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Additive Manufacturing

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On the Optimization of Additively Manufactured Parts Quality Through Process Monitoring: The Wire DED-LB Case

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The wire DED-LB/M Additive Manufacturing (AM) process is time- and cost-effective providing high-quality, dense parts while supporting multi-scale manufacturing, repair and repurposing services. However, its ability to consistently produce parts of uniform quality depends on process stability, which can be achieved through monitoring and controlling key process phenomena, such as heat accumulation and the variations in the distance between the deposition head and the working surface (Standoff distance). Part quality is closely linked to achieving predictable melt pool dimensions and stable thermal conditions which in turn influence the end-part's cross-sectional stability, overall dimensions, and mechanical properties. This work presents a workflow that correlates process and metrology data, enabling the determination of the tunable process parameters and their operating process window. The process data is acquired using a vision-based monitoring system and a load cell embedded in the deposition head, which together detect variations in melt pool area and Standoff distance during the process while metrology devices assess the part quality. Finally, this monitoring setup and its ability to capture the complete process history are fundamentals for developing in-line control strategies, enabling optimized, supervision-free, and repeatable processes.

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Adopting Multi-Material Wire DED-LB in Naval Industry: A Case Study in Stainless Steel and Nickel-Based Alloys

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Multi-material Directed Energy Deposition (DED) Additive Manufacturing (AM) processes enable the integration of different material properties into a single structure, addressing the requirements of various applications and working environments. Laser-based DED has been employed in the past for surface coatings as well as for the repair and repurposing of high-value industrial components, with the goal of extending product lifecycles without relying on expensive and time-consuming manufacturing from scratch. While powder DED-LB has traditionally been used for multi-material AM, the more resource-efficient and cost-effective wire DED-LB process is now being explored as a solution for creating hybrid materials. This work focuses on the critical aspects of implementing multi-material DED-LB, specifically defining an optimal operating process window that ensures the best quality and performance of the final parts. By investigating the possibility of combining stainless steel and nickel-based alloys, this study seeks to unlock new possibilities for the repair and optimization of naval components, ultimately improving operational efficiency and reducing downtime for critical naval equipment. Finally, during the experimental phase, substrate pre-heating and process monitoring with thermocouples will be employed to manage and assess heat distribution in the working area, ensuring defect-free material joining.

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AI-Based Prediction of Mechanical Properties in Additively Manufactured Components

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Additive Manufacturing (AM) is emerging as one of the most promising technologies for producing complex-shaped components. However, several challenges remain with a key issue being the development of a reliable model to predict the mechanical behaviour of additively manufactured parts. This work aims at elaborating a design tool that allows to optimize the choice of optimal process parameters for producing Ti6Al4V parts by Electron Beam Melting (EBM). In this work two sets of samples were produced. In total, three levels of volumetric energy density (VED) have been considered by varying the hatch distance, the beam current, and the scan speed. Each specimen was subjected to a detailed characterization to identify microstructure and metallurgical defects. To characterize the material and verify if process parameters affect the microstructure, XRD analyses, microhardness tests, and metallographic examinations, after grinding, polishing and etching, were performed. The analyses revealed a typical α + β microstructure: α + β phases were arranged in a basket-weave structure formed within the prior β grains. This microstructure causes a material anisotropic behavior since those grains are elongated along the building direction. The analyses revealed that the alloy microstructure does not seem to be significantly affected by process parameters. On the grounds of these findings, it is apparent that the size and morphology of defects affect the alloy mechanical behavior. Metallurgical defect analyses were efficiently carried out by introducing automatic procedures. These defects were characterized in terms of size, morphology, and distribution, as these characteristics significantly influence the mechanical properties of the component.

Subsequently, a predictive model leveraging artificial intelligence (AI) algorithms has been developed. A trained classifier is designed to establish correlations between metallurgical defects and process parameters. Artificial intelligence techniques, such as convolutional neural networks, allow efficient defect detection and AM process optimization, ultimately reducing time and production costs. The implemented classification method, based on an advanced iterative optimization algorithm, provides effective classification results achieving an accuracy of more than 85%.

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Effect of Stress Ratio on Fatigue Crack Growth of Annealed Ti6Al4V Alloy Fabricated by Laser Powder Bed Fusion

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Additively manufactured components of titanium alloys, particularly of Ti6Al4V, have increasingly been used in the healthcare and aerospace industries. However, designing components for applications under fluctuating loads requires a thorough understanding of their fatigue and fracture mechanics behaviors. This study investigates the influence of stress ratio, which is defined as ratio between the minimum and maximum applied stresses, on the fatigue crack growth (FCG) behavior of annealed Ti6Al4V fabricated by laser powder bed fusion (LPBF). A Ti6Al4V block with dimensions of 40 mm×42 mm×70 mm was produced using LPBF, subsequently stress relieved at 650 °C, and then annealed at 950 °C. Afterward, compact tension (CT) specimens were extracted from this block using wire cutting. The CT specimens were tested under three different stress ratios of -1, 0.1, and 0.5. The results demonstrated that the stress ratio considerably influences the FCG behavior of the additively manufactured Ti6Al4V, which can be attributed to crack closure effects.

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Examples of the Development of Printed Metal Components and Education in the Field of Additive Technologies

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The paper presents a comprehensive approach to the development of several metal printed components, the operational loading of which is complex and can cause damage due to multiaxial fatigue.
First, fatigue life research was carried out on small material samples. Tests were carried out under axial, torsional and combined loading. The MS1 tool steel and 316L stainless steel were subjected to the investigation. Criteria proposed by several authors were used to predict fatigue life under combined loading. In conclusion, it was possible to assess the compliance/disagreement of the calculated life with the experimentally determined ones and to recommend (or exclude) their use. The results have already been published in contributions at international scientific conferences.
The conclusions formulated on the basis of research with material samples could be followed by the development of several printed components. These included, for example, a set of optimized variants of the milling head, the development of a turning knife, or the lightening of the console of a tram underpass barrier. Functional samples of components of a folding wheelchair for disabled people were also designed. All resulting components are presented and the development process is described in detail for one selected component.
The authors also present a proposal for a joint project of the Faculty of Mechanical Engineering and the Faculty of Education, which aims to explore the potential of virtual reality in replacing physical excursions in workplaces with modern production technologies such as metal printing.

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Effect of Geometric Imperfections on Aauxetic Lattice-Reinforced Concrete Composites

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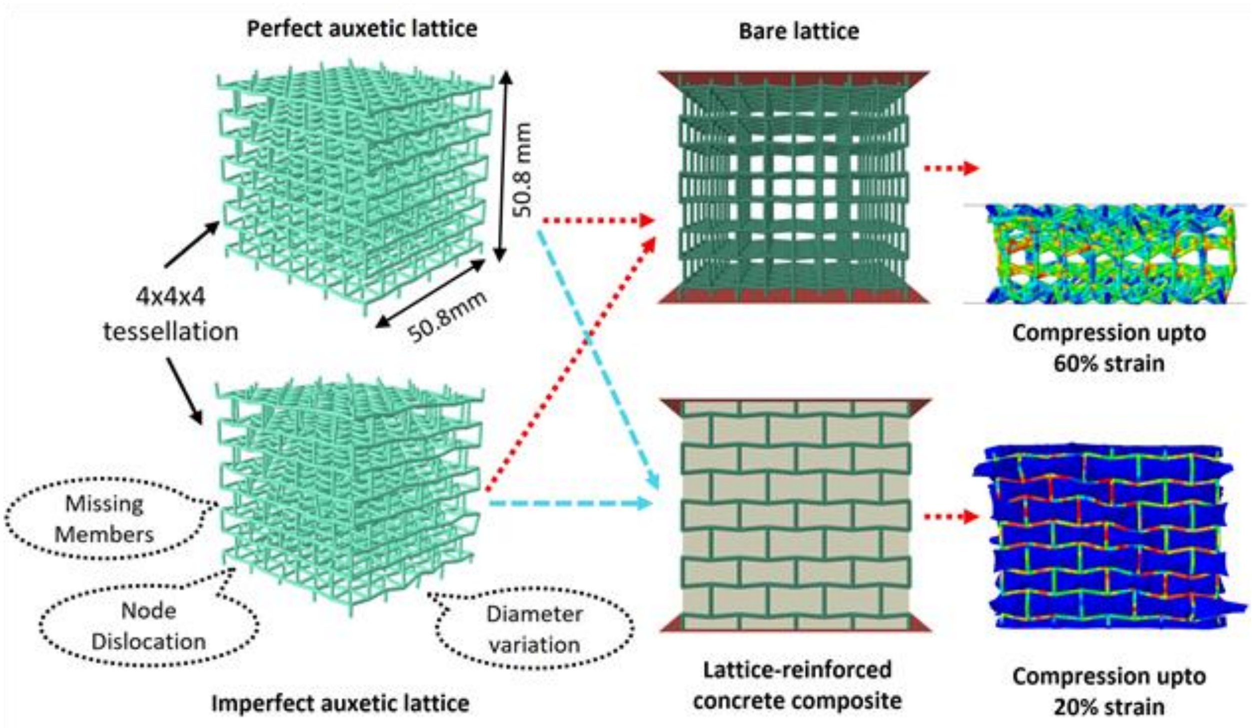
Auxetic steel reinforcements have demonstrated exceptional potential for enhancing the strength and ductility of reinforced concrete members, making it a viable choice for next generation concrete structures. However, the geometry of these lattice reinforcements is complex and achieving defect-free fabrication is challenging. Primarily, the defects in the lattices are geometric in nature that often arise due to manufacturing tolerances and uncertainties in the fabrication process. These imperfections, often overlooked during the design phase, can result in discrepancies between the intended and actual performance of reinforced concrete members. For practical applications, it is crucial to account for uncertainties in the mechanical response of auxetic lattice-reinforced concrete. This study examines the discrepancies between as-designed and as-manufactured auxetic reinforcements, acknowledging that achieving defect-free reinforcements is not feasible with any fabrication process. Specifically, this study focuses on three types of imperfections: node displacement, which can occur in both additive manufacturing and robot-based fabrication, missing members, and section variations, which are more common in additive manufacturing processes.

In this study, we employed a 3D finite element method to analyze the uniaxial compression response of bare and lattice-reinforced concrete composites, considering both perfect and imperfect lattice configurations. To simulate fabrication uncertainties, imperfections were randomly introduced into the perfect lattice, generating imperfect lattices with defect levels of 1%, 5%, 10%, 15%, and 25% of members or nodes. The compressive response was then evaluated in terms of peak stress (σmax) and toughness (τ), providing insights into the impact of lattice imperfections on the mechanical response.

The results indicate that when 25% of the members are missing, peak strength reductions of up to 80% in bare lattices and 60\% in reinforced concrete composites. In contrast, node dislocation defects have a minimal impact on the compressive response. For bare lattices, peak strength showed a slight improvement of up to 1% in some cases, while the maximum decrease is 0.4%. In lattice-reinforced concrete composites, node dislocation led to a maximum strength reduction of 4% at the highest defect level of 25%. These findings highlight that the mechanical response of both bare lattices and lattice-reinforced mortar composites is most sensitive to missing member imperfections, with the severity of defects playing a crucial role. In contrast, node dislocation imperfections have the least effect on overall performance.


Perfect auxetic lattice
Bare lattice
50.8 mm
50.8mm
4x4x4
tessellation
Compression upto
60% strain
Missing
Members
Node
Dislocation
Diameter
variation
Imperfect auxetic lattice
Lattice-reinforced
concrete composite
Compression upto
20% strain

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Effect of Solidification Mode on the Resulting Microstructure of 304L Steel Produced With L-PBF

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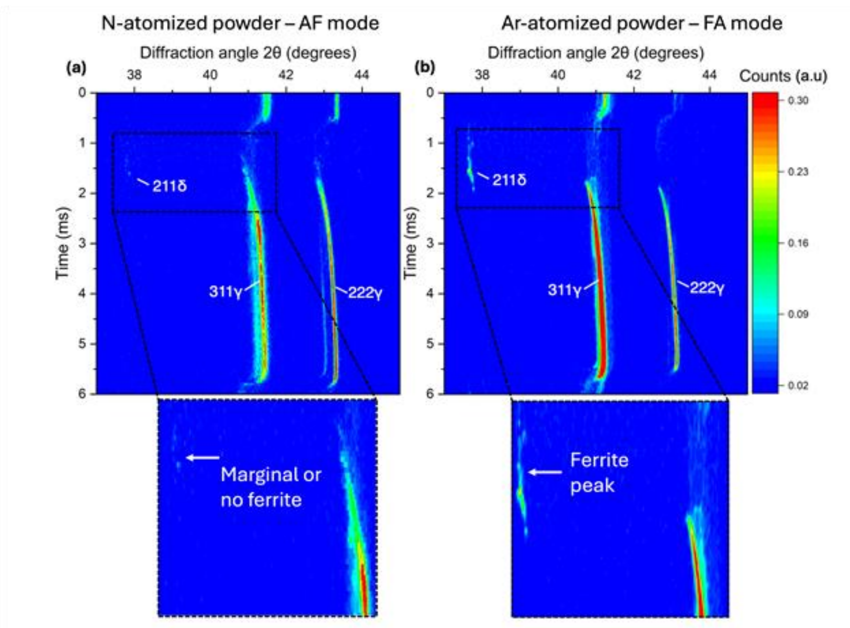
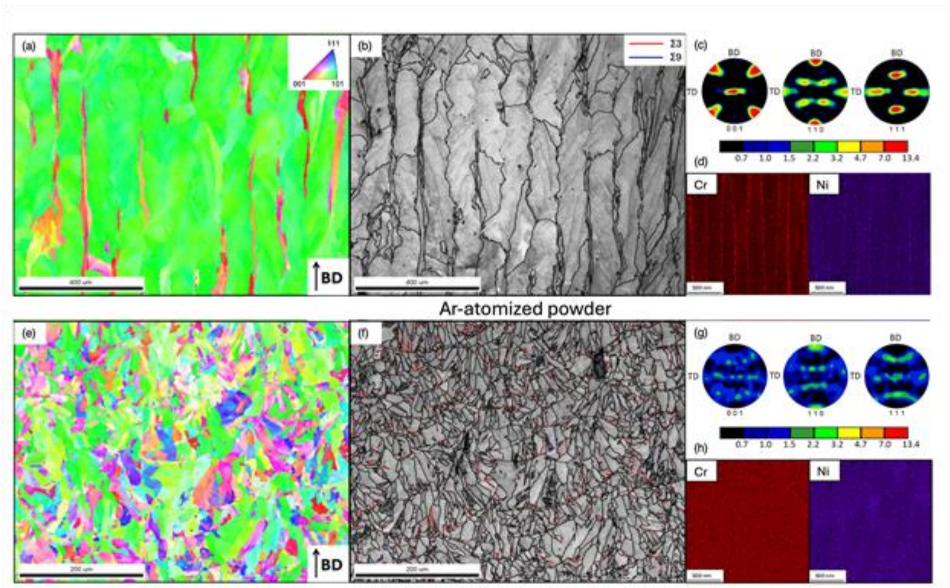
This study investigates the impact of compositional variations on the microstructure and particularly on the crystallographic texture of 304L stainless steel fabricated by Laser Powder Bed Fusion (L-PBF). Despite using identical processing parameters, we utilized two different powders with minor compositional differences that yield vastly different microstructures due to their distinct solidification behaviors. A N-atomized powder forms strongly textured, columnar grains with significant elemental segregation, following a primary γ-austenite with second-phase ferrite solidification (AF) mode. Conversely, an Ar-atomized powder results in less textured, equiaxed grains with uniform composition, adhering to a primary ferrite with second-phase γ-austenite solidification (FA) mode. Comprehensive analysis using operando synchrotron X-ray diffraction during L-PBF at the Swiss Light Source (Figure 1) reveals the critical role of the solidification mode in determining the final microstructure. The categorization of the solidification modes is further supported by the observed grain morphology, elemental segregation, twinning density (Figure 2) and thermodynamic simulations. This study emphasizes the critical influence of solidification conditions in L-PBF in controlling the microstructure. It is particularly highlighted that the gas atomization process can impact the solidification pathway and the resulting crystallographic texture.





EBSD maps with IPF coloring along the BD direction and the corresponding pole figures (c), (g) for the N-atomized and Ar-atomized powders, accordingly. (b), (f) Grain boundary maps for the N-atomized and Ar-atomized powders, accordingly. (d), (h) EDS maps at the cellular structure level for the N-atomized and Ar-atomized powders, respectively. Figure S3 of the supplementary material section includes qualitative analysis of the EDS.

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Fracture Mechanics Approach of Fatigue Life Assessment for Additively Manufactured Nickel-Based Superalloy

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In the present work, nickel-based alloy manufactured by selective laser melting (SLM) was investigated with a focus on the microstructure, the orientation-dependent mechani-cal property and the fatigue performance. This work involves a combination of mechan-ical experiments, computational analysis, and microstructure characterization to offer insights that can be utilized for designing additive manufacturing (AM) components, en-hancing AM processes, and ultimately assessing the structural integrity of AM products.
Comparative material testing and characterization of the SLM and the nickel-based alloy revealed a significant difference in both microstructural and mechanical properties. The columnar grain structure of the SLM alloy leads to the orientation-dependent mechanical property, which matches the Hall-Petch relation. The inhomogeneous microstructures and the slit-shaped lack-of-fusion (LoF) defects from the SLM process result in signifi-cantly lower fatigue properties and deteriorate the fatigue crack growth behavior.
The presence of process-induced defects in intricate geometries diminishes the fatigue life of AM components. By substituting micro-voids with distinct macroscopic artificial holes of diverse shapes, the Gurson-Tvergaard-Needleman (GTN) monotonic damage model was utilized to study the effects of geometrical configurations and matrix material properties. The determination of the equivalent crack length was based on the damage criterion. Through integration with the Paris law, the predicted fatigue lives of various holes subjected to different loading orientations fall within the double scatter band, demonstrating significantly enhanced accuracy compared with the conventional projec-tion method.

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Hybrid Structural Health Monitoring for Impact Damage in PLA Plates Using Lamb Waves and Electromechanical Impedance

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Introduction
The increasing adoption of additive manufacturing (AM) in structural applications necessitates advanced structural health monitoring (SHM) techniques to ensure reliability and detect damage. A significant challenge in AM structures, particularly polylactic acid (PLA) plates, is their susceptibility to impact-induced damage, which can degrade mechanical performance. Traditional damage detection methods often fail to capture subtle internal defects and variations in structural integrity caused by impact events.
To address this, the present study employs a hybrid SHM approach that integrates Lamb wave-based sensing (via Scanning Laser Doppler Vibrometer, SLDV) and electromechanical impedance (EMI) measurements to assess impact damage in PLA plates with varying infill densities (20% to 100%).

Methods
The experimental study involves PLA plates with varying infill densities, subjected to controlled impact loading using a steel ball dropped from different heights corresponding to low impact energies. The bonded piezoelectric (PZT) sensors excite and receive Lamb waves, and the SLDV captures wave propagation characteristics, detecting subtle wave distortions caused by impact-induced damage. Simultaneously, the EMI response of the PZT sensors is recorded before and after impact to analyze electrical quantities shifts, which correlate to the stiffness degradation.

Results
By leveraging the two complementary techniques, this study enables a high-resolution evaluation of impact-induced structural changes. Lamb wave signals reveal changes in wave velocity, attenuation, and dispersion, while EMI measurements provide insights into stiffness loss and impact severity through variations in the impedance spectrum. Lamb wave-based monitoring is highly sensitive to both localized damage and distributed stiffness variations. At the same time, EMI analysis provides a quantitative assessment of damage evolution through frequency shifts and impedance variations. The combined use of these methods allows for a multi-scale damage assessment, offering enhanced detection capabilities compared to single-method approaches.

Conclusions

This research highlights the effectiveness of combining Lamb wave sensing and EMI monitoring for detecting impact-induced damage in AM structures. The correlation between infill density, impact energy, and damage progression underscores the importance of optimizing AM fabrication parameters to enhance impact resistance. The findings will contribute to the advancement of SHM techniques for lightweight polymer structures and improve the design strategies of AM components in aerospace, automotive, and structural applications.

Acknowledgements

The authors acknowledge the funding support provided by the National Science Center, Poland under the OPUS project entitled: Health monitoring of AdDitively manufactured structurES (HADES) (2019/35/B/ST8/00691). The authors are also grateful to TASK-CI for allowing the use of their computational resources. The authors would like to thank Prof. Samir Mustapha for his contribution to the preparation of the investigated samples.

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On the Deformation and Energy Absorption Under Tension and Compression of an Auxetic Structure Made by SLA Resin

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Introduction

Auxetic structures offer innovative solutions in diverse engineering applications [3]. This work studies a 3D printed polymeric re-entrant auxetic structure exhibiting a negative Poisson ratio, focusing on its deformation under tensile and compressive loads and its energy absorption capability. Two versions, i.e. without and with filleted edges were tested in tension and compression by finite element simulation (FEA) as well as experimentally.

Methods

The specimens, measuring 54 X 54 X 10 mm were manufactured on an Anycubic X2 SLA machine, Fig.1a. The material is ‘tough resin’ from Anycubic, its main properties being: density: 1.1-1.15 gr/ccm, tensile modulus: 800-1200 MPa, tensile strength: 50-60 MPa, elongation at break: 30-50%, IZOD impact strength: > 50-60 J/m. Simulation of compression and tension tests was performed in the elastic region on Solidworks environment using h-adaptive meshing, Fig.1b-c

Physical testing was performed on an Instron 4482 machine. First, the simple structure was loaded in the elastic region to compare with simulation. Then, load was increased to reach collapse of the structures.

