, ex vivo bioadhesion testing and ex vivo toxicity testing on human skin explants, to assess structural changes in the skin after topical application of the membranes, determine cellular damage and skin irritation (**Figure 1c**).

The successful in situ modification of BnC membranes with CMC, as well as the immobilisation of bromelain and nisin on the membranes, was confirmed by FTIR, XPS and zeta potential measurements, while the findings from the in vitro and ex vivo experiments utilising ex vivo human skin to simulate a burn wound indicated primarily that the bioactive membranes do not have extremely strong irritating or toxic effects. By employing an innovative ex vivo human skin model to simulate a burn wound and evaluate the effectiveness of bioactive BnC membranes as burn dressings, this study represents a significant translational advancement, effectively bridging in vitro evaluations with clinical applications in burn treatment.

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Preliminary Study of the Catalytic Activity of Gold Nanoparticles Synthesised with Ultrasonic Spray Pyrolysis

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Ultrasonic spray pyrolysis (USP) allows for the continuous synthesis of metallic nanoparticles, such as gold nanoparticles (AuNPs), enabling the production of relatively large quantities of AuNPs for industrial use. One such potential use is as highly efficient room temperature catalysts, an effect that was first observed in 1987 by Haruta et.al., who observed the oxidation of CO at temperatures as low as -70 °C.¹ Since then, hybrid catalysts containing gold nanoparticles have been commercialised by Asahi Kasei for the production of methyl methacrylate, and by Johnson Matthey for the production of Vinyl Chloride Monomer, the latter importantly replaced mercury based catalysts.^{2,3,4} AuNPs can be synthesised via USP from different precursors. In this study we focused on the inorganic precursor gold (III) chloride and the organic precursor gold (III) acetate. As both precursors result in different shapes of AuNPs, as shown in **Figure 1**, the catalytic activity of the different AuNPs was evaluated using the reduction of 4-nitrofenol to 4-aminophenol, monitored with UV-Vis by the absorbance change in the range of 350 – 450 nm. Supporting characterisation using DLS, SEM, ICP-OES and NTA was also conducted, to verify the shape, size distribution, dispersity and concentration of AuNPs. The initial results from testing the catalytic activity showed that chloride based AuNPs offer a faster reaction rate, compared to acetate based AuNPs. However, they become inactive, most likely due to poisoning of the active sites. In contrast, acetate based AuNPs have a slower reaction rate, while being more resistant to the poisoning of active sites. These findings underscore the potential of USP as a scalable and efficient method for producing complex AuNPs based nano catalysts, with different precursors offering different properties. The findings of this preliminary study will enable us to formulate more complex catalysts better by incorporating AuNPs into active support materials to enhance their properties.

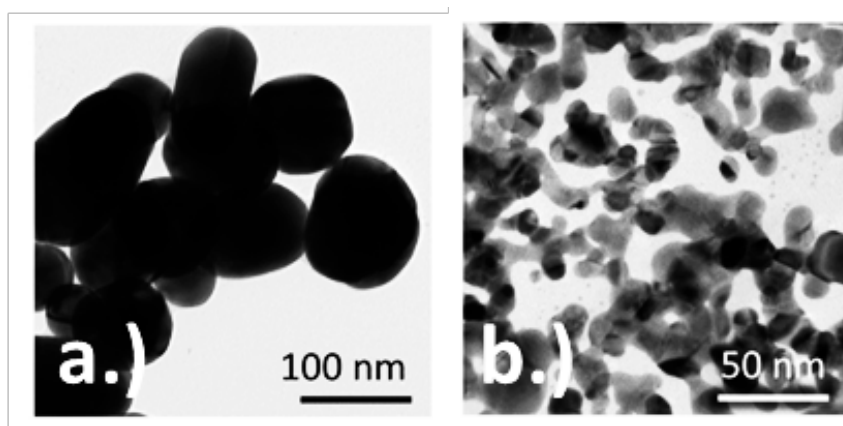


Figure 1: Shape and size of AuNPs synthesised with USP from a.) gold (III) chloride and b.) gold (III) acetate

Acknowledgment: The authors would like to thank the Funding body, the Slovenian Research and Innovation Agency - P2-0120 Tehnologije metastabilnih materialov.