Results

Firstly, simulation results were very close to the physical testing results in the elastic region. Characteristically, the simple structure at 150 N simulated compression load is displaced vertically by 3 mm and horizontally by 0.918 mm absorbing 0.2303 J. In experimental testing horizontal displacement is 0.921 mm but energy is 0,2468 J.

Experimental testing up to the point of collapse (12 mm compressive displacement) revealed total energy absorption of 19.8J for the simple and 16.25J for the filleted specimens respectively. Conversely in tension, the absorbed energy to failure was 4.094 and 4.177 J respectively, Fig.2.

The simple structure in compression it exhibited a characteristic elastoplastic response absorbing energy mainly through the rotation of the cellular elements, while at a higher displacements a sharp increase in stress occurs, up to the maximum, followed by a nonlinear instability region where some cells undergo strong deformation or local collapse. In tension, it exhibited a negative Poisson’s ratio phenomenon with remarkable deformability up to a critical point where sudden fracture occurred at specific stress concentration areas.

In the filleted structure, a smoother transition of the specimen shape distributes the loads more uniformly avoiding peaks occuring in simple specimen. This resulted in reduction in local cracks and smoothness in the absorption of compressive loads. It followed progressive displacement withstanding a greater range of compression without sudden collapse. In tension, fillets worked beneficially in the gradual activation of the cellular elements and the progressive appearance of local damage, in contrast to the simple form.

Conclusion

The simple re-entrant structure offers lightness and increased impact resistance. The filleted variant showed that with simple changes in geometry the response of the structure is improved in terms of gradual failure and deformation capacity without sudden collapse. Further research will exploit simulation ion the non-linear region and topology optimization of the structure.

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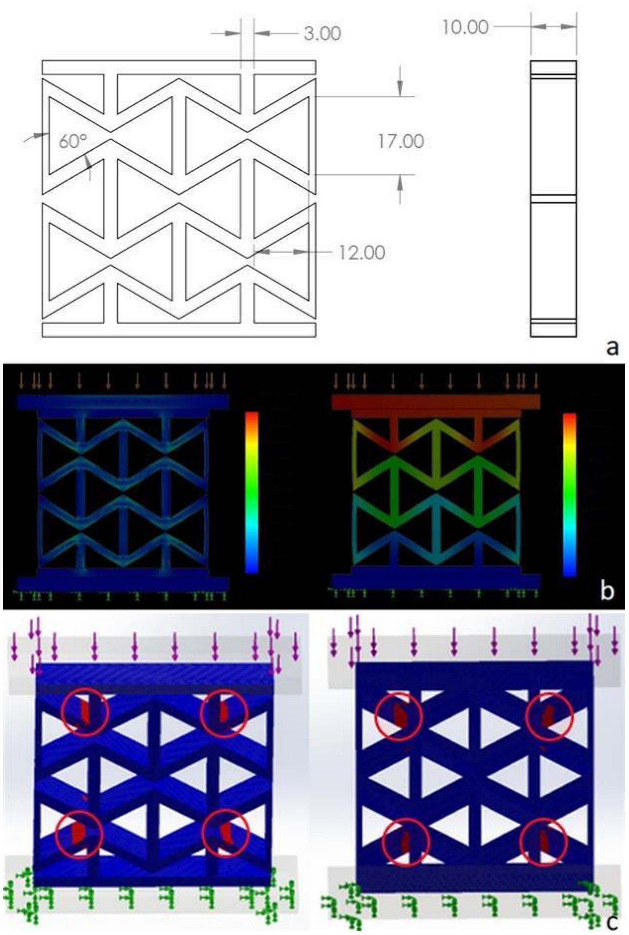

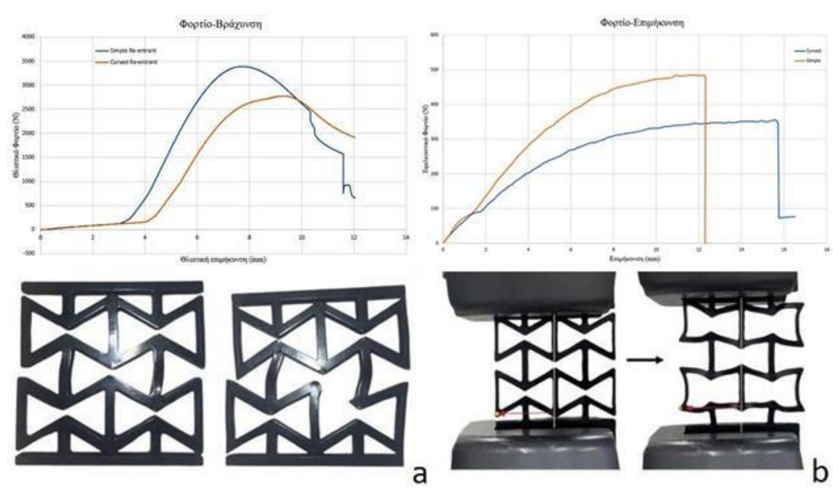

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LPBF-Processing and Multi-Technique Characterization of AlNiCo5 Hard Magnets

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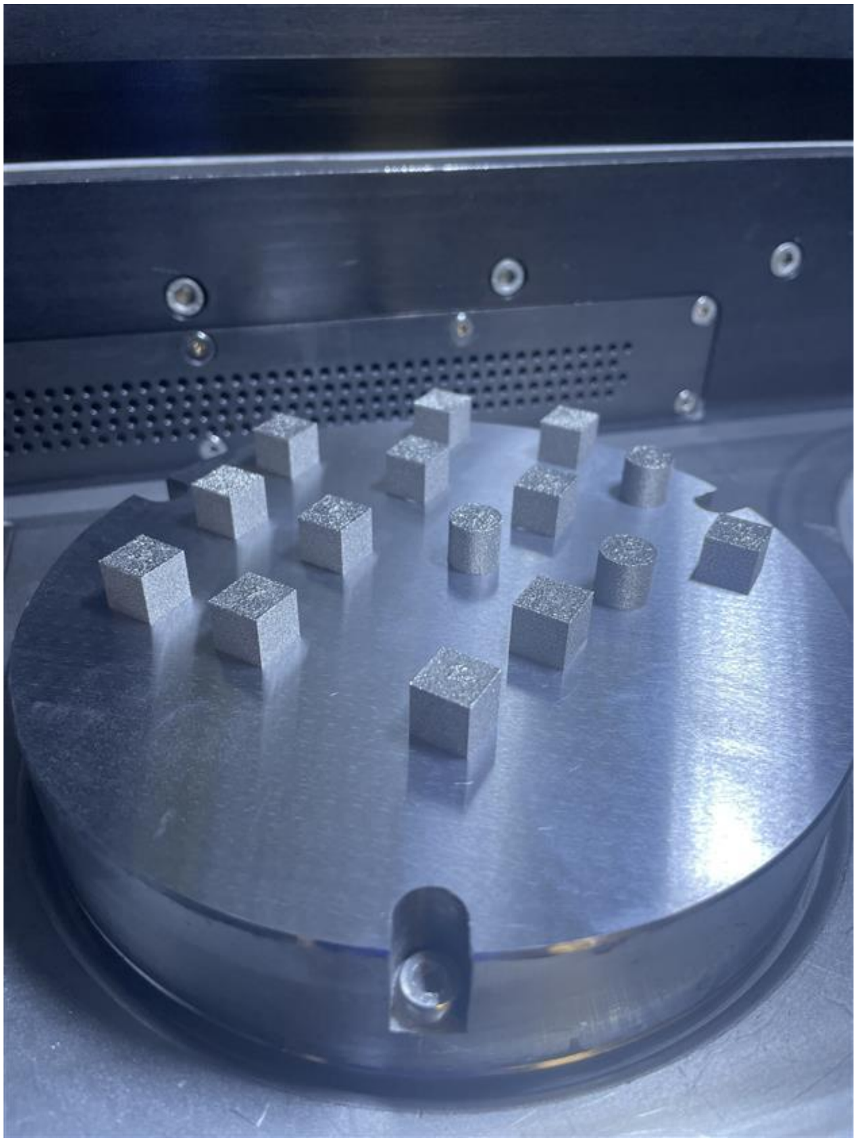
This study explores the laser powder bed fusion (LPBF) of Alnico5 hard magnetic alloy. Alnico 5 was produced using gas atomization to create fine spherical powders suitable for LPBF. The manufacturing process was optimized to investigate how varying parameters influence microstructural development and resultant magnetic properties. Post-process thermomagnetic heat treatments were conducted to tailor the magnetic performance, leading to the formation of a complex microstructure exhibiting refined grain/crystallite sizes and preferred orientations. Advanced characterization techniques including transmission electron microscopy (TEM), and electron backscatter diffraction (EBSD), revealed important insights into the spinodal microstructure, magnetic anisotropies, and magnetic domain behaviours within the material, demonstrating promising coercivity and remanence values The nanomechanical integrity and local plasticity was assessed with the use of Nanoindentation measurements and the magnetic properties were measured via PERMAGRAPH® . This work underlines the potential of LPBF as an innovative approach to fabricate high-performance Alnico magnets, paving the way for sustainable and cost-effective alternatives in diverse applications such as Anti-lock Breaking System (ABS), heat pumps, marine propulsion systems, and headlight range adjustment system.



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Sustainable Recycling of AlNiCo-5 Production Waste and End-of-Life Magnets Through Additive Manufacturing technologies for the Development of Bonded Magnets

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The repurposing of AlNiCo-5 waste from material production and end-of-life (EoL) magnets is explored by reintegrating them into thermoplastic matrices for 3D-printed bonded magnets. A comparative assessment is conducted to evaluate waste forms, product potential, and reduced reliance on rare-earth elements (REEs). Composite thermoplastic filaments were developed as feedstock for Additive Manufacturing (AM), specifically Fused Deposition Modeling (FDM) and Fused Granular Fabrication (FGF), with sustainability and performance considerations.
This study introduces a novel recycling method for AlNiCo-5, focusing on atomized powders (APs) (<20μm), unsuitable for Laser Powder Bed Fusion (LPBF), and crushed particles (CPs) from EoL magnets. Ethylene Vinyl Acetate (EVA), a low-melting-point polymer, aids energy-efficient debinding for sintered bonded magnets, while Polyamide (PA) ensures good mechanical performance for direct-use applications.
Two pre-mixing approaches were evaluated based on AP and CP content in polymer matrices. Compounding was performed via dual-screw extrusion, with in-situ AP alignment using a custom Halbach array to enhance particle distribution. SEM-EDS analysis assessed oxidation levels before and after processing, impacting magnetic properties.
Optimization of 3D printing parameters was conducted for selected compositions. Printed samples underwent mechanical testing, morphology evaluation, filler dispersion analysis, and thermoplastic compatibility assessment. A Life Cycle Assessment (LCA) was performed at each stage to determine the most sustainable recycling route.
This study demonstrates a viable approach for recycling AlNiCo-5 magnets through additive manufacturing technologies. The findings confirm that recycled magnets can be reintegrated into production while maintaining functional properties. This eco-friendly alternative reduces REE dependence and promotes sustainable material utilization.

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Flexural Strength Optimization of Flat-Oriented PLA Filament 3D Printing Parts Under Different Infill Patterns and Printing Conditions

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Fused filament fabrication (FFF) is a widely used material extrusion-based 3D printing process known for its cost-effectiveness, versatility, and ability to produce intricate components. However, the strength of interlayer bonding is significantly influenced by printing parameters, material characteristics, and the chosen printing paths. The present study employs an L9 orthogonal experimental design to investigate the impact of three distinct infill patterns under varying printing temperatures and speeds on the response of flexural strength. Flat-oriented poly(lactic acid) (PLA) specimens were subjected to 3-point bending tests to evaluate their flexural strength for 100% infill rates and 0.2 mm layer height. Besides the experimental investigation and the statistical analysis failure modes of the fractured samples were observed for correlating the independent printing parameters with the response of flexural strength. The results indicated that the infill pattern and printing speed had a significant impact on flexural strength. The optimal parameters were identified as the centroid infill pattern, a printing temperature of 205°C, and a printing speed of 25 mm/s.

Keywords: Fused filament fabrication (FFF), PLA, infill patterns, flexural strength, failure mode.

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Additive Manufacturing of Al-Fe Bimetals via Cold Spray Deposition

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The Aluminium-Iron (Al-Fe) bi-metal is a promising candidate for lightweight, high-performance applications where it combines the low density, high thermal conductivity, and good corrosion resistance of Al with the high strength and excellent wear resistance of the Fe. These bimetals can be fabricated using traditional thermal spray and powder metallurgy techniques. However, most of these techniques involve high-temperature processing, which promotes the formation of intermetallic phases, along with high porosity, microcracks, and thermal residual stresses. These factors contribute to brittleness, increasing the material's susceptibility to brittle fracture. To overcome these challenges, Cold Spray (CS) has emerged as an alternative technique due to its low-temperature, solid-state deposition process. In CS, small particles are accelerated to supersonic velocities using a high-pressure gas stream before impacting a substrate. The kinetic energy of the particles during impact causes plastic deformation and adhesion via solid-state bonding without melting, resulting in the deposition of materials with little interdiffusion, keeping their original compositions.

This study investigates the microstructural and mechanical properties of Al-Fe deposits produced via in-flight powder mixing during CS deposition, aiming to better understand the role of composition and processing parameters in tailoring the properties of the resulting bi-metals. Al and Fe materials were co-deposited onto the substrates using two independent powder feeders, enabling control over chemical composition. The samples were characterized in depth using various microstructural analysis methods as well as mechanical tests. The findings provide valuable insights into optimizing the composition, processing parameters, and mechanical performance of Al-Fe CS deposits, which could be tailored for specific applications where high strength along with the ductility are required.

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High-Temperature Tensile Behavior of Additively Manufactured 316L Stainless Steel Deformed by High-Pressure Torsion

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Additive manufacturing (AM) enables the production of metallic components with enhanced design freedom, reduced material waste, and improved mechanical properties. Among the widely used materials in AM, 316L stainless steel stands out as a versatile alloy employed in various industries, with an operating temperature of up to 600°C. Due to its practical significance, the additive manufacturing of 316L stainless steel via the powder bed fusion of metal with laser beam (PBF-LB/M) technique has been extensively studied in recent years. To ensure reliable performance at high temperatures, the tensile properties of PBF-LB/M 316L must be thoroughly investigated. Tensile testing of PBF-LB/M 316L stainless steel, as reported in [1], was conducted across a temperature range of 20°C to 700°C. The study revealed a significant reduction in both strength and ductility beyond 200°C due to a change in deformation mechanisms. At lower temperatures, the interaction between the PBF-LB/M-induced microstructure and deformation twins played a key role in enhancing mechanical performance. However, as the temperature increased, twinning was no longer observed, and deformation became predominantly governed by dislocation motion, leading to a decline in material strength and ductility.

In this study, 316L stainless steel rods were fabricated using the PBF-LB/M technique. Disk-shaped samples, approximately 11 mm thick, were then extracted from the rods and subjected to high-pressure torsion (HPT) for 10 rotations under the pressure of 5.15 GPa and rotational speed of 0.1 rpm. The HPT-deformed samples exhibited more than twice the hardness of the as-printed material. We investigated the tensile performance of both as-printed and HPT-deformed PBF-LB/M 316L at 20°C, 300°C, and 600°C. At 20°C, the HPT-deformed samples demonstrated approximately three times the ultimate tensile strength of the as-printed material, albeit with a significant reduction in ductility. At 300°C, the strength enhancement remained comparable, while the ductility loss was less severe. Remarkably, at 600°C, the HPT-deformed samples retained twice the strength of the as-printed PBF-LB/M 316L while exhibiting similar ductility. These findings, along with detailed microstructural and deformation analyses, will be presented and discussed at the meeting.

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Microstructural Evolution and Mechanical Properties of Cold Sprayed Copper-Graphene Composites

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Cold spray is a solid-state additive manufacturing technique that enables the deposition of metal powders through high-velocity impacts, resulting in coatings with distinctive microstructural characteristics. Unlike conventional thermal spray methods, cold spray operates at relatively low temperatures, which prevents significant oxidation, phase transformations, and thermal degradation of sensitive materials. The integration of two-dimensional (2D) materials, such as graphene, into metal matrices has attracted increasing attention for the development of 2D Metal Matrix Composites (2DMMCs), offering the possibility to tailor the mechanical and functional properties of metal-based materials.

This study investigates the microstructural evolution and mechanical properties of cold sprayed copper-graphene (1wt.%) composites in both as-sprayed and annealed conditions. Advanced characterization techniques, including electron backscatter diffraction (EBSD), are used to analyze grain evolution and strain distribution, while X-ray diffraction (XRD) is used to provide insights into phase composition, crystallinity, and residual stresses within the deposits. Furthermore, Raman spectroscopy is employed to investigate the structural defects and distribution of graphene in the copper matrix, as affected by the cold spray process and subsequent annealing. The effects of graphene incorporation on grain refinement, interface bonding, and dislocation behavior upon cold spray deposition are explored, as well as its influence on the overall mechanical properties of the deposits.

The results offer a detailed understanding of the microstructural and mechanical behavior of cold sprayed copper-graphene composites, highlighting their potential for a wide range of applications in industries requiring advanced materials with tailored properties. The findings also contribute to the optimization of processing parameters for the development of 2DMMCs in future manufacturing processes.

E10

A Review of the Roles of Biomimicry and Additive Manufacturing in Enhancing Solid-Solid Thermal Energy Storage With Shape Memory Alloys

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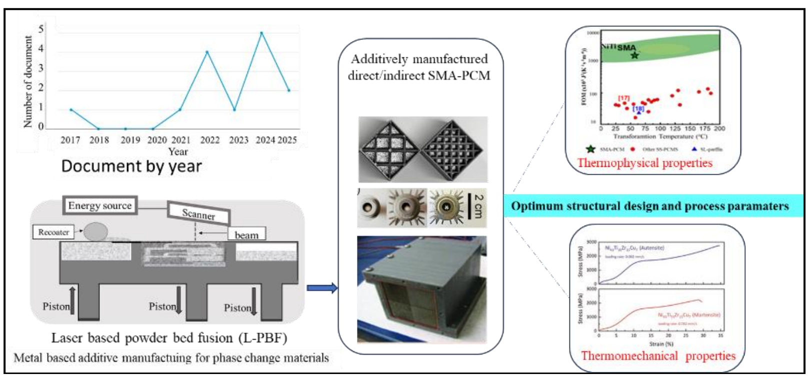
Additive manufacturing (AM) is defined by the ISO/ASTM 52900:2021 as a “process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies.” [1] AM, commonly known as 3D printing, has facilitated the manufacturing of complex commercial phase change materials (PCMs) confinement geometries that enhance heat transfer, energy storage and dissipation capacity. The integration of AM and design optimization has significantly advanced the development of PCM based thermal energy storage (TES) systems. Solid-solid TES are promising for high power, high capacity sustainable energy solutions, suitable for applications requiring faster transitions and high strength. This study explores existing innovative biomimicry inspiring geometries focusing on the application of structural design optimization and powder bed fusion (PBF) capable of improving structural design of TES devices for improved performance and efficiency. Data-driven product designing strategies such as implicit function (IF) modelling and parametric modelling optimization enable structural geometries suiting specific thermal energy functions and mechanical property criteria. The offered manufacturing flexibilities and engineering functioning improvements offered by AM are anticipated to yield direct manufacturing of alternative effective end-use high power and high energy PCMs, specifically, shape memory alloys (SMAs). SMAs are unique materials that can alter their properties and return to their original shape after being deformed when exposed to thermal or mechanical stimuli (e.g., ambient temperature changes, electric, and magnetic).
Th purpose of this review was to analyse if AM can be used to achieve end-use effective metal based SMA-PCMs. The motivation for selecting PBF of SMA-PCMs is the offered flexibility to compositionally and geometrically tailor TES devices mimicking biomimicry functions. The research question that guided this study is what impact does AM have on SMA-PCMs and what is the technological advancement level? This study used peer reviewed journals and conference articles relevant to metal based additively manufactures PCM-TES. The adoption of biomimetic designs and AM was emphasized as a promising approach for developing eco-friendly, metal based PCM-TES alternatives to commercially available solid-liquid PCMs. The review identified key trends and advancements, particularly additively manufactured triply periodic minimal surfaces (TPMS), strut-based lattices, and topology optimized TES devices [2,3]. Findings of the review highlighted the

potential to improve thermophysical and thermomechanical properties with SMA-TES devices [4–6]. Also SMA-TES were noticed to offer effective increase in storage capacity compared to conventional metals [7]. Findings also suggest that leveraging the advantages of AM, SMAs and biomimicry can drive more innovative and effective end-use solid-solid TES devices [2,7–9]. However, the technology is quite new with only four related studies (2020-2024) so far demonstrating this potentials with physical manufactured parts. The comprehensive analysis underscores the importance of continuing scholarly efforts to bridge knowledge gaps and physical values to be derived with alternative additively manufactured SMA-PCMs for solid-solid TES systems.

Keywords
Additive manufacturing, biomimicry, shape memory alloys, thermal energy storage, thermophysical properties, thermomechanical properties, phase change materials.

Graphical abstract



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Fatigue of Additively Manufactured 18Ni300 Maraging Steel

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Introduction
Design and analysis of additively manufactured load-carrying engineering components necessitate a comprehensive understanding of their mechanical behavior. The present work focuses on the thorough study of the fatigue behavior and determination of fatigue properties of additively manufactured 18Ni300 maraging steel. Such properties are essential for the fatigue-based design of engineering components in early stages of development.