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Achieving Hydrophobic Properties on Cotton with Eco-Friendlier Alkyl Ketene Dimer–Polysaccharide Coatings

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A holistic design approach leads progress in sustainable innovation by integrating performance, safety and environmental compatibility, while offering deeper insights and effective tools for problem-solving. One example is the control of wetting properties, which has attracted significant attention due to its wide range of applications across diverse fields.¹ Per- and polyfluoroalkyl substances (PFAS) are used most often as water repellents in textiles.² They are known for their toxicity and environmental persistence, which is especially concerning given their widespread use.³ This study aimed to develop and evaluate PFAS-free, safer and more sustainable alkyl ketene dimer (AKD) polysaccharide-based coatings for enhancing the hydrophobicity of cotton textiles. The coatings were prepared using three different concentrations of AKD (1 wt%, 5 wt%, and 10 wt%) and 4 different polysaccharides: alginate, cellulose nanofibrils (CNF), corn starch and agar. Different preparation methods were explored for the starch and agar-containing coatings (with and without heating). After solution preparation, the coatings were applied using a screen-printing method, followed by low-temperature curing. The results indicate that the AKD-polysaccharide-based coatings exhibit highly prominent hydrophobic performance, with WCA values ranging from 126° to 153°. Scanning Electron Microscopy (SEM) confirmed the successful deposition of the coating by revealing a roughened surface morphology (**Figure 1**).

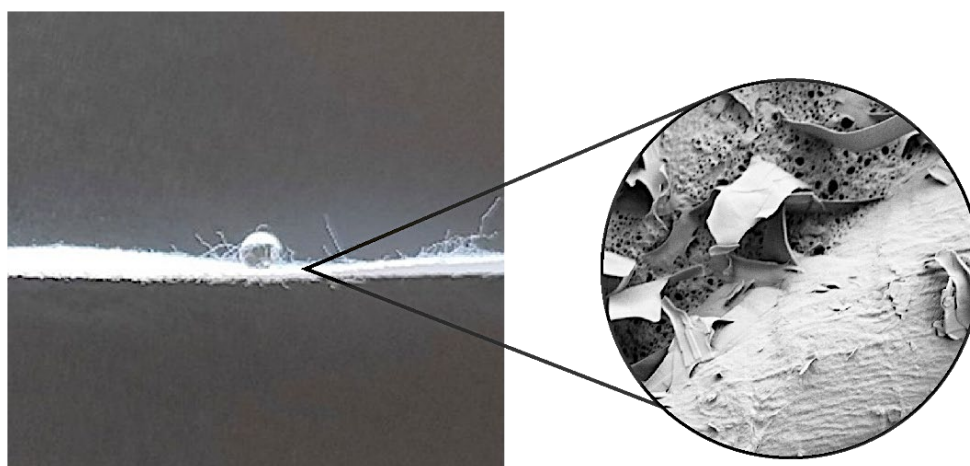


Figure 1: Scanning Electron Microscopy (SEM) image of an AKD-polysaccharide hydrophobic coating

Fourier Transform Infrared Spectroscopy (FTIR) confirmed the formation of covalent bonds between the coating and cotton and the predominant hydrophobic nature of the samples. The coatings showed good abrasion, washing and chemical stability.

The hydrophobicity was retained, even after 20,000 rubbing cycles and 30 washing cycles. The coatings demonstrated good durability across environments with varying pH levels. It was confirmed that the inclusion of polysaccharides in the coating formulation enhances durability, particularly under acidic conditions, where the stability of the reference AKD-only coating is diminished due to hydrolysis. Polysaccharides regulate the reaction between AKD and cellulose, and improve the uniformity of the coating distribution. The results underscore a clear pathway for replacing harmful PFAS-based treatments with safer and more sustainable alternatives. Moreover, these insights extend beyond textiles, and may guide the development of PFAS-free coatings in sectors such as packaging and cosmetics, thereby contributing to the broader transition towards safer materials within the Safe and Sustainable by Design (SSbD) framework.