Methods
Thin-walled flat material specimens of 18Ni300 maraging steel were manufactured using Selective Laser Melting (SLM) and underwent a specific thermal process involving annealing for 1 hour followed by air cooling and then ageing. Extensive monotonic and cyclic tests at a stress ratio R=0.1 were conducted to determine the fundamental monotonic and fatigue material properties.

Results
Investigations by means of optical microscopy reveal the effect of the applied thermal process on the material’s microstructure. Design S-N curves for various probabilities of survival of the 18Ni300 steel have been experimentally determined covering the whole area of technological interest, from the Low-Cycle-Fatigue until the so-called “engineering” endurance limit. Therefrom, fundamental elastoplastic material properties, such as the cyclic ductility coefficient and exponent, the fatigue coefficient factor and fatigue exponent have been accurately estimated.

Conclusions
This study provides valuable new insights into the fatigue behavior of additively manufactured 18Ni300 maraging steel as well as fundamental cyclic material data, addressing a significant gap in the current literature. Moreover, the results provide a set of experimentally verified properties that can be used by designers and researchers in many sectors of engineering component applications.

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Modeling Tensile Properties in Selective Laser Melting of 316L Stainless Steel Using Statistical Multi-Parameter Analysis and Artificial Neural Networks

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Selective laser melting (SLM) is an additive manufacturing technique that applies laser energy to powder beds in order to melt metals and to produce complex geometries. The mechanical properties of SLM fabricated parts are greatly influenced by the processing parameters like laser power and scan spacing and speed.
This study investigates the effect of laser power and laser speed on the deformation and fracture behavior of 316L stainless steel specimens produced by SLM. Tensile tests were conducted in order to evaluate a number of mechanical properties, namely yield stress (YS), ultimate tensile strength (UTS), maximum elongation (el, %) and modulus of elasticity (E). Experimental observations concerning with deformation characteristics and fracture were also monitored in order to analyze and categorize failure modes of the test specimens.
A multi-level factorial design followed by a response surface methodology was employed to generate 21 tests with reference to the experimental levels determined for laser power and laser speed SLM process parameters. The results obtained were analyzed using analysis of variance (ANOVA) with its corresponding statistical tests whilst quadratic regression models were developed to capture the relationships between process parameters and mechanical properties under examination. Main effects and contour plots were generated and examined for the same purpose. It is revealed that decreasing laser power enhanced YS, UTS, and E, while increasing laser speed led to a more brittle behavior with a reduced el (%).
Finally, a number of artificial neural network (ANN) models were studied in order to predict fracture outcomes, aiming to the optimization of SLM parameters for improved material performance in failure-critical applications.

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A Fatigue Life Calculation Procedure Implementing Surface and Depth-Graded Mechanical Properties

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Introduction

Accurate fatigue assessment is essential for ensuring safety, optimizing designs and reducing costs across various industrial sectors. However, conventional durability assessment methods currently used in industry often rely on extensive prototype testing, making the process both time-consuming and expensive. This study presents a straightforward, local stress-based fatigue theoretical calculation procedure aiming to accurately predict the lifetime of high-strength steel suspension components, such as leaf springs, which exhibit depth-graded mechanical properties. By avoiding the need for large-scale prototype testing, this approach enhances efficiency while maintaining reliability in fatigue life estimation.

Methods

The proposed fatigue calculation procedure utilizes measured surface roughness along with depth-graded mechanical properties, such as micro-hardness and residual stress profile. These measurements, obtained from monoleaf specimens subjected to heat treatment and stress shot peening, are implemented into the calculation following the FKM guideline, enabling a detailed investigation of fatigue behavior to determine the component's definitive performance under uniaxial fatigue. The fatigue life of the monoleaves under constant amplitude loading conditions is predicted at various stress levels and compared to experimental results. The model's accuracy is evaluated for specimens with and without stress shot peening, as well as for different loading ratios R, ensuring a comprehensive assessment of its reliability.

Results

The proposed fatigue calculation procedure describes sufficiently the fatigue behavior of the examined components under the considered loading conditions, particularly for the stress shot-peened monoleaves, demonstrating a strong agreement with the experimental results. The fundamental measured properties and surface condition of the material show a strong correlation with the overall fatigue performance of the component, enabling a reliable estimation of its fatigue behavior.

Conclusion

The proposed theoretical procedure calculates the fatigue life of high-strength steel suspension components considering depth-graded mechanical properties. By integrating basic mechanical and surface characteristics, it provides reliable estimates regarding fatigue life without need for any experimental data from the examined component. Therewith, it can be applied in very early stages of development, when prototype components are not available.

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Bending Behavior of the 95% and 99% Alumina Ceramics

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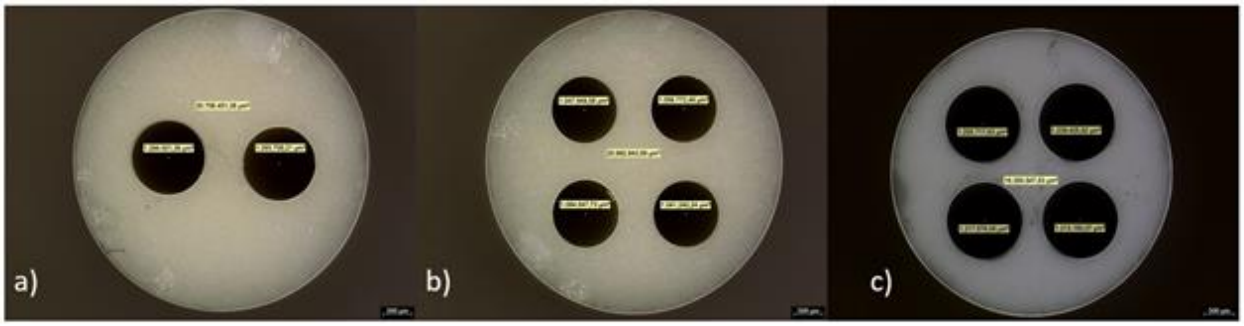
Alumina ceramics are an important branch of advanced mechanical engineering due to their remarkable properties, such as hardness, high-temperature resistance, and chemical stability. Ceramics are an inorganic, non-metallic material produced by sintering. This material, which combines clay, feldspar, and quartz, has various applications due to its durability and strength. Ceramics are not only a molding technique but also a form of art and science that offers unlimited possibilities for exploration and expression.
Ceramics hold considerable importance in society because of their unique properties and the variety of applications they offer. They are employed across the construction, electronics, chemical, and pharmaceutical industries.
The present paper aims to highlight the flexural strength of 95% and 99% Alumina Ceramics. The tests were conducted on tubes with either 2 or 4 holes in the cross-section, and bending tests were performed using both 3-point and 4-point bending methods, respectively.
The macroscopic analysis of the specimens was conducted using a Leica DM6M microscope. With exceptional precision, the automated DM6M microscope ensures accurate and reproducible data while minimizing the risk of errors. The microscope was used to determine the real area of the tested specimens (Fig. 1) in order to assess their bending strength.
It was observed that the bending strength of the 99% Alumina Ceramic specimens was approximately 35% higher compared to the 95% Alumina Ceramic specimens.



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Fatigue Behavior of Miniaturized L-PBF Ti6Al4V Strut-Junction Specimens: The Role of Node Filleting, its Design-Led Compensation, and the Influence of Build and Printing Orientation

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The fatigue resistance of architected cellular materials remains a key challenge in metal additive manufacturing (AM), particularly for lattice structures produced via Laser Powder Bed Fusion (L-PBF). These structures hold significant potential across various industrial fields, yet their widespread adoption is hindered by fatigue-sensitive geometric irregularities introduced during the manufacturing process. As-built lattice components often exhibit highly irregular surfaces characterized by partially molten adhered particles and parasitic mass accumulation, particularly on the lower skin of the specimens. These defects result from the complex interplay of printing orientation, build direction, and process-induced factors such as the recoater blade and gas flow direction, which influence local heat distribution and powder adherence.

Such surface irregularities lead to substantial geometric mismatches between the as-designed and as-built conditions, with the most pronounced deviations occurring at strut junctions. Here, excess material accumulation and deviations from nominal geometries create highly stressed regions that serve as critical sites for crack nucleation and propagation, ultimately compromising the structural integrity of the component. Consequently, ensuring the geometric fidelity of lattice junctions is a crucial factor in enhancing the fatigue life of these structures. One effective strategy to mitigate stress concentrations at junctions is the introduction of a fillet radius, a bio-inspired approach observed in natural load-bearing structures such as tree branches and plant stems. By smoothing junction transitions, filleting can enhance fatigue resistance by reducing peak stresses. However, in the context of AM—particularly at the sub-millimeter scale typical of lattice structures—geometric mismatches can negate the intended benefits of filleting.

To address this challenge, this study focuses on the validation of a design-led compensation framework capable of refining junction fillet geometries and systematically reducing geometric mismatches in L-PBF-fabricated specimens without requiring fine-tuning of process parameters. Following geometric compensation, an extensive fatigue testing campaign was conducted on miniaturized strut-junction Ti6Al4V L-PBF specimens both in their compensated and non-compensated states. The specimens were subjected to uniaxial cyclic loading at an R-ratio of -1 to evaluate fatigue life improvements across multiple build orientations, specifically at 90°, 45°, and 0° with respect to the job plate. Additionally, particular attention was given to the influence of job plate location, recoater interaction, and gas flow direction. The impact of the

printing position on the planar XY surface of the job plate on both the geometric and mechanical performance of the specimens was assessed through statistical analyses and post-mortem surface fractography. The efficacy of the proposed design-led compensation models is then assessed, providing insights into its potential for improving fatigue performance.

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Additive Manufacturing-Based Joining of 316L Stainless Steel and Polylactic Acid: Fabrication and Mechanical Validation Under Static and Dynamic Loads

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As multi-material additive manufacturing advances, the integration of dissimilar materials has become increasingly significant in both technological and industrial applications. This study explores the adhesive-free joining of materials fabricated using distinct additive manufacturing techniques, focusing on the combination of 316L stainless steel, produced via Laser Powder Bed Fusion (LPBF), and polylactic acid (PLA), manufactured using Fused Filament Fabrication (FFF). The research emphasizes the design of specific interface geometries and the optimization of manufacturing parameters to achieve a robust mechanical bond. The primary challenge in this material pairing arises from the disparities in melting points, thermal expansion coefficients, and shrinkage behaviors. A critical aspect of the study is ensuring proper filling of the interface geometries and mitigating shrinkage-induced stresses during the polymer's solidification. To address these issues, various interface geometries are proposed, incorporating differing cavity shapes and surface roughness characteristics to enhance mechanical interlocking and adhesion. The study evaluates the mechanical performance of the joints through experimental tensile testing under both static and dynamic loading conditions. Tensile test specimens are designed with a bi-material configuration, where half of the sample consists of 316L stainless steel and the other half of PLA, joined along their length.

Additionally, finite element analysis (FEA) is conducted, developing a multi-physics thermomechanical transient model to assess the evolution of thermal stresses at the 316L–PLA interface and their influence on principal stress distribution under tensile loads. By carefully controlling the heating of the metallic component, optimizing cavity geometries and surface roughness, and employing effective polymer filling techniques, this study demonstrates the feasibility of achieving strong and durable metal-polymer joints solely through additive manufacturing, without the use of adhesives. The findings highlight a promising approach for multi-material fabrication, offering potential applications in lightweight structures, biomedical devices, and hybrid manufacturing systems.

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The Effect of Cross-Contaminations of ASI10MG to CUCR1ZR Feedstock During Multi-Material Laser Powder Bed Fusion

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Multi-material laser powder bed fusion (MMLPBF) is emerging as a key technology to meet the increas-ing demand for high-precision manufacturing of metallic components with lower lead times and enhanced sustainability. However, one of the main challenges limiting its widespread adoption is the metal powder cross-contamination and its effects on the components' structural integrity. This issue is particularly criti-cal in the automotive sector, where additive manufacturing of bi-metallic structures - such as printing aluminum alloys onto copper alloys and vice versa - is of great interest. The present study includes a pre-liminary investigation to assess the effect of cross-contaminations of the powder feedstock on the effect of AlSi10Mg foreign particles in CuCr1Zr feedstock.

Several powder contamination grades ranging from 0.5 to 5.0 wt. % are processed and compared with uncontaminated powder feedstock with respect to tensile mechanical properties and microstructural char-acteristics. The results revealed that MMLPBF samples exhibited distinct microstructures and mechanical properties depending on the level of foreign particle contamination [1]. The differences in the mechanical properties, were quantified and reported in terms of foreign particles concentration. Additionally, the changes in microstructure analysed by SEM microscopy and characterized in terms of foreign particles concentration. The tensile mechanical properties were used for the calculation of the "quality" of printed samples with different levels of cross-contamination. The damage tolerance quality index QD was exploit-ed from the casting industry of aluminium alloys [2] to assess the printing quality of the MMLPBF sam-ples. The quality index comprises of both, strength and ductility capabilities of the samples and it was as-sociated with the investigated contamination levels. Diagrams of quality level [3] along with the desired mechanical properties were plotted and discussion over the contamination levels and appropriate quality is performed.

Keywords: laser powder bed fusion; multi-material solutions; powder quality; contamination

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Laser Powder Bed Fusion of 316L Stainless Steel and Metal Matrix Composite Development through Ball Milling of Reinforced Feedstocks

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Austenitic stainless steel 316L is one of the most widely processed alloys in laser powder bed fusion (LPBF) due to its excellent weldability, corrosion resistance, and mechanical performance. In parallel, metal matrix composites (MMCs) fabricated via LPBF have gained increasing interest, particularly through the incorporation of oxide or ceramic reinforcements that can enhance strength and stiffness. However, challenges remain in optimizing process parameters to achieve dense, defect-free microstructures and in selecting suitable reinforcement systems that improve performance without compromising ductility or processability.

A full-factorial design of experiments (DOE) was conducted to investigate the effects of laser power, scan speed, hatch spacing, and layer thickness on the densification and anisotropy of LPBF-fabricated 316L. Statistical analysis revealed significant two-way interaction effects among the primary parameters, especially when considering layer thickness and scan strategy. Densities exceeding 95% were achieved above a VED threshold of ~100 J/mm^3, while lower angle scan rotations between layers (e.g., 45°) reduced crystallographic texture anisotropy and suppressed porosity. Grain morphology and orientation were analyzed via SEM and EBSD, revealing the formation of hierarchical microstructures composed of columnar grains, melt pool boundaries, and sub-grain cellular features. Vickers microhardness values plateaued near 233 HV, and anisotropy in mechanical response across orthogonal planes was attributed to residual stresses and orientation-dependent deformation mechanisms.

Once the processing window for unreinforced 316L was established, high-energy ball milling was explored as a feedstock modification strategy to develop 316L-based MMCs with nanoscale reinforcements. Systems investigated included additions of 2 wt.% SiO_2, Al_2O_3, and SiC. Oxide reinforcements (SiO_2 and Al_2O_3) were successfully distributed via milling and retained during LPBF, as confirmed by TEM and EDS. However, their incorporation did not lead to significant improvements in hardness or strength compared to unreinforced 316L, and no observable grain refinement was achieved. In contrast, SiC-reinforced samples exhibited a clear increase in yield strength and ultimate tensile strength relative to both cast and additively manufactured 316L. These gains were accompanied by a reduction in ductility, consistent with the formation of brittle phases and interface-induced embrittlement typical in ceramic-reinforced MMCs.

These results highlight the need for precise control over powder processing, reinforcement selection, and laser-material interaction in LPBF-based MMC fabrication. Ball milling offers a promising route for developing reinforced powders with tailored dispersion, but the final properties are highly dependent on reinforcement type, morphology, and interfacial behavior during melting and solidification. Ongoing work aims to optimize the balance between strength and ductility through refined processing, post-treatment, and hybrid reinforcement strategies.

Advanced Materials

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Optimizing Sol-Gel Hybrid Coatings for Corrosion Protection of Al AA2024-T3 Specimens

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Corrosion, commonly associated with ferrous materials, also affects aluminum alloys. Given the degradation that corrosion can inflict on aluminum structures, this study focuses on optimizing nanostructured Sol-Gel Silica-Zirconia coatings to mitigate the transition of the phenomenon to the substrate.
Using aluminum AA2024-T3 rod specimens (3.5mm thickness) as substrates, coatings were synthesized via a Sol-Gel technique, employing tetraethylorthosilicate, 3-Glycidoxypropyltrimethoxysilane, tetra-n-propoxyzirconium and ethyl acetoacetate as precursors. The coatings, comprised of a silicon matrix with dispersed ZrO2 particles, and were applied on the substrate using dip-coating, while various temperatures were evaluated during their annealing, to stabilize the coatings. Surface roughness of the aluminum samples was evaluated before and after coating, alongside micro-hardness measurements. Surface morphology, coating thickness, and Electrochemical Impedance Spectroscopy measurements (conducted in a 3.5% NaCl solution to simulate a marine environment) were assessed via Scanning Electron Microscopy, highlighting the utility of these type of coatings for anticorrosive protection of aluminum.
Keywords: Nanostructured coatings; Silica; Zirconia, Physicochemical characterization

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Profile Cracking Prediction for 6000 Series High Strength and Toughness Aluminum Alloy During Hot Extrusion

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The 6000 series high-strength and tough aluminum alloy is utilized extensively in products for weight reduction, primarily in the transportation sector. However, these alloys have high deformation resistance and are susceptible to surface defects, known as profile cracking. Profile cracking typically occurs at high temperatures and high ram speeds, adversely affecting productivity. In this study, a revised profile cracking criterion has been adopted to explain the profile cracking that occurs during extrusion. A finite element method (FEM) coupled with the profile cracking criterion is used to predict profile cracking during hot extrusion. A modified extrusion die structure is proposed and found to be effective in reducing flow resistance, decreasing profile cracking sensitivity, and increasing the productivity of the WHS-2 alloy.

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Design of Novel High Strength, High Electrical Conductivity and High Thermostability Twitch Aluminum Alloys

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Recycling aluminum alloys presents the best practice to reduce the carbon footprint of automotive aluminum products since the energy consumption required for the recycling process is relatively lower to the primary manufacturing from raw materials. Vehicles that have reached the end-of their-life can be recycled via shredding and sorting, providing a major source for Al recycling, the fragmentized aluminum derived from this process is referred to as "twitch". This aluminum scrap is generally contaminated with significant levels of Si and Fe impurities and the cost of the recycling techniques that have been developed for the refinement and purification of the aluminum scrap is significantly high. In parallel, the U.S. electricity delivery system undergoes changes to improve its reliability and resilience to extreme weather conditions. The design of a novel thermostable aluminum-based cable conductor for overhead transmission lines utilizing high volumes of aluminum twitch is a promising solution and a cost competitive way to recyclability. The present study employs CALPHAD-based ICME tools for the design of an aluminum cable conductor with high strength, high electrical conductivity, and high thermostability utilizing aluminum twitch via melt-spinning and high temperature aging. The material design is based on a hierarchical system approach integrating the interrelation of processing, structure, properties, and performance. Thermodynamic calculations using CALPHAD databases are performed, aided by high-throughput DFT databases to design novel intermetallic compounds supporting new classes of aluminum alloys compatible with twitch. The main design objectives are to maximize the electrical conductivity through complete gettering of the impurity elements and maximize the precipitation strengthening through the formation of Q phase and the elimination of Si phase. Based on a parametric design, two compositions that meet the requirements were selected and aluminum specimens that utilize twitch were prepared via rapid solidification. Electrical resistivity measurements, using a 4-point probe method, and microhardness measurements were carried out at room temperature, while the microstructure of the specimens was characterized via STEM and APT analyses. The experimental data suggest that thermodynamic equilibrium values have not been reached yet, and a two-step aging process should be considered to accelerate the precipitation kinetics during aging.

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Study on the Correlation Between Microstructure and Cross-Scale Stress in TIG Welding of 7A52 Aluminum Alloy

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7A52 aluminum alloy is widely used in aerospace, transportation, military armor and other lightweight fields. However, the microstructure of welded joints in conventional melt-cast 7A52 (CM 7A52) aluminum alloys is extremely inhomogeneous, such as the second phase and dislocation caused by the local distortion produced by the microscopic stress will affect the uniform distribution of macroscopic residual stress and accurate determination. The main objective of this study is to investigate the relationship between microstructure with macroscopic residual stresses (Type I stresses), inter-granular stresses (Type II stresses), and intra-granular stresses (Type III stresses) by comparing the in-situ generation of nano Al_2O_3 powder metallurgy 7A52 (PM 7A52) aluminum alloy with the CM7A52 of TIG welding organization. The microstructure, inter-granular stresses and intra-granular stresses were analyzed by HR-TEM and HR-EBSD, while macrotexture and internal macroscopic residual stresses were characterized with a self-developed short wavelength characteristic X-ray diffraction (SWXRD) technique. The results indicated that the grain refinement in the weld zone (WZ), heat affected zone (HAZ) and base metal (BM) after welding existed to different degrees. The texture strength of the PM 7A52 aluminum alloy was effectively reduced by 36% in the WZ. Moreover, the macroscopic residual stresses in the WZ of PM 7A52 was reduced by 22% compared to CM 7A52 aluminum alloy. The differences in macroscopic residual stresses were mainly attributed to grain size and texture strength. Notably, the inter-granular stresses and intra-granular stresses of PM 7A52 were also lower than that of CM 7A52 in WZ. The inter-granular stresses and intra-granular stresses were mainly related to the grain boundary angle, the size and distribution of precipitated phases, and the dislocation distribution. The inter-granular stresses and intra-granular stresses in the WZ were generally greater than the macroscopic residual stresses, due to the fact that the microscopic stress were balanced against each other.