Acknowledgment: *The authors would like to thank the Funding body for financing this research work, the Slovenian Research Agency (Research Programme P2-0118: Textile Chemistry and Advanced Textile Materials, and Programme P2-0152), as well as the Horizon Europe projects PROPLANET (GA), REMEDIES (GA) and UPSTREAM (GA).*

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Multifunctional Features of MXene-coated Fibrous Cellulose for Advanced Applications

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Due to the exceptional and abundant properties of a new family of two-dimensional (2D) materials known as MXenes (the transition metal carbide and nitride), i.e., good dispersion, high electrical conductivity ($\sim 10^6$ S/m), high electrochemical activity, high specific surface area, tunable surface chemistry and layered structure¹, there is much interest in flexible, MXenes-based fibrous composites for advanced applications, including energy storage devices for powering wearable electronics, energy harvesting devices for generating power, sensors, real-time monitoring of healthcare, personal thermal management and wearable antennas for wireless communication. The main aim of the presented research was to apply $\text{Ti}_3\text{C}_2\text{T}_x$ MXene (synthesised from 100 μm MAX phase precursor)² equally on cellulose fabric using the dip-padding procedure. Herein, a 2×2 cm^2 sample was dipped into an individual 10 mL aqueous solution (10 mg/mL of $\text{Ti}_3\text{C}_2\text{T}_x$ in deionised water) for 5 min, followed by a vacuum-assisted drying at 60 °C. The dip-coating/drying procedure was repeated three times. The MXene-coated fabric was characterised additionally according to its morphology and multifunctional features (electroconductive, thermal, flame-retardant and UV blocking), using scanning electron microscopy (SEM), a two-probe electrical resistance testing method, thermal IR imaging, thermogravimetric analysis (TGA), a flammability test and UV spectrophotometry. The selected results are presented in **Figure 1**. The obtained data indicate a successful MXene-based functionalisation of the fabric, attaining diverse advanced features.

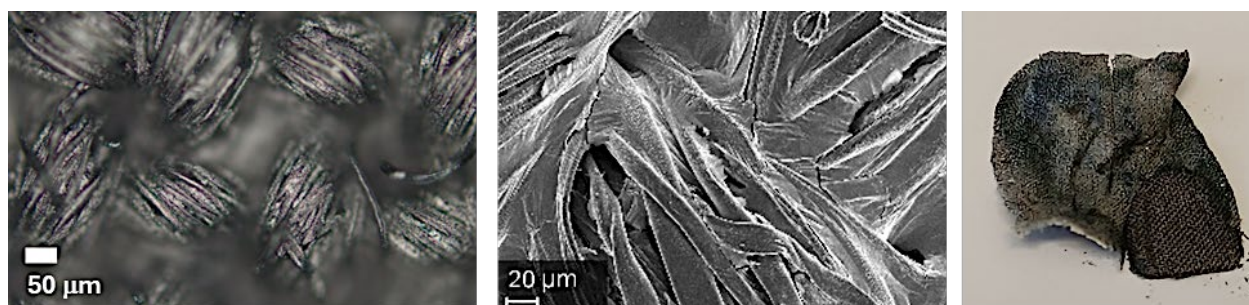


Figure 1: Optical microscope image (left), SEM micrograph (middle) and residue in flammability test (right) of MXene-coated cellulose fabric.

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P(VDF-TrFE) impregnated nonwoven for flexible and wearable self-powering electronic devices