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Influence of Artificial Ageing on Fatigue Crack Growth Behavior of Al-Cu-Li AA2198

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Over the past decade, third generation Al-Cu-Li alloys have been extensively used in aerospace and aircraft applications due to their superior specific strength, reduced weight, excellent corrosion resistance and damage tolerance, particularly in terms of fatigue crack growth behavior and fracture resistance [1,2]. Since aircraft structures are usually exposed to cyclic mechanical loads throughout the course of their service life, superior damage tolerance properties are essential and for that purpose, processes are pursued that enhance fracture resistance [3]. The current study examines the fatigue crack propagation (FCP) characteristics of 3rd generation Al-Cu-Li alloy 2198 under different artificial ageing conditions. The artificial ageing performed aims also at simulating the alloy's natural aging process occurring under long term operation.
The material utilized was a wrought aluminum alloy 2198-T3 which was supplied in sheet form with a nominal thickness of 3.2 mm. C(T) specimens were used for fatigue crack growth tests in accordance with ASTM E647 requirements. In order to simulate various aging tempers corresponding to under-ageing (UA), peak-ageing (PA), and over-ageing (OA), the specimens were subjected to artificial ageing heat-treatment for varying ageing times. The experimental results (Figure 1) showed that at low ΔK levels, FCP rates were lower in T3 temper, however, at medium to high ΔK values, the UA condition was more damage tolerant because of the increased volume percentage of precipitates and the mechanism that promotes crack propagation by bypassing precipitates. The PA condition, on the other hand, was associated with greater FCP rates and precipitate shearing along the crack path.

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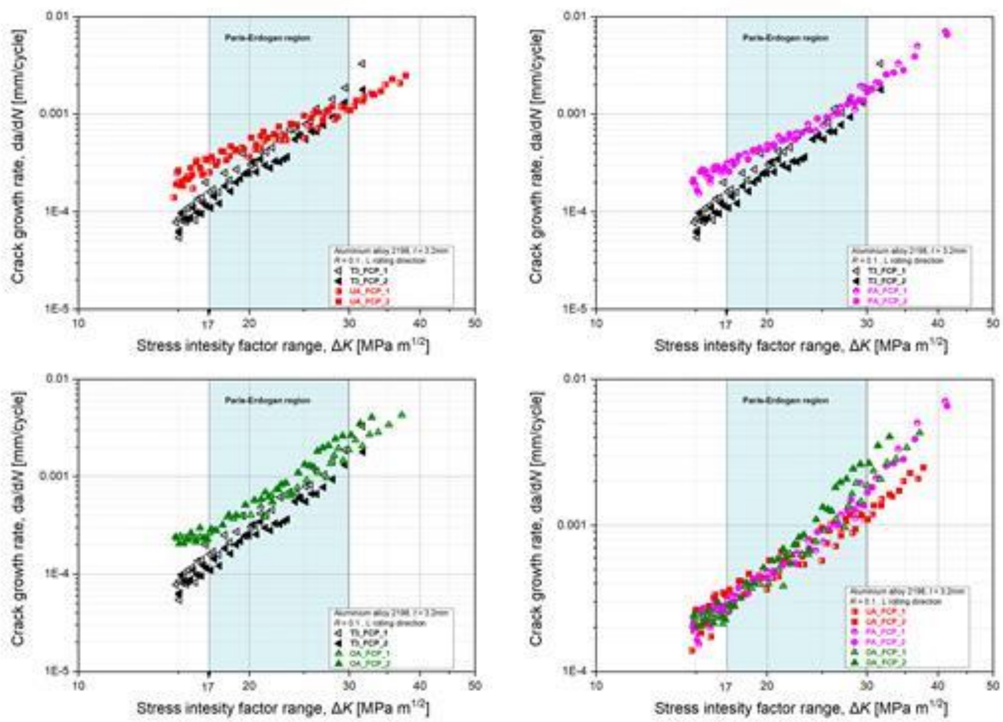
Acknowledgements. The work has been financed by the Hellenic Foundation for Research and Innovation H.F.R.I.-Project ID 03385 Acronym CorLi “Corrosion susceptibility, degradation and protection of advanced Al-Li aluminum alloys”.



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Analysis of Surface Layer Zone Properties With the Aid of Finite Element Simulation of Chip Formation in Machining

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Machining of metals is essential for generating appropriate surface conditions and integrity on designated parts' interfaces. The prediction of the cutting forces in the context of optimally adjusting the process as well as its outcome plays a pivotal role. This study applies Finite Element Analysis of the chip formation in orthogonal cutting of AA6061-T6 aluminium alloy. With the aid of a two-dimensional explicit dynamic model, it sheds light on critical machining parameters and their influence including cutting forces, temperature distribution, strain rates and chip morphology.
The Lagrangian formulation was employed to accurately capture material deformation, while the Johnson-Cook constitutive and damage models were utilised to simulate plasticity and failure mechanisms. Various cutting conditions, including tool rake angle, tool edge radius, cutting speed, and depth of cut, were systematically examined to evaluate their effects on chip formation and cutting efficiency. The numerical results demonstrated strong correlation with analytical models, particularly in predicting shear angle and chip segmentation. The findings contribute to optimising machining with complex kinematics, improving precision and efficiency in industrial applications.

E02

Dissimilar FSW Lap Joints of Al-Cu-Li alloys: Insights Into Microstructural Evolution and Mechanical Performance

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The current study investigates the microstructural evolution and mechanical properties of friction stir-welded (FSW) lap joints made from 3rd generation Al-Cu-Li alloys as candidates for the manufacturing of lightweight fuselage structures in the aeronautic industry. The top plate is an AA-2099-T83 extrusion, a 2 mm-thick aircraft stringer, while the bottom plate is AA-2060, a 2.45 mm-thick aircraft skin. The objective is to create robust welds with sufficient penetration depth and minimal defects, ensuring that the welds produced meet the stringent demands of aerospace applications, particularly in lightweight aircraft fuselage construction.

The FSW experiments were designed using the Taguchi method, which provided selected matrix parameters, including vertical applied force, stirring tool rotational speed, and travel speed. Experiments were carried out using a modified milling machine as the FSW setup. A load cell was integrated to measure and assist in controlling the applied force during welding, ensuring precision and repeatability. The rotating head of the stirring tool is made of H-13 tool steel and consists of a specially designed pin with a spiral shape and a shoulder. Several combinations of experimental conditions were studied to define the optimum penetration depth along with accepted weld characteristics free of defects.

The microstructural evolution during welding was studied using advanced characterization techniques, including Optical Microscopy, SEM/EBSD, microhardness measurements, Tensile and CTOD tests. The precipitates inside the different zones of the welds were identified and correlated with the microhardness profile and the tensile strength of the joints. Moreover best experimental conditions were identified based on the penetration depth achieved during the experiments, the microstructural characteristics and the mechanical properties (Tensile, CTOD) of the welds.

In summary, this research highlights the feasibility of FSW for aerospace applications, confirming that aluminum stringers and fuselage components can be welded rather than riveted while meeting industry requirements. The findings provide insights for minimizing defects, enhancing weld performance, and improving mechanical properties, thereby supporting the broader adoption of FSW technology in aeronautics.

E14

Research on the Parameters Processing on the Structural Integrity of Aluminium-Graphene Composites

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The present paper constitutes a dedicated investigation into the prospect of utilising aluminium-graphene composites for overhead conductors deployment in overhead power lines. The employment of graphene or alternative allotropes of carbon is advantageous due to their elevated electrical conductivity, substantial mechanical strength, and elevated melting temperature. These properties can positively influence the characteristics of the composite, thereby enhancing its resistance to operational conditions, particularly prolonged exposure to temperature, a parameter closely associated with the current carrying capacity of the cables. However, it is important to acknowledge the limitations in synthesising graphene and aluminium, including the minimal solubility of carbon in aluminium, and the lack of wettability of carbon and aluminium.

This paper presents the results of research on the production of a composite based on aluminium powder and graphene, as well as the identification of structural integrity of composite with different graphene content 0.1-0.5 wt.%. The study identified that the method of mixing and compaction of the aluminium and graphene mixture has the paramount influence on the structural integrity, which consequently decides to achieve high electrical conductivity and strength of Al-C composites.

Structural studies were performed on the fracture obtained during the uniaxial tensile testing of aluminium-graphene rods with varying carbon material content. The observations made during this process allowed for the identification of the presence of graphene in the composite. This was found to be in the form of agglomerates of loosely arranged carbon layers that were unconnected to the aluminium matrix. The images obtained clearly demonstrated the absence of a permanent connection between graphene and the aluminium matrix, as evidenced by the numerous fractures observed in the composite's cross-sections. The number of these fractures increased in proportion to the increase in the carbon material content within the composite.

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Estimation of Fatigue Life After Prior Corrosion Using a Murakami-Based Approach in a Simulated Recycled 6082 Al-Alloy

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The current focus in using recycled Al-alloys in engineering components brings new challenges like deterioration of fatigue and corrosion properties on account of the presence of high content of trace elements like Fe, Cu and Zn. The synergistic influence of both fatigue and corrosion damage, which is often experienced by engineering components, is evaluated in the present study by carrying out high cycle fatigue (HCF) tests after prior accelerated intergranular corrosion, ranging from 1-24 h, in as-extruded condition. An attempt towards fatigue life improvement by surface treatment is made by conducting HCF tests after sandblasting, on both pre- and post-corroded specimens. Finally, the Murakami method -which is widely used for prediction of fatigue strength based on defects and inclusions- is employed for estimating remaining useful fatigue life with prior corrosion damage.

Characterization of prior corrosion for different durations shows that corrosion damage is manifested as pits or intergranular cracks especially in the smaller recrystallized grains in the surface. The “maximum corrosion depth” shows an increasing trend for (mostly) all corrosion durations, for as-extruded as well as sandblasted condition. On the contrary, fatigue life is found to reduce with consecutive levels of increasing corrosion duration, but the reduction is significant only at shorter corrosion durations. This depicts an inverse relationship between fatigue life and corrosion depth, indicating the possibility of a critical corrosion depth beyond which corrosion attack does not affect the fatigue life significantly. Sandblasting is found to significantly improve the fatigue life compared to the as-extruded in uncorroded condition, while such improvement is only minor in corroded conditions. A methodology for prediction of remaining useful fatigue life is then employed by approximating the corroded regions as defects as per Murakami’s approach. The experimental fatigue life is found to reduce in accordance with the increase in defect size (corrosion damage), with predicted fatigue limit (employing Murakami’s approach) showing a similar trend. The reduction in (predicted) fatigue limit with respect to the uncorroded specimen is found to be at most 20% when the maximum corrosion depth extends up to the entire recrystallized layer. This points out that tailoring the recrystallised layer could be a possible way to mitigate the corrosion damage and its subsequent effect on fatigue properties, especially since corrosion damage is manifested primarily at the recrystallised layer at the surface. On the other hand, in sandblasted condition, the experimental fatigue life shows a poor correlation with defect size (corrosion damage). Moreover, inspite of having a larger defect size compared to the as-extruded condition, the fatigue life in sandblasted condition is found to be slightly higher compared to the as-extruded condition. This indicates that fatigue life in sandblasted condition is not entirely dependent on the

corrosion-induced defects. This is attributed to the generation of compressive residual stress under sandblasting which has a beneficial impact on fatigue life. Such positive impact is offset to a great extent by pre-corrosion, but not fully which results in slightly better fatigue life in sandblasted condition compared to the as-extruded despite larger defect size.

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Influence of Trace Elements on Mean-Stress Sensitivity in a Simulated Recycled 6082 Al-Alloy

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The need for using recycled aluminum in manufacturing sector is increasing by the day, driven by the high energy consumption and emissions associated with the primary production. Since fatigue is a key design consideration for load-bearing engineering components, assessing the fatigue behavior of recycled aluminum alloys is crucial for their suitability in such applications. One of the key challenges in using recycled aluminum is the presence of trace elements, which can potentially degrade its fatigue performance. To address this, the present study investigates the impact of these trace elements viz. Fe, Cu and Zn on the high-cycle fatigue (HCF) properties of a simulated recycled 6082 aluminum alloys, on three different variants GA1, GA2 and GA3 (designed as a function of increasing amount of trace elements). The fatigue loading experienced by the components normally comprises of varying mean stresses which makes understanding of the mean stress sensitivity (defined as the reduction in fatigue life with respect to increase in R) important from the viewpoint of fatigue design. Accordingly, fatigue tests were carried out at three different R-ratios viz. -1. 0.1 and 0.4, at two different specimen orientation -transverse and longitudinal- with respect to the extrusion direction.
The variant with the highest level of trace element viz. GA3 is found to show poorer fatigue properties compared to GA1, at all R-ratios. Detailed microstructural characterization through electron back-scattered diffraction revealed a higher Scmidt factor in the recrystallized grains -where fatigue crack initiation occurs- in GA3 compared to GA1, indicating a higher cross-slip tendency in the former case. Moreover, surface roughness characterization by confocal microscopy indicated a higher surface roughness marked by the presence of deeper die-lines -which are specific surface features that develop during the extrusion process- in GA3 compared to GA1, indicating a higher notch effect in the former case. Although the above arguments explain poorer fatigue properties in GA3, the mean-stress sensitivity is found to be similar between GA1 and GA3. This indicates that the way the intrinsic factors like surface roughness, slip character governs fatigue damage for a particular alloy variant does not change with change in R. The fatigue properties are found to be better in the specimens oriented in the longitudinal direction compared to that in transverse direction (for the alloy variant GA3), with higher mean-stress sensitivity in the former case. This indicates that the influence of change in mean stress on fatigue life, is more in longitudinal direction compared to transverse. To explain this phenomenon, the relative role played by the intrinsic factors viz. (a) difference in surface roughness marked by relative orientation of die-lines (b) difference in slip character (evidenced from Scmidt factor distribution) and (c) difference in grain-size along with extrinsic factors like change in mean stress, is utilized. The test data is utilized further to generate constant life Haigh diagrams between different specimen orientations, which showed lower allowable stresses, in longitudinal direction compared to the transverse.

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Effects of Sr on Microstructure and Properties of 5182 Aluminium Alloy With High Fe Content for ABS Applications

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The effects of Sr addition on the microstructure, mechanical properties and corrosion resistance of 5182 aluminium alloy with high Fe content for automotive body sheet had been studied by optical microscopy, scanning electron microscopy, transmission electron microscopy, tensile test and intergranular corrosion test. A large amount of fish-bone like Fe-rich phases and Mg_2Si phases in the shape of Chinese-characters were observed in as-cast 5182 aluminium alloy with high Fe content. With Sr micro-element addition, the grain size of the as-cast state was reduced by half compared to the condition without Sr. Fe-rich phases of elongated needle and granular form distributed in grain boundary. The percentage of Fe-rich phase area remained basically unchanged, but the equivalent diameter was found to be decreased significantly. The Fe-rich phases were further broken to small size during subsequent hot and cold rolling processes. It was observed that the finer dispersed Fe-rich phases had a small detrimental effect on the ductility of 5182-Sr alloy with O temper. The elongation of about 25% for 5182-Sr alloy with high Fe content can be obtained, which is higher performance than 20% of 5182 without Sr alloy. The weight lost can be achieved to the lower value of 2.0 mg/cm^2, due to much finer Fe-rich particles compared to that of 5182 without Sr alloy.

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Microstructure Modification Strategies for High Fe Containing Recyclable Al-Si Cast Alloy

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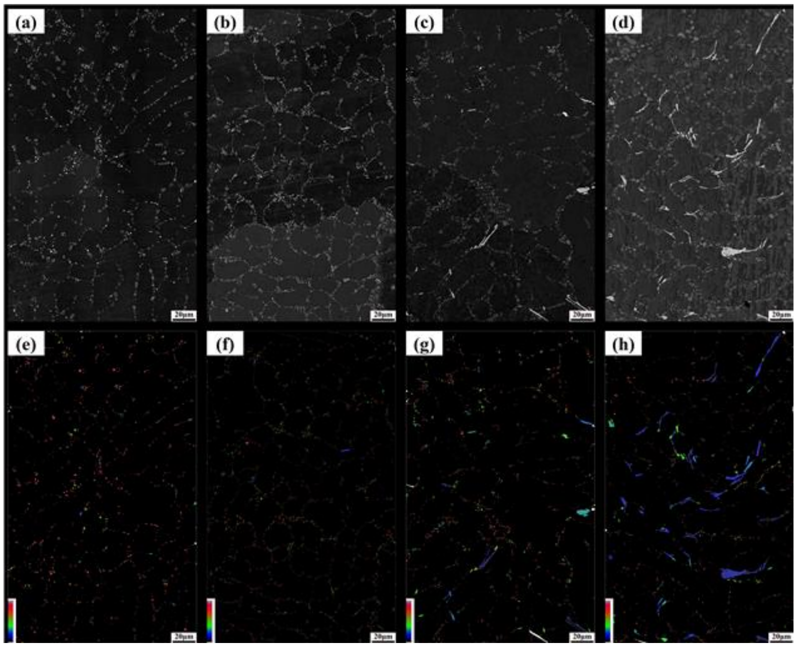
Aluminum is an infinitely recyclable material, and the high global recycling rate underlines the economic and environmental value of scrap aluminum. However, due to the presence of the iron containing intermetallic compound beta -Al9Fe2Si2 phase, high iron impurity affects the castability and mechanical properties of the recycled Al-Si alloy. Therefore, the challenge is to modify iron impurities to maintain a more harmless morphology of the FIMC (Fe Intermetallic Compound). In this work, the microstructure modification strategy for high Fe containing recyclable Al-Si cast alloy is focused. The effects of cooling rates and Fe content on the solidification microstructure of Al-Si-Mg alloy were investigated through directional solidification technology, with a focus on FIMCs. A large number of microstructural images and mechanical properties have been obtained using OM, FESEM, HRTEM and universal tensile testing. The results revealed that increasing cooling rates induced a morphological evolution of FIMCs from elongated skeletal structures to blocky forms and finally to fine equiaxed particles, accompanied by a more homogeneous dispersion. A critical Mn/Fe ratio threshold was identified to govern FIMC modification, which exhibited a strong dependence on solidification rate. Below critical values of 0.22, 0.33, and 0.34 at cooling rates of 1K/s, 5K/s, and 20K/s, respectively, FIMCs exhibited significant coarsening and morphological deterioration. Additionally, the morphological and distributional evolution of micro-nano precipitates under various heat treatment strategies was systematically analysed to optimize the alloy’s fatigue performance. These findings establish quantitative process-microstructure relationships critical for enhancing the recyclability and mechanical properties of high-iron Al-Si alloys.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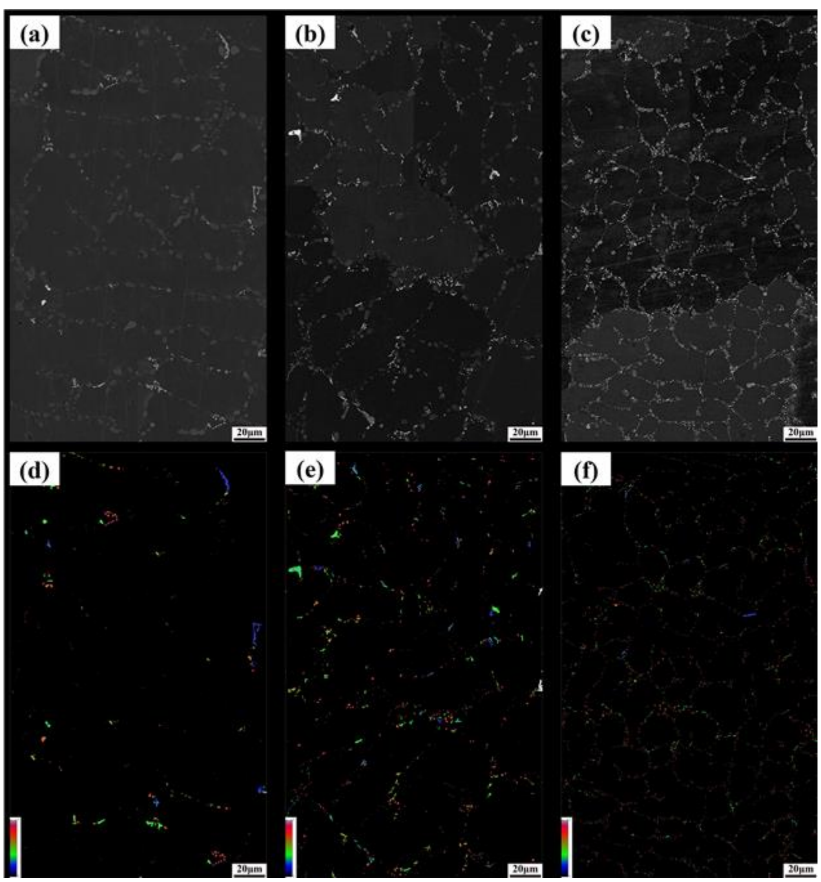
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Exploring the Effect of Scrap Content, Increased Fe Levels and Cooling Rate on the Microstructure of Al-Si Foundry Alloys

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In this work we explore how using Al recycled from incinerator bottom ash (IBA Al) as a material source affects the as-cast microstructure of an AlSi11Mn0.6Mg0.3Fe0.11 foundry alloy and compare with as-cast microstructures of the pristine alloy with increased levels of Fe (up to 0.6wt%), since Fe is the main impurity in IBA Al. Castings were performed both on a Cu plate (fast cooling) and in a sand mold (slow cooling), in order to study the effect of different cooling rates on the resulting microstructures. Under high cooling rates (~20 C/s), the αc-Al15(Mn,Fe)3Si2 phase is the predominant intermetallic phase to form. Upon increasing the scrap content, the morphology of the αc-Al15(Mn,Fe)3Si2 phase is transformed from small distributed particles along Al grain boundaries to large blocky and Chinese-script particles, in line with observations with increased Fe levels. However, the αc particles are much larger in the scrap containing alloy compared to the pristine alloy with comparable Fe level, suggesting different nucleation mechanisms of the αc-Al15(Mn,Fe)3Si2 phase when scrap is added, compared to in the pristine alloy with increased Fe. For the slower cooled samples (~4 C/s), plate-shaped particles, identified by EDS to have a composition consistent with the δ-Al(Fe,Mn)Si2 phase are predominant in the pristine alloy and with with low Fe levels, but transformed into large Chinese-script α-Al15(Mn,Fe)3Si2 particles with addition of scrap and also with increasing Fe. Our work contributes to build fundamental understanding of the effects of impurities contained in IBA Al on microstructure Al-Si foundry alloys, which is a critical step towards a more sustainable Al industry.