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PVDF and its copolymers are receiving increasing attention, being related to their excellent and tunable piezoelectric ($d_{33} \approx 20 - 33$ pC/N) and dielectric properties, as well as high flexibility and good processability with easy preparation by various technologies (such as screen printing, casting, hot pressing, electrospinning)¹. The intrinsic piezoelectric response of P(VDF-TrFE) can additionally be induced by increasing the content of ferroelectric (β and γ) polar crystalline phases. Many techniques have been proved to induce dipole alignment, such as further thermal treatment, stretching² polarisation under a high electrical field³, and blending with nucleating agents (organic and inorganic fillers) to a favourable interaction between the P(VDF-TrFE) molecular chains and the surface of an additive. Although the electrospinning method has been shown as highly promising for the batch preparation of flexible PVDF-based nanofibres¹, the strength requirements are hardly satisfying compared with the existing nonwovens, and the method relies on expensive equipment. Considering mass production, the nonwoven mat with a randomly stacked highly porous structure can thus also be a promising support for fabricating wearable self-powered devices, depending on the fabrication method and material selection. Moreover, it can serve as an electron-accepting material, and its nonwoven structure with an irregular pore distribution can lead to internal deformation even without a spacer. In this study, existing fibre-based viscose and PET nonwovens were thus impregnated with P(VDF-TrFE) solutions of different viscosities by deep-casting and rod-coating, in order to obtain different weight mass deposition. The interactions between the P(VDF-TrFE) and fibres, as well as their influence on the electroactive (β/γ) phase crystallinity after thermal annealing, were studied by XRD and FTIR spectroscopies. The electrical poling of differently P(VDF-TrFE) coated nonwovens was performed, to align the P(VDF-TrFE) dipole moments. Before the poling process, the samples were coated with a silver conductive ink (100 nm) onto both composite surfaces to act as electrodes. The dielectric and piezoelectric performance was evaluated of the fabricated nonwoven devices. The P(VDF-TrFE) coated nonwoven with the highest and homogeneously distributed β -phase crystallinity exhibited a stable piezoelectric behaviour of $d_{33} \approx 7-10$ pC/N, showing a potential for the development of clothing with built-in piezoelectric healthcare sensors or energy-harvesting devices for wearable electronics (robotics).

Acknowledgment: The authors would like to thank the Slovenian Research and Innovation Agency (J2-60048, P2-0424) for financing this research work.

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Slot-die Coating of Lignin-decorated Microcrystalline Cellulose for Improved Barrier Properties of Paper

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Surface coating with biopolymers (like nano/micro-cellulose, lignin, chitosan) is an emerging approach to improve the barrier properties (above all air, oxygen, and UV) of paper to be used in various packaging applications (pharmaceuticals, food, medical), following the circular economy and overall sustainability.¹ However, using relatively low-viscous nanocellulose suspensions, multiple layers (between 5 - 10) of deposition are required to cover the base paper's surface fully (generally between 10-15 g/m²), thus to achieve the desired barrier effects. A uniform and relatively-higher coat weight (>10 g/m²) at high coating speeds (up to several 10 m/min) can be achieved only by the curtain or slot-die coating process, as well as blade coating, leading to complete coverage of the paper's surface. In this contribution, the slot-die coating¹ of moderately concentrated microcrystalline cellulose (MCC) suspensions (MCC) with and without different quantities of lignin content (5-50 wt%) onto the paper by a fully automated slot-die coating device will be presented, and using NIR drying as an advanced alternative to the conventionally employed convective heating. The effect of the established coating parameters (coatig speed and wet thickness settings at a given slot gap thickness and slot-to-paper distance) at optimal drying kinetics will be presented, by evaluating the coating homogeneity, and paper physical (weight, thickness, density) and barrier (air, oxygen, UV, water vapour permeability) properties.

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The Effectiveness of Textile Decontamination Using Saturated Steam During the Drying Process

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The disinfection effects of two household tumble dryers were investigated, including their drying programmes under different load conditions (4 kg, 6 kg, 8 kg) and an initial ballast moisture content of 70 %. Additionally, the capacity to prevent microorganism cross-contamination of the components involved in the drying process was assessed, including the ballast, dryer surfaces and the condensed water. Each tested drying programme using textile bioindicators was followed by a thermal disinfection programme for the ballast textiles and the washing/drying machine itself (90 °C/20 min, 40–60 °C/2.5 min, 25–35 °C/3 min). Due to the lack of specific Standards, recommendations, or Good Laboratory Practice (GLP) principles in the field of Evaluating Disinfection Efficacy in Textile Drying Processes, two model microorganisms (MO) were selected in accordance with SIST EN 16616, which refers to industrial laundering processes. The selected microorganisms were: *Staphylococcus aureus* (Sa ATCC 6538) – used for low-temperature textile washing processes` evaluation (20 °C < T < 60 °C), and the more thermally resistant *Enterococcus faecium* (Ef ATCC 6057) – intended for evaluating washing processes equal to or above 60 °C. The initial concentration of microorganisms on the textile bioindicators was CFU_{initial} = 1.5 × 10⁷ CFU/mL. The disinfection effect, defined by microbial reduction (RED) and the percentage of inactivated microorganisms (PIM), was evaluated according to the relevant International Standards and German Hygiene Guidelines (VAH, RKI). In assessing the disinfection efficiency of the drying process, the criterion defined by SIST EN 16616 was applied, which states that a textile care process can only be considered effective if it reduces the initial bacterial count by more than 7 logarithmic levels (RED > 7 log). A new drying programme was developed, based on the analysis of the microbial reduction results from the existing programmes. It is based on the introduction of saturated steam (14 g/min) into the drum during the drying process. A noticeable decrease in Sa bacterial population on textile samples was observed after 30 minutes, while complete microbial reduction was achieved after 60 minutes of steam treatment (RED > 7.14), qualifying the process as disinfection effective. The newly developed drying/disinfection programme also prevented cross-contamination successfully, as no microorganisms were detected on the ballast, dryer surfaces, or in the condensate.

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Thermal Analysis of Filter Cake: An Analytical Approach Development for Determining the PET/Cotton Microfiber Mass Ratio

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The increasing presence of microfibres in aquatic environments, originating from textile materials, such as polyethylene terephthalate (PET) and cotton fibres, has raised concerns about their environmental impact. In this study, we present a novel approach for quantifying the ratio of PET and cotton microfibres in filter cakes obtained after water filtration. While lately researchers have utilised thermogravimetric analysis (TGA) for microfibre identification and quantification due to its specific thermal decomposition profile^{1,2}, our work introduces an improved method that enables analysis of larger sample volumes while ensuring homogeneity and reproducibility. The developed methodology is based on controlled ashing in a muffle furnace under varying thermal conditions, optimised to distinguish between synthetic and natural fibres through selective degradation. To support and validate our approach, TGA was used as a complementary technique, allowing us to refine the ashing parameters. The filter cakes were analysed both as bulk powder and in compressed pellet form, the latter prepared with a hydraulic press to enhance sample uniformity. The primary advantage of our method lies in its scalability compared to traditional TGA, which is limited by small sample mass and restricted oxygen flow. Our findings demonstrate that the optimised ashing procedure differentiates and quantifies PET and cotton fibres in environmental samples reliably, offering a robust alternative to TGA when larger, heterogeneous filter residues must be assessed. This method has the potential for broader application in environmental monitoring and textile fibre pollution studies, especially in cases where material recovery and mass balance are required across large filtration systems.

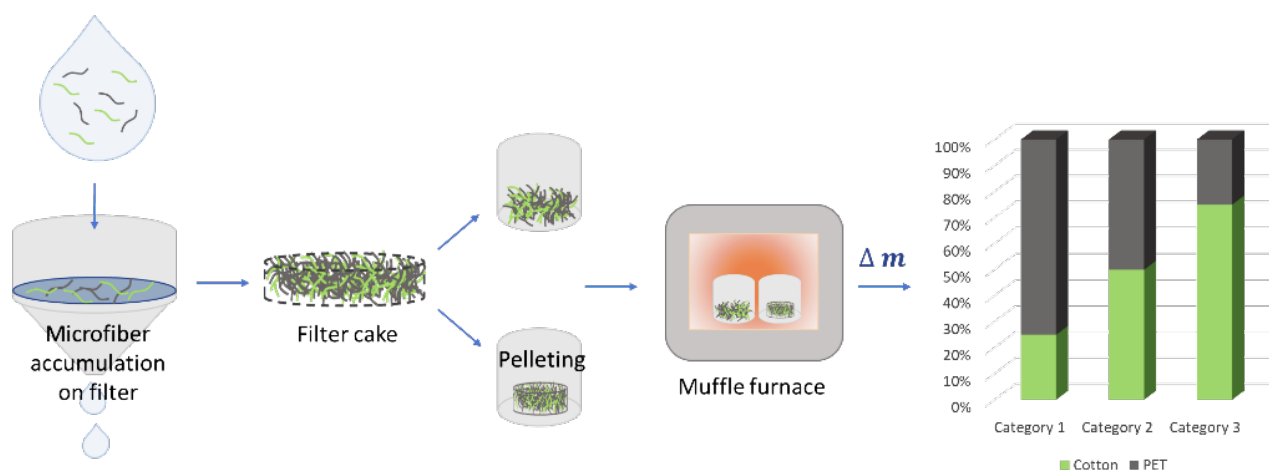


Figure 1: Thermal analysis using a muffle furnace of post-filtration residue of a microfibre blend