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Sustainability and Economic Viability of Chemical and Plasma Solvolysis Processes From End-of-Life CFRP Parts

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The demand for Carbon Fibre Reinforced Composites (CFRCs) is expected to reach approximately 190 kilotons by 2050 due to their exceptional properties. However, their end-of-life (EoL) management remains a major sustainability challenge. Currently, CFRCs are primarily disposed of via incineration or landfill, both of which contribute to environmental pollution and resource loss, contradicting circular economy principles. Solvolysis presents a promising recycling approach, reducing costs by approximately 15% compared to virgin carbon fibers (vCFs) , ,

The Eurecomp project aims to develop sustainable strategies for recycling and reusing CFRCs across various industries, including aeronautics and wind energy. Circularity will be achieved through repair, repurposing, and redesign, as well as material recovery from EoL components, contributing to waste and cost reduction while enabling high-value applications.

This study compares chemical-assisted and plasma-assisted solvolysis for CFRC recycling with other EoL treatments such as landfilling, incineration, mechanical recycling, and pyrolysis, from both environmental and economic perspectives. While conventional solvolysis processes may still have environmental drawbacks due to solvent use, this study explores alternative methods that regenerate and reuse chemicals, reducing overall impacts and costs.

Life Cycle Assessment (LCA) results highlight the environmental benefits of solvolysis in CFRC recycling. Chemical-assisted solvolysis demonstrated lower environmental impacts than plasma-assisted solvolysis, whereas Life Cycle Costing (LCC) analysis showed plasma-assisted solvolysis to be more cost-effective at a lab scale. Additionally, solvolysis recovers approximately 90% of carbon fibers, reducing reliance on energy-intensive vCF production, which emits approximately 30–40 kg CO_2 per kg of fiber. In contrast, pyrolysis, though achieving 60% CF recovery, has the highest environmental impact among EoL treatments. Mechanical shredding, while energy-efficient, recovers only 24% of CFs with significant mechanical degradation.

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Keywords: Life Cycle Assessment; Life Cycle Costing; Solvolysis; End-of-Life management; Circular economy; Recycling strategies

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Leading Edge Erosion of Wind Turbine Blades: Solutions From Recycling

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Leading edge erosion (LEE) describes the erosion phenomena of a wind turbine blade's leading edge by rain, hail, UV, sand, dust, insects, and other airborne particulates. This erosion has a deleterious effect on the blade's aerodynamic efficiency, reducing the turbine's annual energy production (AEP) and lifetime profitability. Almost all wind turbines will be affected by LEE due to the ubiquity of its causal factors. A possible solution is the application of protective polymer coatings to the leading edge of wind turbines. In this talk, I will present a novel methodology for the manufacturing of such protective coatings based on turning decommissioned wind turbine blade composite materials (fibre-reinforced polymers, FRPs) into powders that can be used as reinforcing filler nano/microparticles for such coatings. Both glass and carbon fibre epoxy-based composites have been considered. The novel coatings will help protect wind turbine blades from erosion caused by raindrops and other particulates and extend their lifetime. Furthermore, they could also be used in other applications such as in-built environment or to prevent corrosion of cables of suspension bridges.

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Retention Analysis of Mechanical Properties of Carbon Fibers Recycled via Plasma-Assisted Solvolysis

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Conventional chemical recycling methods, such as solvolysis, oxidation, and the use of supercritical liquids, often generate high amounts of chemical waste and consume significant energy. Integrating plasma into solvolysis can enhance fiber recovery rates while preserving fiber properties. This study aims to optimize the plasma-assisted solvolysis process of CFRPs in terms of the tensile properties of recovered carbon fibers (CFs). The solvolysis process was conducted by varying multiple parameters, including plasma heads, plasma power input, plasma gas mixture, reactor flow, nitric acid concentration, the composite specimen mass-to-solvent molar ratio, and process duration. After solvolysis, the Young's modulus and tensile strength of recycled fibers were determined through single-fiber tension tests. A sensitivity analysis was conducted to determine the influence of each parameter on fiber strength, followed by a supplementary analysis of variance (ANOVA) to assess their impact on the variance of strength. Based on these results, the number of parameters for further analysis was reduced. After the statistical evaluation of the mechanical properties, the optimization analysis was focused on fiber strength, as the Young's modulus showed statistically insignificant variance. A predictive model was then trained using machine learning to establish relationships between process parameters and fiber properties, ultimately identifying optimal conditions for maximum performance. To validate the model, new solvolysis experiments, not previously included in training, were conducted. The results demonstrate that optimizing solvolysis conditions significantly improves fiber recovery and mechanical properties.

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Plasma-Induced Oxidative Degradation of Epoxy/Anhydride Carbon-Fiber Composites

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The widespread production of epoxy Carbon Fiber Reinforced Composites (CFRCs) has triggered environmental concerns due to the substantial waste they generate, mainly due to the end-of-life components. Conventional disposal methods such as landfilling and incineration have been increasingly restricted due to their environmental impact and resource inefficiency. In response, chemical recycling, or solvolysis, has emerged as a promising alternative. This technique enables the recovery of valuable fibers and monomers by selectively cleaving critical chemical bonds of the crosslink network within solvent-catalyst systems. Solvolysis with a suitable solvent and the right conditions, can efficiently liquefy the resin matrix, minimizing fiber damage. These attributes position solvolysis as the most promising recycling technology for CFRCs, offering a sustainable solution to the growing waste management challenges in the composite materials industry [1].

Anhydride cured epoxy resin poses challenges for chemical recycling because of its cross-linked three-dimensional (3D) structure. Thus, leading to unsustainable energy demands when aggressive conditions are employed or excessive treatment time when mild conditions are applied. In order to overcome those challenges plasma-induced solvolysis of CFRCs is proposed, where concentrated nitric acid is activated with nitrogen and argon plasma. The ignition of plasma in the solvent generates a wide array of new reactive species in both the liquid and the gas phase potentially enhancing both the disintegration of the matrix and the diffusion of the polymeric fragments to the bulk of the solvent. This process can be performed at low temperature (90-100 °C) and normal pressure compared to other recycling methods [2,3].
In the present work the decomposition of custom-made anhydride cured epoxy CFRPs with continuous fibers was investigated. The % resin degradation was examined in terms of a) treatment time, b) plasma power input and c) temperature. The process energy demands and the amount of produced wastes required for full recovery of CFs were used for the evaluation of process efficiency. The surface quality of the retrieved CFs was monitored by using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX) and a general mechanistic scheme of anhydride cured epoxy matrix degradation is discussed.

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Automated Defect Recognition and Property Prediction Based on Non-Destructive Evaluation of High Pressure Die Cast (HPDC) Samples Based on Primary and Partially Secondary AlSi10MnMg Alloys

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The present study investigates the possibility of using AI methods to identify and characterize defect populations in thin-walled HPDC samples using data from non destructive testing (NDT). Specifically, X-ray radioscopy and ultrasonic evaluation are considered in this respect. Automated Defect Recognition (ADR) and statistical characterization is enhanced using synthetic training data. Beyond ADR, the authors study the possibility of basing predictions regarding failure locations, mechanical properties and stress-strain relationships observed in tensile testing on the results of the non-destructive evaluation.

Tensile test samples have been produced via the HPDC process using a Frech DAK 250-34 cold chamber high pressure die casting machine with a locking force of 290 t. Samples were cast from three different variants of an AlSi10MnMg alloy: Besides a 100 wt.-% primary alloy supplied by Aluminium Rheinfelden, two further materials with 58 wt.% and 89 wt.-% sourced from Aluminum Rheinfelden and Raffmetall, respectively, were employed. The as-cast samples were subjected to radioscopy at Fraunhofer IFAM using an Yxlon MU 2000 system (50-150 kV, 0.2 mm FSD, SSD detector, 100µm pixel size, 1000x1000 pixels), and by University of Koblenz using a proprietary X-ray micro-focus radioscopy equipment (20-60kV, 35µm FSD, screen-camera detector, 40/100µm pixel size, 1920x1080 and 1200x800 pixels). Furthermore, ultrasonic testing was performed by University of Koblenz using a proprietary high-frequency pulse-echo ultrasonic system (1-10 MHz, 2-6 mm surface contact diameter).

Following the non-destructive evaluation, samples were subjected to tensile testing at Fraunhofer IFAM. Fracture surface analysis was used in order to identify the origin of failure, and the type of defect responsible for it.

The results and data gained from mechanical testing were correlated with the preceding non-destructive evaluation, and the capabilities of AI/machine learning approaches to predict (a) the level of mechanical properties such as yield strength, ultimate tensile strength and elongation at failure, (b) the general expression of the stress-strain curve and (c) the location of failure within the sample.

The X-ray radioscopy images are processed by a ML feature marking detector model (CNN-based pixel classifier trained with synthetic data) that marks detected pores (with pixel resolution). A following density clustering algorithm (DBSCAN) groups the feature pixels to groups. The pixel groups are finally fitted with a geometric model (ellipse) to get geometric features for each identified pore, finally aggregated by a statistical analysis. The statistical and distribution properties of pores are correlated by another ML classification and regression model to predict material parameters, e.g., tensile strength, or classify different material grades. In a second step a direct prediction model should be tested, i.e., predicting material properties directly from X-ray images, using a more complex and deeper CNN architecture with a FCNN classification and regression layer. A comparison study should highlight possibilities and disadvantages of both approaches with respect to accuracy, conformance with experiments, and the degree of generalization, especially regarding different detection systems.

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Optimizing Cooling Conditions for Increased Fe Tolerance in Recycled Aluminum Alloy Wheel Production

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The demand for increased recycled content in aluminum alloy wheels is driven by the sustainability requirements of Original Equipment Manufacturers (OEMs). However, higher scrap utilization often leads to elevated impurity levels, particularly Fe, which can degrade mechanical properties by promoting the formation of brittle intermetallic phases. To mitigate the adverse effects of Fe-rich intermetallics, an optimized casting strategy is required in addition to Mn modification. In this study, water cooling was introduced in mold designs to enhance cooling efficiency, refine the microstructure, and improve mechanical performance. The increased cooling rate not only reduces cycle time and boosts productivity but also raises questions about the tolerable Fe levels in aluminum alloy wheels. To address this, wheels with increased scrap content (elevated Fe levels) were cast using both air- and water-cooled dies to assess the effects of cooling rate on Fe tolerance. Standard mechanical tests (tensile, dynamic cornering fatigue test, 13-degree impact test, etc.) and characterization techniques (porosity analysis, microstructural evaluation, etc.) required by OEMs were performed. Additionally, all wheels underwent production steps such as heat treatment and painting to ensure conditions representative of actual manufacturing. The findings provide insights into optimizing casting parameters for sustainable aluminum wheel production while maintaining required performance standards.

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Enhancing Precipitation Modeling and Property Prediction in Cast Aluminum Alloys Using Physics-Based Models and AI

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Modeling precipitation kinetics and predicting material properties in multi-component cast aluminum alloys is challenging due to microstructural heterogeneities, including grain size variations in cast parts, solidification-induced microsegregation, and increased secondary phase content with various morphologies. These microstructural features significantly influence the nucleation, growth, and coarsening of strengthening precipitates, which, in turn, affect mechanical properties and thermal conductivity under industrially relevant heat treatment conditions such as T5, T6, and T7. Additionally, the impact of secondary phases, such as eutectic Si and Fe-rich intermetallics, on final material properties varies across different casting alloy grades and casting techniques (permanent mold, sand mold, HPDC, LPDC, etc.), further complicating accurate predictions. While physics-based models, such as the Kampmann-Wagner numerical (KWN) framework, can provide a fundamental understanding of precipitation kinetics in cast aluminum alloys, their predictive capability can be enhanced by integrating data-driven machine learning (ML) tools. Such a hybrid approach can enable more accurate predictions of strength and thermal conductivity for different heat treatment conditions. In this work, the combined use of the KWN framework and AI tools is evaluated to predict the material properties of different cast aluminum alloy grades subjected to different heat treatment conditions. Key challenges, including microstructural variability, data availability, and model interpretability, are discussed to establish a more comprehensive framework for property prediction in cast aluminum alloys.

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Influence of Graphite Degenerations on Mechanical Properties of Ductile Iron

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Ductile iron - also referred to as nodular cast iron or spheroidal graphite iron (SGI) - is a versatile material that exhibits a wide range of applications through various material grades. The mechanical properties of SGI materials highly depend on the microstructure, which is a combination of a ferritic, pearlitic, or ferritic-pearlitic matrix with a spheroidal graphite morphology. The microstructure, along with the graphite morphology, is affected by several factors, including the alloying components of the melt, the casting system, and the solidification conditions. With increasing wall thickness of SGI components, the associated local solidification times as well as the risk of an accumulation of impurities present in the melt rises, leading to larger graphite nodules and often local deviations in graphite morphology, up to so-called graphite degenerations. However, the influence of these deviations in the graphite morphology, particularly the different types of graphite degenerations, on mechanical properties is often not sufficiently known. To estimate the fatigue strength of an SGI component in presence of graphite degenerations, and thus optimally utilize the strength as well as the lightweight potential in the design of cast components, it is necessary to develop methods for a generalized classification of deviating graphite morphologies and identify their effects on mechanical material properties.

Therefore, specimens taken from SGI castings with different graphite degenerations were used for quasi-static and cyclic material tests to derive the fatigue properties. Metallographic analysis close to the fracture surface of the tested specimens were carried out to identify parameters for the classification of the graphite morphology and especially of the graphite degenerations. Finally, the correlation between the determined fatigue strength and the type and proportion of graphite degenerations was investigated. It could be shown that there are distinct parameters to identify graphite degenerations and to classify the graphite morphology. Moreover, a negative effect of the different graphite degenerations on the mechanical properties of SGI materials was determined, indicating the importance of knowing the local properties and thus the graphite degenerations for an optimized component design in terms of lightweight, safety and lifetime.

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Design and Construction of a Strain Sensor for Monitoring Bending Information

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Sensors play a crucial role in monitoring structural health and predicting potential failures in structures, machinery, and infrastructure [1]. Additive manufacturing offers several advantages, including rapid prototyping, cost-efficient production, and flexibility in constructing components, material selection and geometry optimization. These advantages can be leveraged to produce efficient low-cost sensor devices [1,2]. The concept of designing and building a sensor that generates a signal when subjected to a force could significantly aid in predicting failure.

In the present work, a strain sensor was designed and fabricated using the Fused Deposition Modeling (FDM) 3D printing method. The sensor consists of two layers of Acrylonitrile-Styrene-Acrylate (ASA), which serve as both a structural base and a protective layer for the conductive part, composed of a Carbon Nanotube (CNT) Nylon Conductive composite material. The conductive layer is encapsulated between the two ASA layers, ensuring electrical functionality and mechanical durability; the device's structure is illustrated in Figure 1(a). Applying the sensor to the surface of a substrate or a structure enables detection of bending deformation by generating a response signal in the form of a change in electrical resistance. Initial results revealed instability on the sensor's signal. Thus, a 20-hour thermal treatment (annealing) at 102 °C was performed to optimize electrical conductivity and enhance the performance of the sensor [3]. To validate its functionality, the sensor was embedded in Fiberglass Reinforced Plastic (FRP) and tested in an experimental setup, where a bending force was applied at the center of the structure while monitoring the sensor's response by recording the variation in its electrical resistance. During the test cycle, no force was applied for the first 5 minutes, followed by a constant bending force (ranging from 20 to 100 N) for 5 minutes. The response obtained is illustrated in Figure 1(b), showing a significant variation in recorded resistance, which confirms the sensor's functionality. As observed, increasing the applied bending force results in a greater resistance difference (ΔR) between the unloaded and loaded states, leading to hysteresis. This behavior may be attributed to minor permanent deformations acquired during testing or to the rearrangement of carbon nanotubes within the conductive matrix due to bending of the entire assembly.

The idea of creating a 3D printed strain sensor capable of generating a resistance signal based on the applied force is feasible, enabling failure prediction. Additionally, advancements in 3D printing technology allow for testing of different geometries and building materials in order to optimize the sensor's structure and improve measurement accuracy.

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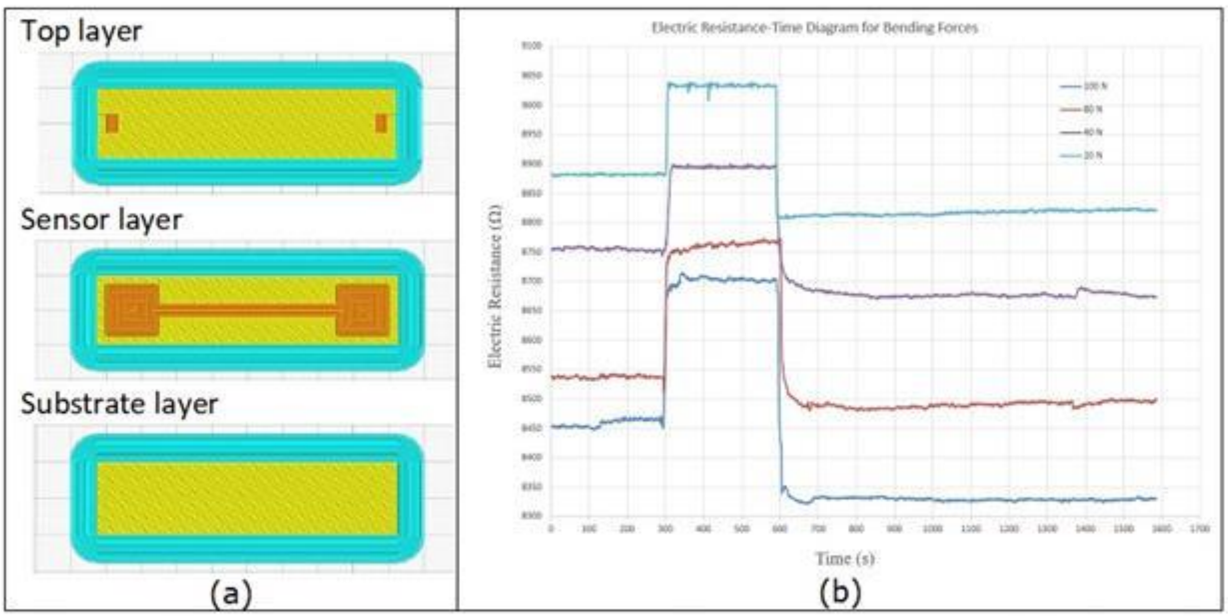

Fig. 1. (a) Sensor structure, consisting of three main layers; (b) Sensor's response to bending.

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Design and Construction of a Floating Wind Turbine Scale Model With Composite Materials and its Integration Into Gravity-Based Offshore Structures

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Objective

The objective of this paper is to present the design and construction of a floating wind turbine scale model, composed of composite materials, and its subsequent integration into offshore gravity-based structures. The 5 MW NREL wind turbine model (tower - blades - nacelle - hub) is made of composite materials, with the aim of placing it in an offshore gravity-based structure in a finite water depth. The dimensions of the scaled model have been selected based on the experimental tank at the University of West Attica, which will be utilized to conduct the requisite trials. The depth of the tank is measured at 0.6m, and the wind turbine's support substructure is designed to have this draught, extending 0.1m out of the still water level. At the gravity-based structure, the wind turbine pylon, with a height of approximately 0.9m, will be mounted, along with the blades, the nacelle, and the hub.

Methods

The subsequent sections will provide a comprehensive description of the manufacturing process of the blades which will be made from composite materials and the nacelle/hub which will be manufactured by 3D printing. In the offshore industry, there is a growing interest in enhancing efficiency, reducing energy consumption, and aligning with sustainability objectives. In this context, the adoption of composite materials and 3D printing technology promises to significantly improve shipbuilding processes. Additive manufacturing, a process that involves the layer-by-layer construction of objects from a solid foundation, has significant potential in the field of shipbuilding. It can rapidly create prototypes of various components, such as hull models, propellers, and other structural elements, which can then be used for hydrodynamic testing in experimental tanks, facilitating the optimization of offshore structures based on the obtained results. Additionally, large-format 3D printing has emerged as a pivotal technology in the fabrication of wind turbine blades, particularly in the use of advanced materials such as glass-fibre and carbon-fibre reinforced polyester composites.

To ensure the stability and reliability of the wind turbine support base, the hydrodynamic loads caused by sea waves are calculated using analytical methods. In the context of linear wave theory, the boundary conditions associated with a fixed vertical cylinder play a pivotal role in the solution of the hydrodynamic problem. The following boundary conditions are of paramount importance:

- The velocity potential must satisfy the Laplace equation,
- The normal component of the particle velocity on the surface of the cylinder must be zero,
- At the base of the water domain, there is no flow through it,
- The free surface conditions (kinematic and dynamic), and
- The far-field conditions must be satisfied.