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Developed Nanocomposites of Magnetic Polysaccharides and Graphene Oxide for Potential Next-generation Electrochemical Antibiotic Detection

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The escalating global threat of antimicrobial resistance (AMR), fuelled by the ubiquitous and uncontrolled release of antibiotics into aquatic systems, food chains and drinking water sources, poses a serious challenge to public health and environmental safety. Despite the high urgency, the current regulatory framework for routine monitoring of antibiotic residues at trace levels is inadequate. Even at extremely low concentrations ($\mu\text{g/L}$ to ng/L), antibiotics can disrupt ecosystems, bioaccumulate in organisms and accelerate the spread of resistance genes. This urgent scenario requires the development of rapid, cost-effective and highly sensitive detection technologies that work in complex environmental matrices. Electrochemical sensors have emerged as a promising alternative to conventional analytical methods, due to their portability, low cost and excellent analytical performance. However, their practical implementation depends on the availability of efficient electrode modifiers, where the use of nanomaterials presents a highly innovative approach. In this work, we present a novel nanocomposite synthesised for the first time by integrating magnetic nanoparticles (MNPs) functionalised with cationic chitosan (catCH) and graphene oxide (GO). The resulting nanostructure combines the magnetic responsiveness of MNPs@catCH with the high conductivity and large surface area of GO, resulting in potential multifunctional material with abundant electroactive sites and enhanced charge-transfer properties. The MNPs were synthesised by co-precipitation and functionalised with catCH to generate a strong positive surface charge, which enables electrostatic bonding with the negatively charged GO to form the nanocomposite. A comprehensive physicochemical characterisation was performed using transmission electron microscopy (TEM), X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), X-ray photoelectron spectroscopy (XPS), thermogravimetric analysis (TGA), electrophoretic mobility measurement and vibrational sample magnetometry (VSM). These analyses confirmed the successful synthesis, stable integration and functional integrity of the composite. This nanocomposite shows significant potential as a next-generation modifier for electrochemical sensors. It offers magnetic enhancement, improved analyte accessibility and signal amplification for ultra-trace detection of antibiotics. Its dual functionality and modular design provide a versatile platform for the development of portable, selective and high-performance electrochemical sensors tailored for environmental, food safety and biomedical applications.

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Upcycling Polyolefins into Magnetically Functionalised Vitrimers via Reactive Extrusion and Transesterification Pathways: A New Paradigm in Polymer Science

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The growing demand for sustainable and reprocessable polymer systems has prompted significant research into Covalent Adaptable Networks (CANs), particularly vitrimers, which combine the durability of thermosets with the reprocessability of thermoplastics. This study presents a novel approach to the development of magnetic vitrimer nanocomposites, by incorporating surface-functionalised iron oxide nanoparticles into a transesterification-based vitrimer matrix. The vitrimer network was synthesised using polypropylene-grafted maleic anhydride (PP-g-MA) and diglycidyl ether of bisphenol A (DGEBA), catalysed by triphenyl phosphate (TPP) through reactive extrusion. Iron oxide nanoparticles exhibiting magnetite and maghemite crystalline phases were synthesised and functionalised with citric acid (CA) and cysteamine (CYS). These functional groups enabled magnetic responsiveness, while ATR-FTIR (attenuated total reflection Fourier transform infrared spectroscopy) and TGA (thermogravimetric analysis) confirmed successful surface modification and quantified grafting levels. Despite the poor thermal stability of the functional layers, incorporation into the vitrimer matrix was achieved via compounding and injection moulding. Characterisation of the PP-CAN confirmed successful crosslinking and gel formation. However, the thermal and mechanical properties remained largely unchanged, attributed to enhanced nanoparticle dispersion as evidenced by the inorganic content variation in TGA. Differential scanning calorimetry (DSC) analysis suggested that the MNPs acted as nucleating agents by narrowing the crystallisation peak. Magnetic property measurements revealed superparamagnetic behaviour, enabling inductive heating upon exposure to alternating magnetic fields. This confirmed the feasibility of triggering dynamic covalent bond exchange remotely through localised magnetic heating. The novelty of this work lies in its systematic investigation of nanoparticle surface chemistry on vitrimer network dynamics, revealing how functionalised magnetic fillers can enable magnetically induced self-healing and thermal reconfiguration in polymeric systems. By establishing a platform for magnetic activation in vitrimers, this study demonstrates a strategy to overcome the conventional limitations associated with filler inclusion in reprocessable networks. These findings provide key insights into the design of smart, reconfigurable, and upcyclable magnetic vitrimers. This approach supports the circular economy goals, and presents new opportunities for applications in soft robotics, flexible electronics for textile and biomedical devices—highlighting the potential of magnetic-CANs in next-generation sustainable materials.

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Dental Gold Alloys and Gold Nanoparticles for Biomedical Applications

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The presented monograph¹ explores recent developments in dental gold alloys and gold nanoparticles (GNPs) for biomedical and other applications. Dental gold alloys combine several highly desirable mechanical properties, such as high strength, ductility and elasticity, with an extremely robust chemical stability in the mouth. When in nanoform, gold attains additional useful properties in several fields, from catalysis, electronics, to cosmetics and optics. Significant advancements have been made in the use of GNPs as novel gold biomaterials, offering a multifunctional platform for cellular imaging, biosensing, and targeted drug delivery in tumour immunotherapy and photothermal therapy. A thorough overview of the evolution and application of dental gold alloys is given, emphasising the key material properties essential for dental use. These include microstructure, chemical and mechanical stability, ageing behaviour, biocompatibility and colour retention. Novel gold and noble metal alloys are investigated in the context of a modern dental practice, where there is a need for materials with a high biocompatibility performance combined with a high aesthetic value. The role of GNPs in dentistry is also explored, starting with a general overview of various synthesis methods designed to control their size, shape and stability in biological and other environments.

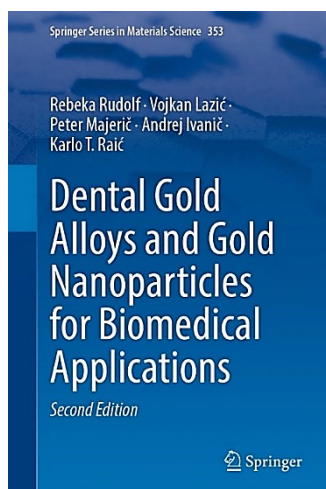


Figure 1: *Dental Gold Alloys and Gold Nanoparticles for Biomedical Applications, Second Edition (2025), Springer Cham, Springer Series in Materials Science, 166. ISBN: 978-3-031-98637-6*

For biomedical applications, factors such as exposure routes, surface chemistry, and the steric effects of nanoparticle coatings are investigated for their influence on biodistribution and toxicity in the human body. Additionally, their uses in the various fields mentioned above are explored, along with their structural and surface modifications for these applications, along with the working principles, state of development, environmental impact, global production and the evolving regulatory aspects for their use.

Supported by the current literature and recent experimental findings, this monograph serves as an attractive resource for researchers and engineers engaged in the study and development of gold-based biomaterials, for both therapeutic and consumer applications.

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Water Hammer Risk Assessment and Mitigation in Industrial Pipelines: 1D and 3D Numerical Approaches

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Water hammer events in pipelines can generate severe transient pressure surges, posing risks of structural damage and operational disruption. The presented case study focuses on a 3.4 km long DN400 pipeline undergoing a sudden pump failure, to assess pressure transients, cavitation and water column separation. This presentation explores a comparative simulation study of water hammer phenomena using two numerical approaches: a one-dimensional (1D) inviscid model based on the Euler equations with the method of characteristics, and a three-dimensional (3D) viscous model employing the Navier-Stokes equations in OpenFOAM. The 1D model proved effective for predicting pressure wave behaviour and identifying cavitation risks quickly, while the 3D model offered a high-fidelity view of multiphase flow dynamics, including cavitation bubble formation and collapse. As a mitigation strategy, a pressure relief valve was incorporated into the system and evaluated through 3D simulations. The results demonstrated the valve's role in reducing extreme pressure spikes and limiting cavitation as an alternative to the traditional surge tank technologies¹. The conducted research also opens the potential to develop coupled 1D-3D solvers, that are able to simulate wave propagation on the whole pipeline, as well as the cavitation bubble collapse and the viscous effects at the pump area of the pipeline.