The aforementioned boundary conditions are instrumental in determining the velocity potential surrounding the fixed cylinder within the framework of linear wave theory. Solving this system of equations analytically enables the calculation of the first and mean second-order wave loads.

Fig. 1 The NREL 5-MW wind turbine scaled model

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Strength Performance of Carbon Fiber Sandwich Composites With an Additively Manufactured Fiber-Reinforced Polyamide Grid Core

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Carbon fiber-based composites have been extensively used in marine construction due to their low specific weight, high strength-to-weight ratio, enhanced stiffness and corrosion resistance. So far, they have been employed for the construction of marine structures, such as small boat hulls, decks, hatch covers, masts, as well as tidal turbine propellers and rotor sails [1]. Common practice refers to the construction of sandwich structures consisting of a thick, low-density core material, such as foam, grid or truss, and two thin, high-strength skins of carbon fiber, usually fabric or sheet, firmly bonded on the external/outer surfaces [2]. Material extrusion (MEX) is an additive manufacturing technology that creates objects either as solids with 100% infill density or as lattice structures, by depositing fused thermoplastic material in subsequent layers [3]. The choice of infill density and grid pattern determines the weight and properties of the final object, while its overall quality and durability also depends on the material and the printing process parameters.
In the present work, the fabrication and mechanical testing of sandwich specimens that combine a 15% carbon fiber-reinforced polyamide (PA-CF) core and skins of carbon fiber fabric (CFF), have been investigated. The core of the specimens was additively manufactured on a MEX 3D printer with a cubic grid pattern at 50% density. For 3D printed specimen (core), CFF impregnated with epoxy resin was attached on the outer surfaces to form the skin of the composite. The strength performance of the sandwich specimens was then determined experimentally through tensile, three-point flexural, and impact tests (figures 1,2) and the results were compared to the 3D printed specimens of PA-CF at 50% and 100% infill density.
The results showed that sandwich specimens exhibited the highest ultimate tensile strength of 145.8 MPa, which corresponds to a remarkable increase of 64.5% compared to the 50% density PA-CF specimens, i.e. 88.6 MPa, and an increase of 24.3% compared to the 100% density PA-CF specimens, i.e. 117.3 MPa. The sandwich specimens also showed the highest elongation at break. In addition, the flexural and impact strength of the composite specimens was enhanced by 24.5% and 69.0% respectively, compared to the 50% density PA-CF specimens. Similar experimental results were obtained for sandwich specimens fabricated with one additional internal CFF layer.
The enhanced mechanical behavior of the fabricated sandwich specimens is mainly attributed to the higher tensile properties of the CFF reinforcement embedded in the polyamide-based core. The fabrication of carbon fiber sandwich structures using MEX technology to create the 3D printed grid core can be promising for small-scale lightweight structures with improved strength and stiffness. The unique characteristics of these structures can contribute to improved performance and increased energy efficiency.
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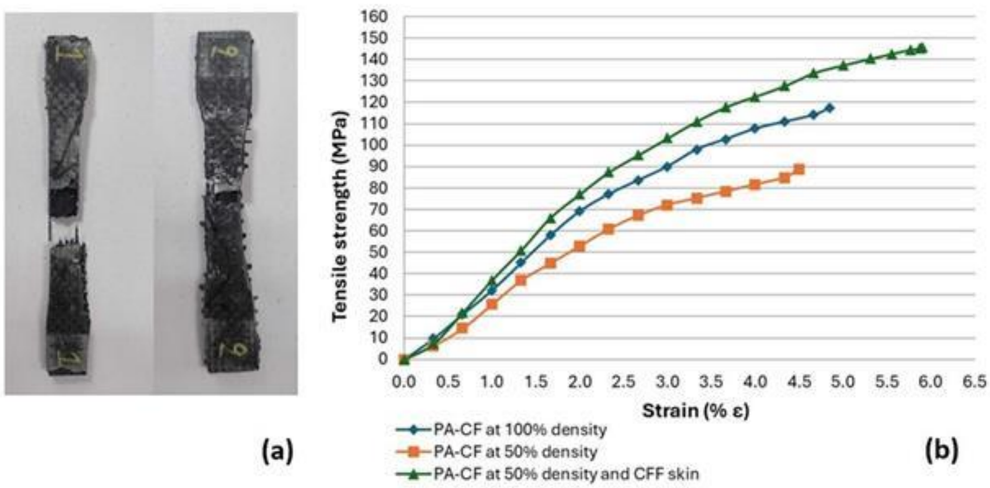

Fig. 1. Sandwich specimens after tensile test (a) and stress-strain curves of the fabricated composites (b).

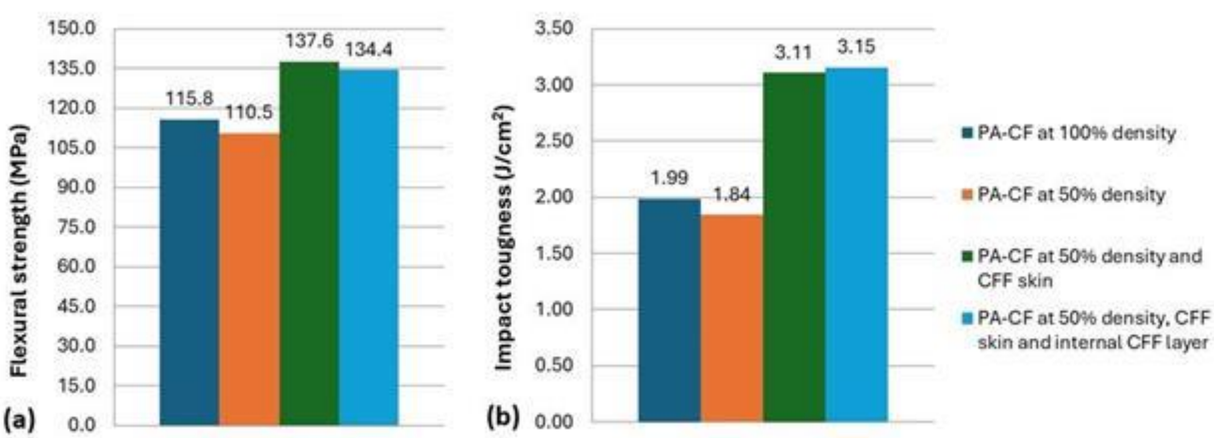

Fig. 2. Flexural strength (a) and Impact toughness (b) of the fabricated composites.

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Methodology for Accurate Geometric Modeling of Filament Wound Structures and Mechanical Analysis

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Filament winding (FW) is a particularly well-suited manufacturing method for cylindrical composite structures used to achieve a high strength to weight ratio. A wide range of derivatives of FW find applications in several industries, including aerospace, automotive and marine. Notable products of FW are pressure vessels used to transport fuel or gas, rods, driveshafts, blades, booms and sailing masts etcs. A substantial body of research is dedicated to understanding the mechanical behavior of filament wound composite structures due to their advantages, including high strength, stiffness, low weight and resistance to corrosion. Research studies utilize a range of methodologies, including theoretical, experimental, and computational engineering approaches. Most studies focus on two main areas: the materials used, such as matrix and reinforcing materials, the FW pattern and the sequence of layers, considering and elucidating their effect on the mechanical behavior of these structures. However, most studies that are focused on the optimal solution of pattern have the disadvantage of being unable to model the actual fiber pattern when using finite element analysis. The present study is conducted with the objective of addressing the identified weakness, and the proposed methodology involves creating a realistic model that incorporates the trajectory of the fiber, the fiber band, and the sequence of layers. The key parameter for the realistic geometry is the calculation of fiber trajectory, which is achieved by utilizing a script capable of calculating and visualising these trajectories. The script significantly reduces the time required for CAD creation. The main idea is to automate the fiber creation process by using a loop, ensuring that each fiber is treated uniformly across all layers. This approach eliminates the need for manual adjustments for individual fibers, regardless of the number of layers required to fully cover the mandrel. Subsequently, these trajectories are fed into the CAD program 'Space Claim' in an automated manner. The generation of the fiber path from these trajectories results in the formation of the filament wound structure geometry. Ultimately, the generated geometry is incorporated into the ANSYS mechanical suite, within which the mechanical behavior of the FW tube is studied. It is anticipated that this methodology will generate more accurate results than other methods currently in use. The FW tubes configured, with the accurate microstructure, were subjected to axial tension and radial compression, in the elastic and plastic deformation regime. Load-displacement diagrams are calculated via finite element analysis and compared with experimental results. In addition, a series of preliminary computational analyses were considered, comparing different FW patterning and layering, to elucidate the underlying mechanics in various loading cases.

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Effects of Manufacturing Processes on the Mechanical and Physical Properties of Reinforced Polymers for Marine Applications

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Fiber-reinforced polymers (FRPs) are increasingly utilized across various industries, including energy, construction, automotive, aviation and marine sectors [1]. Various manufacturing methods are available for producing lightweight structures, using FRPs to combine a high strength-to-weight ratio with stiffness and flexibility. The choice of a manufacturing method induces processes that determine the properties of the product, directly influencing the performance and stability of the final structure. Each method offers distinct advantages and limitations. Certain features, such as the mechanical behavior, durability, performance, production speed, and cost efficiency, depend on both the chosen materials and the applied manufacturing process. However, failures under operational conditions have been reported in several instances, often due to mechanical loading and exposure to elevated temperatures or harsh chemical environments [2]. These factors can lead to material degradation, compromising performance and long-term durability.

In the present work, certain physical and mechanical properties of FRP specimens produced using various experimental methods were examined. Specifically, void volume content, water uptake resistance, and tensile load response were assessed and analyzed. The effects of vacuum-assisted methods were compared to those of non-vacuum techniques, such as wet hand lay-up laminating and mechanically compressed methods.

The results indicate that the physical properties and mechanical performance of the produced composite materials are influenced by, and can be controlled through, the chosen manufacturing method. Both the applied vacuum and the external mild compression enhance the flow of the matrix phase during polymerization, effectively filling gaps and ensuring an even distribution. This results in a higher density, which in turn improves tensile strength and increases resistance to water uptake in the specimens.

These findings highlight the importance of selecting the appropriate manufacturing method to optimize the performance and durability of FRP materials under demanding operational conditions.

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Experimental and Numerical Study of Mode II fatigue Delamination via End-Loaded Split Specimens

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Introduction
Delamination is one of the most frequently observed failure modes in fibre-reinforced polymers. An experimental testing campaign was performed to characterise the interlaminar properties of a carbon fibre-reinforced polymer under both Mode II fatigue and static loading.
The measurement of crack length under Mode II loading has been a topic of ongoing debate, primarily due to the challenges in accurately identifying the crack tip. Over the years, several test methods have been developed to determine the Mode II fracture toughness, including the End-Notched Flexure (ENF), the four-point End-Notched Flexure (4-ENF), and the End-Loaded Split (ELS). However, only two of these methods have been standardised: ASTM D70905, which uses the ENF method, and ISO 15114:2014, which employs the calibrated ELS approach. The standard ENF test tends to be unstable, providing reliable results only for fracture toughness initiation. In contrast, the ELS test offers stable propagation, a critical factor when studying fatigue.

Methods
The ELS test setup was selected for the present study. Experiments were conducted using T700/DT120 carbon fibre-reinforced polymer specimens, with static tests performed to determine the fracture toughness and fatigue tests carried out to study the crack propagation under different displacement ratios. Additionally, a model was created in the Finite Element Analysis software Abaqus, using cohesive zone models for high cycle fatigue through a user-defined subroutine.

Results
The results from experimental testing showed stable crack propagation across all tested displacement ratios and were compared with data available in the literature. The numerical model was validated against the results from the experimental campaign, showing a strong correlation and highlighting the accuracy of the implemented model.

Conclusion
The study demonstrated that the ELS test method effectively characterises Mode II delamination with stable crack propagation in carbon fibre-reinforced polymers under both static and fatigue loading conditions across various displacement ratios supported by results from both experimental tests and numerical simulations.

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Experimental Characterization of the Effect of the Adhesive Type and the Temperature Exposure on the Mode I Fracture Toughness of Hardwood Bonded Joints

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Engineered wood products (EWPs) rely heavily on structural adhesives, with glue lines between board faces playing a crucial role in ensuring the stability and load-bearing capacity of structural elements. The mechanical interaction between adhesive and wood is very complex due to the local failures (i.e. non-uniform cracking in adherend/adhesive, fiber bridging, etc.) that could occur. Understanding of fracture in wood and wood composites is important because internal flaws (such as cracks) can lead to failure before the ultimate load capacity is reached as determined by stress criteria. Overall, one of the most revealing properties to assess the bond quality and behavior is the fracture energy (or toughness), which traditionally been characterized by a stress intensity factor, an initiation strain energy release rate (Ginit) or a total energy to fracture (Gf). However, in the case of timber, these parameters provide an incomplete fracture characterization, as toughness evolves during crack propagation. Therefore, appropriate tests were conducted to estimate fracture toughness and to characterize fracture behavior throughout crack propagation by measuring a full crack resistance R-curve.
In the last decades, multifactorial reasons led to increase research and production interest for hardwood species for structural purposes. Many of the research which were carried out, pointing out hardwoods' excellent mechanical properties, but also their marked variability, since their performance can vary considerably depending on the combination of species and adhesives. One of the key point to assess is the efficiency and long-life of adhesives, especially when they undergo thermo-hydrometrical modifications.
In this work, the Mode I fracture toughness behavior of two different categories of adhesives for structural applications was investigated, namely melamine-urea-formaldehyde (MUF) and phenol-resorcinol-formaldehyde (PRF) in combination with two different hardwood species: beech and chestnut. The tests were conducted according to the ASTM-D5528 standard guidelines. Lately, the same tests were replicated at a temperature of 150° to assess the thermal effects. The results revealed different fracture toughness behavior between the various adhesives and species with a marked reduction of fracture toughness for chestnuts in thermal conditions. The fractured surfaces are also characterized by means of optical microscopy.

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Evaluation of an AI-empowered Materials Failure Knowledge Management System

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NAVMAT is an intelligent, multilingual knowledge management platform designed to record, classify and analyse material, component and system failure incidents in a marine environment. A number of algorithms were developed and incorporated into a knowledge management platform facilitating real-time, multilingual search and intelligent indexing, while offering valuable insights from past incidents and knowledge resources. It employs a customized natural language processing methodology based on a carefully engineered ontology. The ontology, regularly updated by materials failure domain experts, enriches the retrieval mechanism by instilling domain specific knowledge.

The ontology and taxonomy of NAVMAT system is based on the following classes or concepts: Every failure incident is identified, described and associated with a component, which is a part of a system, belonging on a platform such as a ship or a vehicle of even an industrial installation. The component is made out of a specific material, following a suitable fabrication method. The failed component (or system) operates in defined environment, being subjected to a loading regime. It exhibits a mode of failure initially identifiable by the observer, but further assessed and analysed only by an expert. Should such a failure analysis take place, the root cause of failure may also be confirmed. The full documentation of the incident and related content is classified and indexed for future reference.

The authorised user can contribute with failure incident announcements and failure analysis assessments, as well as with comments on incidents and assessments introduced by other users (recording module). Upon submitting an incident or an experts' opinion, the system proposes similar incidents and reports, ranked according to a relativity index (intelligent indexing and retrieval modules). The experts may recommend terms and suggest failure modes and mechanisms, which they subsequently may be incorporated to the system ontology (machine learning module). The user may search with free text terms (currently in Greek and English but expandable in other languages) while the system responds with without being obstructed by language variations, synonymity of the term or orthographic mistakes.

NAVMAT evaluation, reported in the current paper, employs cutting-edge performance metrics akin to those utilized in contemporary information retrieval systems. The evaluation process involved continuous expert engagement, focusing on two distinct retrieval mechanisms: one designed to identify and rank similar past incidents and another enabling free-text searches. Both retrieval mechanisms leverage the ontology in different ways and were therefore evaluated separately. Experts assessed the effectiveness of both approaches, considering the accuracy of retrieved results, the relevance of rankings, and the overall system usability. The findings highlighted the crucial role of ontology-driven retrieval, as its removal led to a significant decline in search performance, semantic consistency, and the system's ability to capture domain-specific terminology. This study underscores the value of expert-in-the-loop evaluation in refining knowledge-based retrieval systems for maritime incident analysis.

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Residual Tensile Strength of Fabric Reinforced Hybrid Epoxy Composites after Low Velocity Impact

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The epoxy composites reinforced with fabrics are widely used in various industrial sectors (aerospace, automotive, sports goods and other applications) due to their mechanical strength and lightweight. However, they are vulnerable to the low-velocity impacts, which can cause internal damage that is difficult to detect and weakens the material's overall mechanical performance. By strategically layering different fabrics within epoxy composites, particularly carbon fibers, it is possible to optimize their impact strength and mechanical response. This hybridization technique allows for the precise tailoring of material properties based on the arrangement of the fabric layers. Adding fillers to the epoxy pre-polymer mixture is also a common strategy to enhance the low-velocity impact resistance and residual mechanical strength. The resulting composite's impact and post-impact behavior are determined by the filler's properties, matrix compatibility, interfacial quality and morphology.
This research explored how fabric ply orientation and addition of fillers to the epoxy matrix affected the low velocity impact resistance and post-impact tensile strength of hybrid composites. Thus, four composite materials were created using five types of woven fabrics: pure carbon, pure aramid, a mixed carbon/aramid (with a 2:1 warp and 1:2 weft ratio) and two pure glass with different specific densities. Two of these composites varied in ply orientation (0°, 30°, 45° and 60°). The other two contained different filler combinations (potato starch, carbon black, talcum powder, barium ferrite, short carbon fibers, and clay powder) within epoxy matrix between certain plies. Potato starch was consistently used across all materials to ensure even filler distribution and prevent clumping.
The hybrid composite laminates were subjected to low-velocity impact loadings at three energy levels (15 J, 30 J and 45 J) using a drop weight impact testing machine in order to determine the residual tensile strength. The tensile tests, both before and after impact, were performed at 2 mm/min using a mechanical testing machine. The damage mechanisms of the epoxy composites were investigated by X-ray computed tomography and it was found that the most delaminations occurred between the adjacent layers made of different types of fabric. According to the tensile results recorded before and after low velocity impact loadings, it was determined that the filler addition into the epoxy matrix between certain layers improved significantly the residual tensile strength of the epoxy hybrid composite with ply orientation at 0° at energy levels of 30 J and 45 J.

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Nanocellulose as a Filler for ABS Composites

Prof. Lubomir Lapcik[1], Dr. Barbora Lapcikova[1], Ms. Apurva Shahaji Vadanagekar[1]

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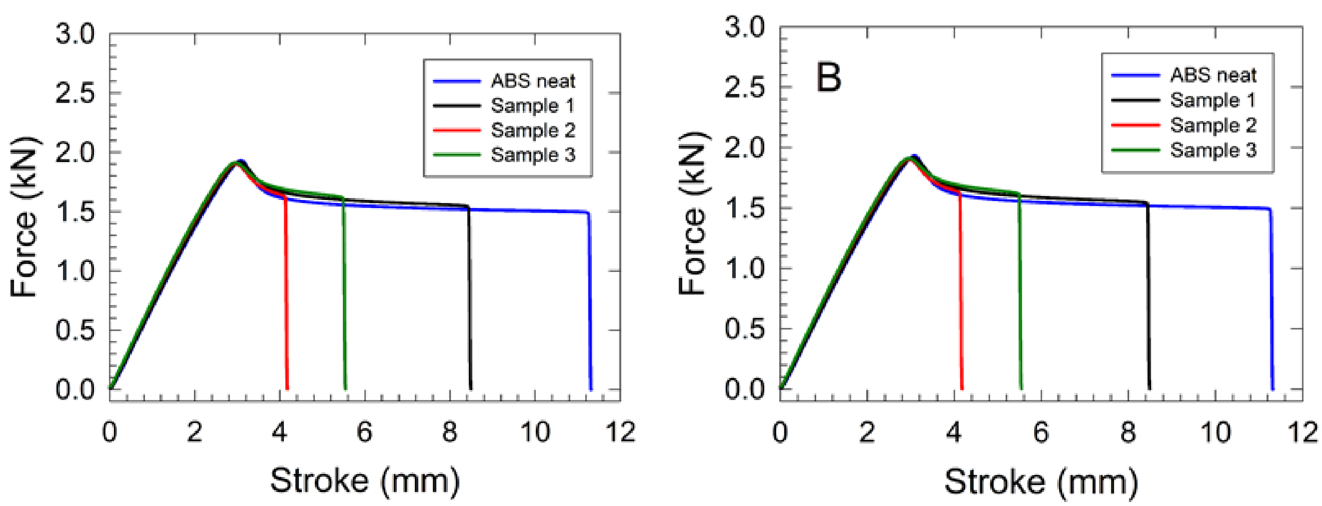
The effect of nanofiller concentration on the mechanical properties of composite materials for biomedical applications is examined in this research. Cellulose nanofibers are utilized as the filler within an ABS polymer matrix. The findings indicate that Young's modulus is significantly influenced by nanofiller concentration, with a notable interaction between concentration and material composition. While yield stress remains largely unaffected, fracture toughness decreases at higher concentrations, suggesting an optimal range for balancing mechanical properties. Significant differences are also observed in hardness and mechanical measurements, particularly in indentation creep and hardness. These results indicate that optimizing both the concentration and type of nanofiller, such as cellulose nanofibers, enhances the mechanical performance of ABS-based composites for long-term biomedical applications.



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Epoxy/Graphene Nanocomposites for Technical Applications

Prof. Lubomir Lapcik[1], Dr. Barbora Lapcikova[1], Ms. Apurva Shahaji Vadanagekar[1]

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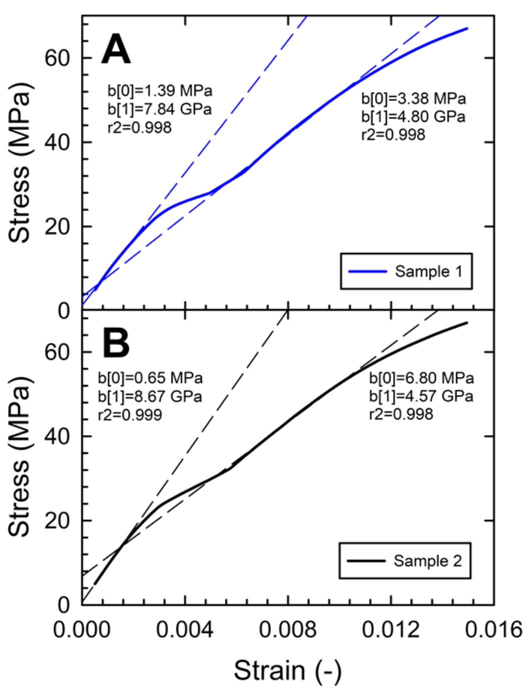
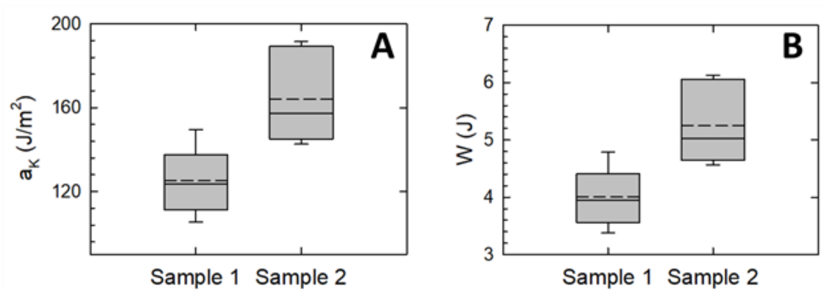
Basalt fibre-reinforced polymer (BFRP) composite pipes have been recognised as a promising alternative to glass and carbon fibre-reinforced composites for industrial applications. Their high recyclability makes them suitable for aerospace, marine, and automotive industries. In this study, the mechanical properties of virgin basalt-epoxy composite pipes were compared with those of graphene-modified counterparts. Pipe section specimens were prepared using a flex grinding machine, and graphene nanoplatelets (GnPs) were uniformly incorporated into the basalt-epoxy composites at a specific concentration. The inclusion of GnPs resulted in significant changes in mechanical stiffness compared to virgin basalt-epoxy pipes. Mechanical properties were assessed through a series of tests, including uniaxial tensile, Charpy impact, microhardness, Shore D hardness, uniaxial 3-point bending, and dynamic displacement transmissibility tests. The results indicated that pure basalt-epoxy composites exhibited lower ductility than graphene-reinforced counterparts after uniaxial mechanical loading. Non-destructive dynamic mechanical vibration testing was conducted to analyse the complex mechanical response of the materials. The frequency-dependent behaviour observed reflected a combination of ductile and brittle mechanical performance in the developed composites.





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Engineering Hybrid ZnO-Based Nanostructures for Plant Protection Applications

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The challenge of feeding an estimated global population of 9.7 billion by 2050 presents significant pressure on current agricultural systems. Nanotechnology address this demand, by providing innovative solutions to enhance crop productivity and protection. Inorganic nanoparticles (INPs) are particularly promising due to their unique physicochemical properties, which improve plant health by controlling pathogens, increase nutrient availability, and enable controlled release of agrochemicals. [1]. In that vein, several members of engineered INPs of bioessential metals(Cu, Fe, Zn, Mn) were prepared by us in a variety of nanoarchitectures, well physicochemically characterized (size, shape, composition, and surface features) and their activity against several species such as bacteria, fungus and nematodes were investigated[e.g 2]. Hybrids engineered nanomaterials can combine different functionalities and have emerged as multimodal agents with new artificial properties. Herein, we present different hybrid ZnO-based nanostructures and their effect on photosystem II (PSII) activity in tomato plants. Thus, pegylated ZnO (ZnO@PEG), pegylated zinc-doped ferrite (ZnFer@PEG) and hetero-nanocomposite composed of oleylamine-coated ZnO@OAm and $Ca(OH)_2$@OAm nanoparticles (Ca(OH)2/ZnO@OAm) were synthesized via wet chemical procedures. Their physicochemical properties were characterized by X-ray diffraction, vibrating sample magnetometry, thermogravimetric analysis, FT-IR and UV–Vis spectroscopies, dynamic light scattering and transmission electron microscopy. Subsequently, their impact on tomato photosynthetic efficiency was evaluated by using chlorophyll a fluorescence imaging analysis to estimate the light energy use efficiency of photosystem II (PSII), 30, 60, and 180 min after foliar spray of tomato plants with distilled water (control plants) or 15 mg L^{-1} and 30 mg L^{-1} NPs. Beside the inherent semiconducting properties of the inorganic core, surface properties of the organic/inorganic coating in each case present both beneficial and detrimental effects on the photoreactivity of the nanostructures on tomato plants and suggested the need for caution in their applications in crops.

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Silica Aerogels as Catalysts for Hydrogen Production via Water Splitting

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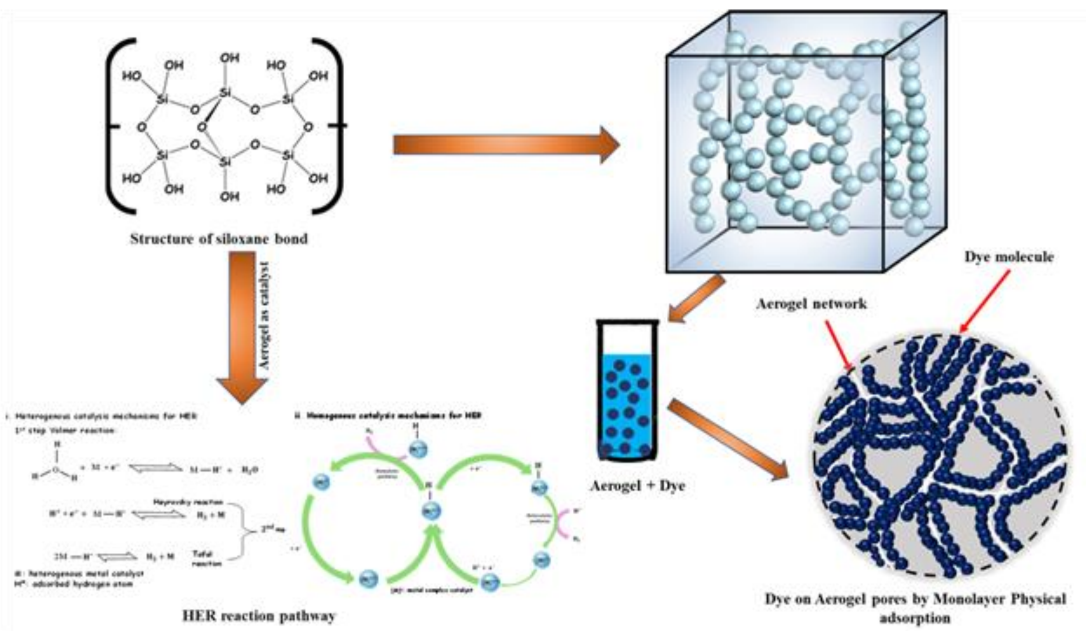
This presentation delves into the potential of silica aerogels in environmental remediation, emphasizing their significance amid rising energy and water consumption. As the need for effective purification strategies grows, silica aerogels have emerged as promising materials due to their unique properties. This paper explores their synthesis, drying methods, and key insights from both experimental and theoretical studies. It highlights their dual role as adsorbents and catalysts, particularly in hydrogen production and industrial dye degradation, showcasing their effectiveness in pollution control. The findings underscore the necessity for innovative synthesis techniques, well-informed policies, and continued research to maximize the environmental benefits of silica aerogels.



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Mechanical Properties of High Density Poly(ethylene)-Perlite Nanocomposites

Prof. Lubomír Lapčík[1], Prof. Barbora Lapčíková[1], Mr. Jan Stehlík[1]
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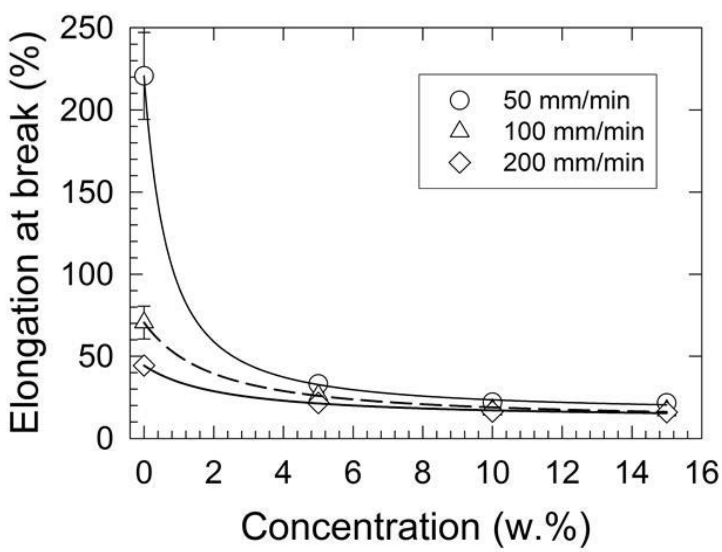
This paper investigates the application of perlite mineral as a filler in polymer nanocomposites for technical applications. The results indicate a significant influence of the perlite nano-filler on the mechanical and thermal properties of high-density polyethylene (HDPE) composites. An increase in Young's modulus was observed with higher filler concentrations, indicating enhanced stiffness. This increase in stiffness, identified through mechanical tensile testing, was further validated by non-destructive vibrator testing using displacement transmissibility measurements based on the forced oscillation single-degree-of-freedom method. Fracture toughness exhibited a decreasing trend with increasing perlite content, suggesting the occurrence of brittle fracture. However, SEM analysis also revealed ductile fracture mechanisms at higher filler concentrations. Additionally, SEM imaging demonstrated relatively strong bonding between polymer chains and filler particles.

Keywords: Perlite fillers; HDPE composites; Mechanical testing; Vibration damping; Thermal analysis.



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Printability Assessment of an Atomized G91 Powder Steel Using Laser Beam Directed Energy Deposition

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9Cr-1Mo generally known as G91 is a ferritic martensitic steel used in energy applications as pressure vessels, pipping systems and/or steam generators due to its resistance to high temperatures. This improved steel presents a reduce carbon content and a tighter control of residual elements such as P and S. In addition, it has minor quantities of V and Nb as carbide forming elements and traces of N, to promote the formation of MX precipitates in the martensitic matrix, providing this steel with a high creep strength and good thermophysical properties. Among the manufacturing processes that can be used, additive manufacturing, and, specifically, Directed Energy Deposition is preferred due to its ability to repair, add additional material to existing components. and produce relatively large parts with minimal tooling, together with the capability of producing spare parts on demand. But G91 alloy does not exist as powder feedstock and parts are not conventionally made using powder metallurgy routes; therefore, the microstructure and properties determined by the chemical composition, production route and thermal treatment are unknown.

In this study we have focused on assessing the printing capability of the G91 atomized powder steel using Laser beam Directed Energy Deposition (DED-LB) process. The powder with a particle size distribution between +45|-130 µm has been characterized first in terms of static flowability using a Hall funnel (flowrate and apparent density), quasi-static flowability (first avalanche angle) and dynamic flowability (aeration, cohesive index, angle and roughness index) using the rotating drum powder tester Granudrum™. Different process parameters such as the laser power, robot speed, powder flow and argon carrier and protection gas flow have been evaluated. Several coupons have been printed under the selected conditions with varying energy densities, , and their microstructure and mechanical properties have been analysed. Optical Microscopy (OM) and Scanning Electron Microscopy (SEM) have been used to assess the quality and the microstructure, revealing no noticeable porosity or cracks. Mechanical properties have been determined in the as built coupons and correlated with the microstructure and the energy densities used during the process. The capability of using ferritic martensitic steels in the as built condition to eliminate the tempering heat treatment is discussed.

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Influence of Process Parameters on the Mechanical Properties of FDM-Printed Parts Using Commercially Available Materials

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Fused Deposition Modelling (FDM) has become one of the most widely adopted additive manufacturing (AM) techniques due to its accessibility and versatility. However, unlike conventional manufacturing processes, FDM introduces inherent anisotropy and layer-dependent variability of mechanical properties, presenting significant challenges in the prediction of material behaviour. This paper deals with the influence of key FDM process parameters on the mechanical properties of 3D-printed components and deals with the development of a high-accuracy numerical material model.

Preliminary research has pointed to considerable performance variations in 3D-printed parts fabricated under different conditions, requiring a thorough investigation. The objective of this research was to evaluate the impact of build orientation, printer setup, and time between layer depositions on mechanical behaviour. Furthermore, the hypothesis that FDM parts can be accurately represented using simplified numerical models was also tested.

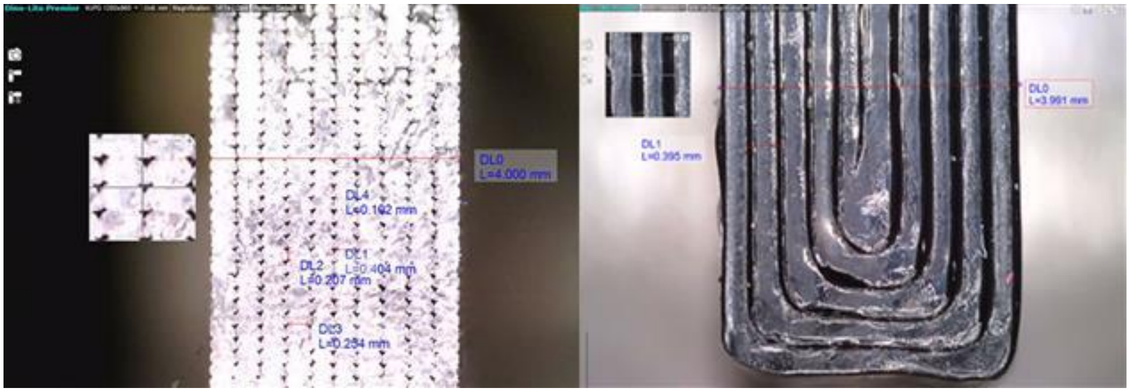
During the research standard ISO 527 tensile tests were performed on PLA and PETG specimens. Test samples were printed with varying orientations and layer times to reflect a broad range of real-world conditions. The measured mechanical properties include Young's modulus, ultimate tensile strength, and interfacial bonding strength (IFBS). The results have revealed a strong correlation between printing parameters and mechanical performance, notably a correlation between prolonged layer times, typically due to simultaneous multi-part printing, and reduced IFBS because of increased cooling between layers, resulting in weaker interlayer adhesion and reduced structural integrity.

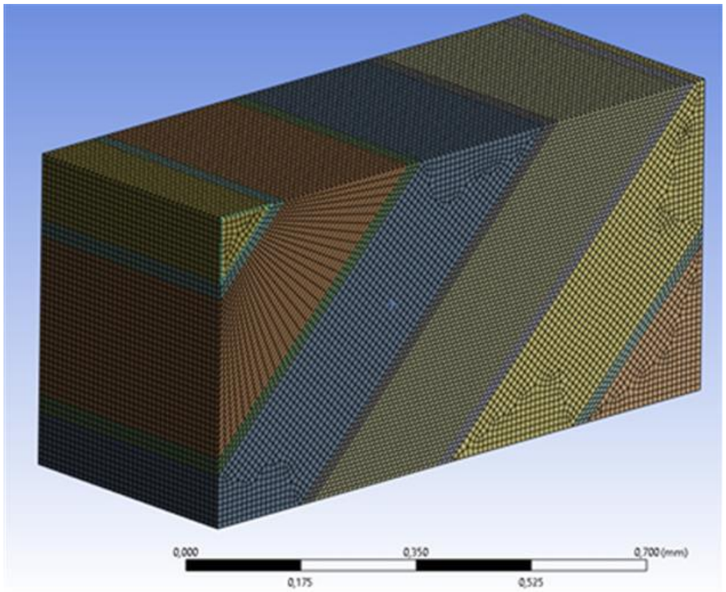
Microstructural analysis of fractured specimens was performed to assess internal structures, void formation, and layer bonding quality (Fig.1). These insights were essential for the design of a numerical model able to reflect the physical behaviour of FDM parts. The model consists of two isotropic material regions: one representing extruded filament lines and another simulating the bonding between layers. The model was implemented using Finite Element Analysis (FEA) and validated using angled tensile specimens. It was observed that the model successfully captured the anisotropic and nonlinear mechanical response of the printed parts (Fig.2).

The results of the research presented in this paper provide reliable, reproducible data on the mechanical performance of components manufactured commercially available desktop FDM printers and materials. It is a foundation for the predictive modelling of the mechanical properties of printed structures and provides practical guidance for FDM printing settings optimization for target performance. Critical process–property relationships that are often overlooked in simplified print setups but are vital for ensuring consistent material behaviour have been also noted and pointed out, providing additional research value.

The research results were used to develop a set of practical design and manufacturing guidelines proposed in this paper. These include recommendations for build orientation, material selection, and print strategy optimization, focusing on the minimization of print defects and improved interlayer bonding strength. Finally, the integration and cross-checking of experimental results with numerical modelling contributes to a deeper understanding of FDM printed part behaviour and supports the development of additive manufacturing workflows providing improved print reliability and efficiency.

This work has been supported by the University of Rijeka under project number uniri-iskusni-tehnic-23-168 and uniri-iskusni-tehnic-23-224.





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A Comparative Study of Directional Grown and Direct Energy Deposited Alnico 5

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[1]AIMEN Technology Centre , O Porriño, Spain, [2]University of Oslo, Oslo, Norway, [3]SINTEF Industry, Oslo, Norway, [4]Magneti , Ljubljana, Slovenija, [5]CEIT, Donostia-San Sebastian, Spain

Permanent magnet (PM) Alnico alloys, with the basic elements Fe, Co, Al, Ni and Cu, were invented and developed from the early 1930's. With respect to magnetic strength and energy product, rear earth element (REE) based magnets (ex. Nd2Fe14B, NdDyFeCoB, and Sm-Co alloys) are superior to Alnico alloys at room temperature. However, the limited access to REE and the high temperature stability of Alnico alloys have revitalized the interest for these PMs.

We report on an ongoing comparative study including the development of Laser Beam Direct Energy Deposition using metal powders (DED-LB/Mp) additively manufactured (AM) and directional [001] grown (DG) Alnico 5 magnets with nominal compositions listed in Table 1.

For the DED-LB/Mp printing, a pre alloyed, gas atomized Alnico 5 spherical powder was used. A systematic set of process parameters were tested on single and multilayer tracs and ~1x1x2 cm3 coupons were printed.

Table 1. Nominal composition (weight %) of the Alnico 5 DG sample and the pre-alloyed Alnico 5 powder alloy used for the DED printing process.

The structure and magnetic properties are evaluated and the alloying effects of Nb are discussed.

		Al	Co	Cu	Fe	Nb	Ni	Si	Ti
Alnico 5 DG	Bulk	7.58	23.80	3.09	50.73	0.43	14.03	0.32	0.02
Alnico 5 DED	Powder	7.94	23.77	3.02	50.55	0	13.91	0	0

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On the Effect of Dislocation Cell Structure on the Transformation Behavior of a Highly Metastable 304L Steel Processed by Laser Powder Bed Fusion

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[1] Institute of Physics of Materials, Czech Academy of Sciences,, Brno, Czech Republic,[2] Paul Scherrer Institute, Laboratory for Neutron Scattering and Imaging (LNS), Villigen PSI, Switzerland,[3]Laboratory of Technology and Strength of Materials, Department of Mechanical Engineering & Aeronautics, University of Patras, Patras, Greece

Introduction

Specific microstructure formed during the laser powder bed fusion process affects resulting properties of the manufactured materials in several aspects. In the metastable austenitic stainless steels, initial microstructure is the second most crucial factor after chemical composition, affecting the ongoing phase transformation. Present study explains the effect of the dislocation cell structure on the martensitic transformation of metastable austenitic stainless steel by comparing the deformation behavior in as-built conditions and after heat treatment, which reduced the dislocation density within cell walls.