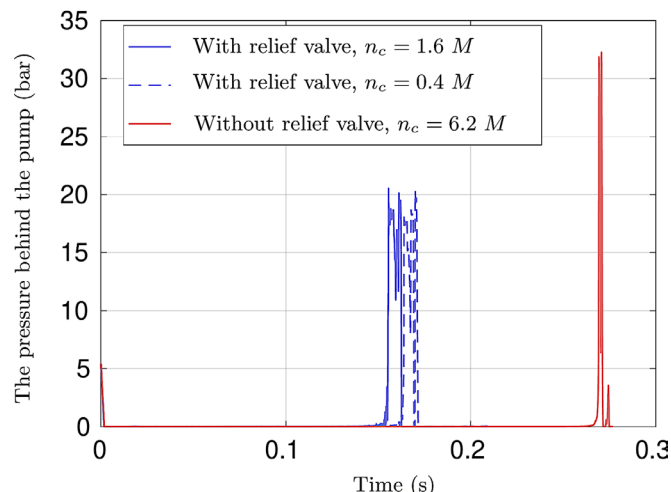


Figure 1: Comparison of the water hammer effect for a pipeline with and without relief valves.

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Experimental and Numerical High Cycle Fatigue Analysis of 2D Chiral Auxetic Structures

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The High Cycle Fatigue (HCF) behaviour of two 2D chiral structure was investigated in this study. These types of structures are increasingly gaining interest, due to their unconventional mechanical properties, such as a negative Poisson's ratio, high deformability and energy absorption, which makes them attractive for applications in aerospace and automotive engineering ^{1,2}. This work aims to get an insight into the fatigue behaviour of tri-anti-chiral and tetra-anti-chiral geometries (**Figure 1**).

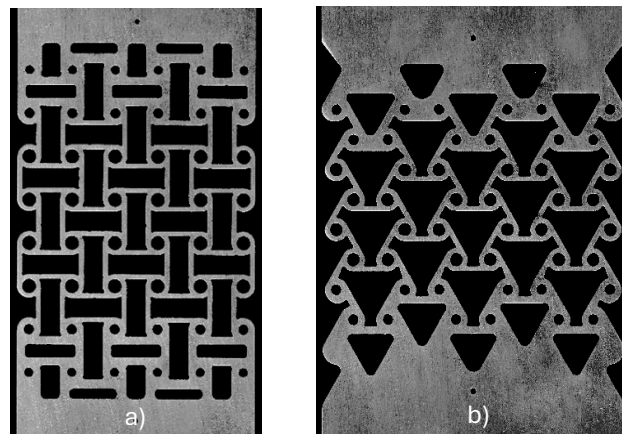


Figure 1: a) Tetra-anti-chiral, and b) Tri-anti chiral test specimens made from the aluminium alloy AA 5083-H111

The specimens were fabricated from AA 5083-H111 aluminium alloy using the abrasive water jet technology. Static and fatigue experiments were conducted in the HCF regime using a Zwick/Roel Vibrophore 100 pulsator at a load ratio of $R = 0.1$. Additionally, numerical analyses were performed in Ansys Workbench using the stress-life method to predict the fatigue life numerically ^{3,4}. The comparison of the experimental and numerical S-N curves showed a good correlation, validating the computational model. These results suggest that this approach can be used to assess fatigue properties in the future when designing or optimising chiral auxetic geometries.

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ENGINEERING MATERIALS AND PROCESS TECHNOLOGIES: 2ND CONFERENCE OF PROGRAMME GROUPS OF THE FACULTY OF MECHANICAL ENGINEERING UNIVERSITY OF MARIBOR, BOOK OF ABSTRACTS

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The publication presents an overview of the research achievements of Programm Groups of the Faculty of Mechanical Engineering: P2-0424 Design of Novel Properties of (Nano)Materials & Applications, P2-0063 Design of Cellular Structures, P2-0120 Technologies of Metastable Materials, P2-0118 Textile Chemistry and Advanced Textile Materials, and P2-0196 Research in Power, Process, and Environmental Engineering from 2024 to 2025. Members of the program group present their research innovations and progress achieved within the framework of the program group's activities.



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