Methods

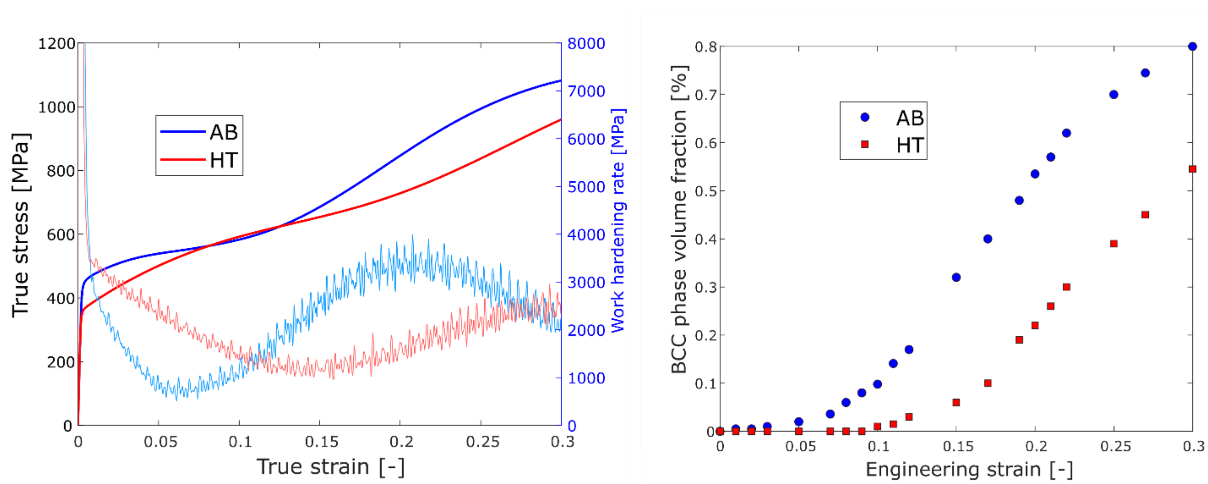
Metastable austenitic stainless steel of 304L grade was used in the study. The powder was processed via Ar-atomization, resulting in very low Nitrogen content. In order to reduce the dislocation density, the heat treatment consisting of annealing at 800 °C for 4 hours was applied on one series of specimens. The evolution of the deformation-induced martensite upon straining was monitored via a series of in-situ straining experiments using Neutron diffraction (ND) at the time-of-flight diffractometer POLDI at the Swiss Spallation Source, SINQ at the Paul Scherrer Institute, Switzerland. The samples were strained up to 30% engineering strain, with a 0.01 mm/s displacement rate. The obtained data were fitted using a Gaussian function in Mantid to obtain the integrated intensity of the diffraction peaks for both γ-austenite and α'-martensite. In order to monitor the evolution of the deformation-induced martensite during the early stages of the deformation, additional straining experiments were carried out, with specimens strained up to 5 % engineering strain, during which evolution of the ferromagnetic alpha prime phase was monitored using feritscope Fisher FMP-30. To explain observed mechanical behavior, specimen gauge lengths after straining experiments were longitudinally cut for microstructure observations and subjected to SEM and TEM characterization.

Results

Application of the heat treatment significantly reduced the macroscopic yield strength and significantly altered the work hardening rate evolution. Martensitic transformation starts significantly earlier during the deformation in the case of the AB series, with a higher total volume fraction of α′ after 30 % engineering strain. On the other hand, a mild decrease of the WHR in the HT series suggests a much larger capacity for dislocation forest hardening in the earlier stages of the deformation.

Conclusions

The cell structure with high dislocation density within the cell walls significantly hinders dislocation motion, significantly increasing the critical resolved shear stress. Under such conditions, when the material is macroscopically strained, the multiple slip systems are activated early in during the deformation in order to accommodate strain, resulting in the formation of the shear band intersections acting as nucleation centers of the formation of alpha prime martensite. Reduction of dislocation density via heat treatment application expectedly reduced the CRSS, and the amount of the shear band intersections observed in the early stages of the deformation was significantly reduced, resulting in the suppression of martensitic transformation upon straining.



Structural Integrity, Fracture & Failure Analysis

5

Analysis of the Accuracy of Methods for Estimating Component Service Life Under Multiaxial Loading

Prof. Michael Vormwald[1], Dr. Jan Kraft[1]
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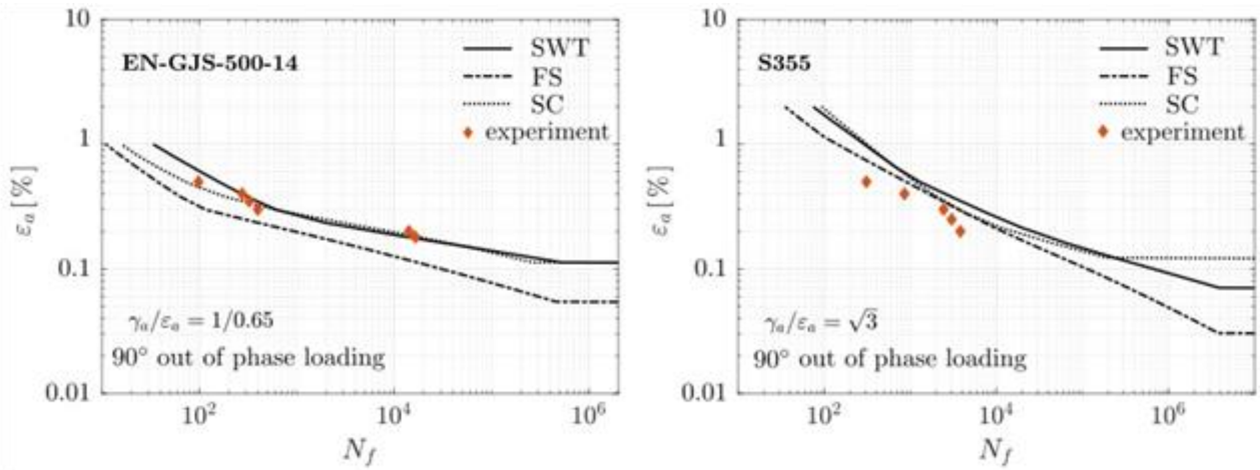
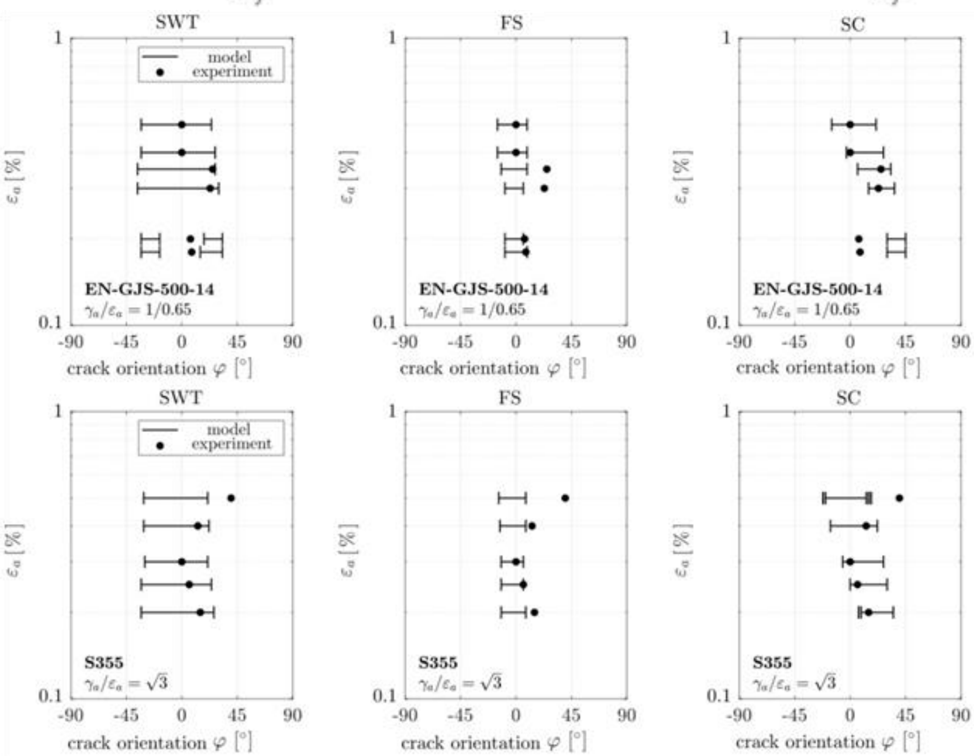
Introduction
The assessment of service life under multiaxial loading in guidelines for performing a proof of strength is an ongoing challenge. In a planned release of the recommendations published by the Forschungskuratorium Maschinenbau (FKM) updated critical plane approaches are considered to be launched. The present study is intended to validate the oncoming algorithms.

Methods
In this study, the multiaxial fatigue behavior of two materials, ductile steel S355 and cast iron EN-GJS-500-14, is investigated. Both fatigue lives and crack initiation angles are measured and compared to numerical results. To model the fatigue behavior, the critical plane method is used.

Results
All models – some of them are supposed to be included in future guidelines – can predict fatigue life with decent accuracy. The accuracy of the predicted crack initiation angles is less satisfactory. For the Smith-Watson-Topper (SWT) and Fatemi-Socie (FS) models, a weak correlation between the quality of fatigue life and crack orientation prediction is observed, depending on the materials ductility. The best fatigue life prediction for both materials is provided by the short-crack model (SC). Nevertheless, crack orientation estimation for the SC model is less accurate than the predicted fatigue life. Results are shown in the figures.

Conclusions
Both the FS-model and the SC-model are well suited to be disseminated as recommended procedures. Remaining inaccuracies must be covered by appropriate factors to provide conservative strength estimates under requested reliability margins.


EN-GJS-500-14
SWT
FS
SC
experiment
$\gamma_a/\varepsilon_a = 1/0.65$
90° out of phase loading
S355
$\gamma_a/\varepsilon_a = \sqrt{3}$
ε_a [%]
N_f


SWT
FS
SC
model
experiment
EN-GJS-500-14
$\gamma_a/\varepsilon_a = 1/0.65$
S355
$\gamma_a/\varepsilon_a = \sqrt{3}$
ε_a [%]
crack orientation φ [°]

50

Fatigue Performance of Hot-Formed Automotive Antiroll Bars

Dr. Christos Gakias[1], Dr. Efstratios Giannakis[1], Mr. Paschalis Adamidis[1], Mr. Yucheng Wang[2], Prof. Georgios Savaidis[1]

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Introduction

Antiroll bars are critical safety components of the axle suspension system in light, medium, and heavy trucks. Their primary function is to increase the torsional stiffness of the suspension, improving the vehicle's dynamic stability and steering behavior. Achieving the required fatigue strength depends significantly on heat treatment and surface shot peening, both of which are highly sensitive manufacturing processes. During operation, antiroll bars experience multiaxial-proportional stresses, making their fatigue performance a key factor in their design. This study investigates the primary factors influencing fatigue behavior and provides reliable S-N curves that can directly support stress-based fatigue design.

Methods

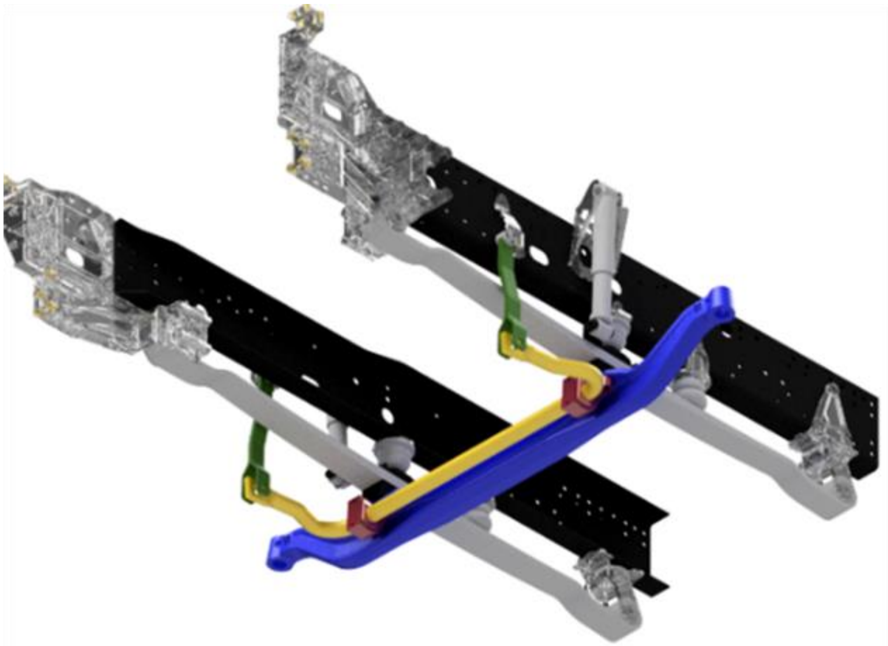
A series of fatigue tests at the load ratio of R=-1 was conducted on several serially manufactured components. Three different stress amplitudes were investigated. Fracture surfaces of selected specimens were analyzed to identify the causes of failure by means of optical microscopy. In addition, fatigue life affecting surface properties have been determined.

Results

S-N curves for various probabilities of survival have been experimentally determined, that offer insights into the durability of this critical automotive component. Furthermore, the study provides a comprehensive characterization of the microstructure and the mechanical surface properties at both the micro- and macro-scale.

Conclusions

The findings of this study serve as a foundation for developing advanced design methodologies for antiroll bars, particularly by accounting for the multiaxial stress state in failure-critical areas. the results set a solid base for analytical and computational approaches to fatigue life prediction, further enhancing the reliability and performance of these essential suspension components.



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On the Structural Integrity of Seam Welds in Cylindrical Pressure Vessels

Mr. Paschalis Adamidis[1], Dr. Christos Gakias[1], Dr. Efstratios Giannakis[1], Prof. Georgios Savaidis[1]
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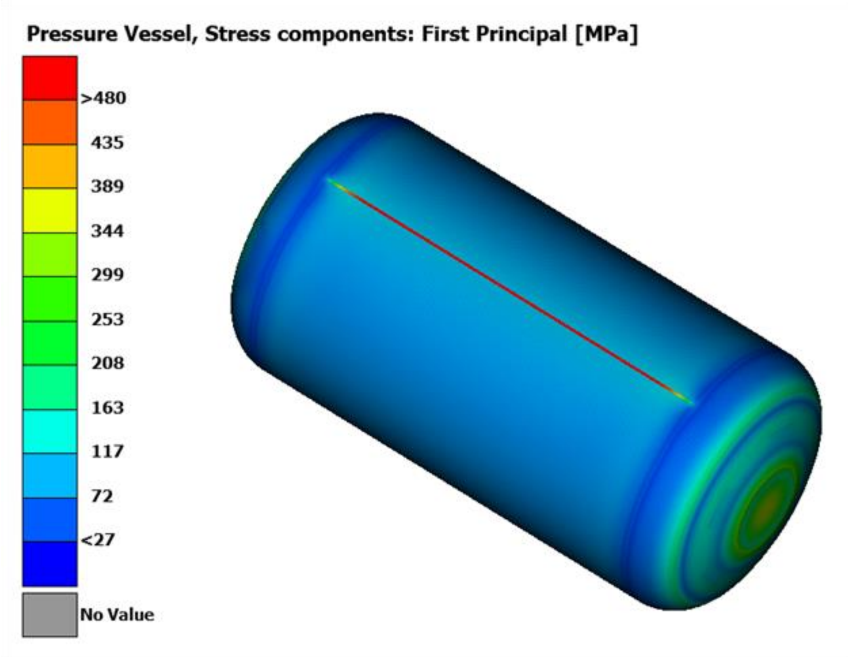
Introduction
Pressure vessels are widely used in industries where structural integrity and safety under cyclic and static loading is critical. Welded joints, being inherent stress concentrators, significantly influence the fatigue performance and load-bearing capacity of these structures. In particular, the degree of weld penetration can impact both fatigue life and static strength, affecting long-term reliability and safety. This study investigates the effect of weld penetration on the fatigue life and structural integrity of a welded pressure vessel, providing insights into the implications for design and manufacturing.

Methods
The analysis evaluates two welding conditions: full penetration and half penetration welds. Fatigue life is assessed using Nominal Stress, Structural Hot Spot Stress and Effective Notch Stress methods, following established guidelines such as EN 13445-3-2014, the International Institute of Welding (IIW) recommendations and the commonly used FKM guideline. The static strength of the welds is also analyzed to determine the maximum allowable operating pressure.

Results
For the load assumptions under consideration, half penetration seam welds exhibit both significantly reduced maximum permissible pressure and durability compared to full penetration welds. These reductions are quantified in dependence on the guidelines used for the theoretical calculation.

Conclusion
The findings of this theoretical study and analysis highlight the crucial role of weld penetration in the structural performance of pressure vessels. Full penetration welds ensure superior fatigue resistance and higher static load capacity, whereas half penetration welds significantly reduce structural reliability. Moreover, these results provide valuable guidance for the design, manufacturing and regulatory compliance of welded pressure vessels.


Pressure Vessel, Stress components: First Principal [MPa]
>480
435
389
344
299
253
208
163
117
72
<27
No Value

153

Innovative Fatigue Design Approaches for Tension Springs Using the FKM-Guideline „Analytic Strength Assessment for Springs“

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Introduction

The standard EN 13906-2 forms the essential basis for the design and calculation of helical tension springs. It is used not only nationally, but throughout Europe and internationally in the spring industry and by spring users. With regard to cyclic design, the standard only refers to fatigue tests to be carried out. There are no formulas for the analytical calculation of the existing stresses in the loops and no methods or diagrams for determining the permissible stresses for tension springs. Overall, there is no method for a mathematical verification of strength.
There are also no reliable analytical formulas in the scientific literature for calculating the existing stresses in the various loops and for the loop transitions. Due to the special properties of spring steel wires and the high residual stresses caused by winding, bending and heat treatment, “classic” procedures and guidelines for fatigue strength verifications cannot be applied.

Methods

In order to overcome the inadequacies, the tension spring design method was based on the FKM guideline “Analytic Strength Assessment For Springs”. However, the guideline only contains a general concept for verifications on springs and no procedure adapted to tension springs to determine permissible stresses at the fatigue-critical points. For tension springs, there are also no reliable analytical approaches for determining existing stresses in the transition from the spring body to the loops.
New analytical calculation approaches were therefore developed and compared with numerical simulations in an extensive parameter study. Parallel to the computational and methodological developments, an extensive test program with different materials, spring measurements and loop shapes was carried out, statistically evaluated and compared with the calculations.
The application of the guideline´s safety concept lead to conservative permissible stresses for the failure-critical areas, which had to be proofed by the test results.

Results

The comparison of the calculations with the test results shows good overall agreement. The mathematical description of existing stresses in tension springs is significantly improved or even made possible in the first place by considering the loops and the variables influencing the fatigue strength.
Easily applicable methods for determining existing and permissible stresses are developed as a basis for the design for the static and cyclic use.
The permissible stresses were determined for reference springs and prepared for spring engineers in the form of Goodman and Haigh diagrams. The new fatigue strength diagrams developed can be used directly for standard springs in standard applications, as known from compression spring´s fatigue design.

Conclusion

Concerning the state of the art and science, there are no practicable approaches for strength assessments or fatigue strength diagrams for tension springs.
The new method and the validation with extensive test data give an easy-to-use and yet reliable tool for designing tension springs for the first time. Competitive tension springs can be calculated for the first time and with less testing effort. The long-term goal is to update the previously mentioned FKM-guideline as well as the standard EN 13906- 2 for helical tension springs with the new approaches and fatigue strength diagrams.

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Analysis of the Cause of Failure of the Receiving Bridge of the Spreader

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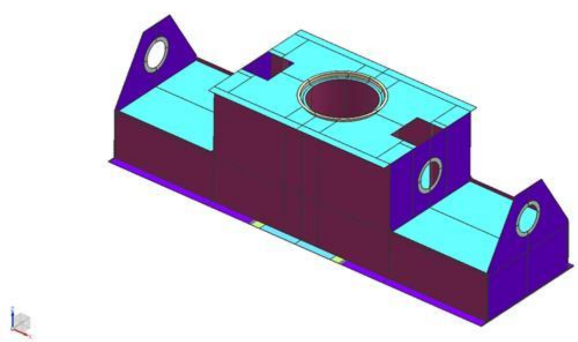
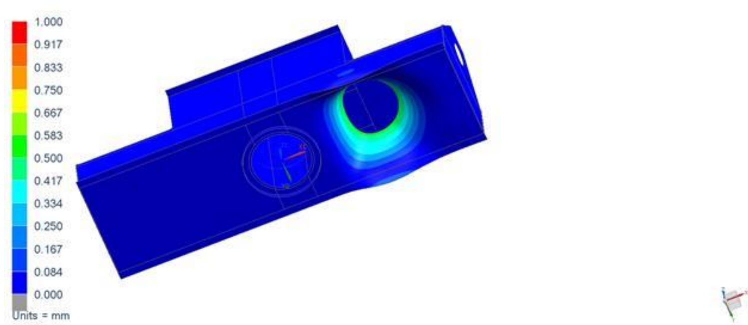
The article describes the causes of failure in the component of the receiving bridge of the spreader support system. In the described case, the traverse of the support system of the component in question has failed. The symptoms of the failure were sudden plastic deformation during the operation of the mentioned element (traverse) in the form of buckling of the lower chord of the steel structure. The article describes the situation and location in which the buckling phenomenon occurred. The process of verifying the actual state of traverse construction with the design state is also described. Its purpose is to verify the correctness of the behavior and execution of the elements of the carrying structure. The purpose of the numerical calculation was to determine the buckling factor as well as to evaluate the stress level of the original design. The results of the calculation showed that the buckling factor is equal to 1.5, which is the limit value allowed by the standards (assuming the standard operating conditions). The numerical buckling mode is shown in Figure 2 and is consistent with the one recorded on the real object.





E01

The Contribution of Human Factors in the Failure of Mechanical Components and Structures

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Failures of mechanical components and structures are often attributed to material or manufacturing defects, inefficient design, or operational overloads. However, a significant yet underexplored contributor is the role of human factors throughout the lifecycle of these systems. This is because the people who are responsible for the engineering design, materials selection, manufacturing and construction, quality control, operation, and maintenance make mistakes. Even the top management of an organization with the responsibility to ensure the necessary assets for safe operation make mistakes and are responsible for negligent administration. This work highlights the importance of human factors through the discussion of case studies of real-world failures: The BP Texas City refinery explosion, the Fukushima nuclear accident, the Tesoro Anacortes refinery explosion and the Eschede train accident. These examples indicate that the role of human factors in system safety is not being sufficiently addressed. By integrating human factors engineering into the design and operational workflows, the likelihood of failure can be significantly reduced. This work calls for a holistic approach, incorporating the development, certification and monitoring of safety culture in an organization to mitigate risks associated with human error, ultimately enhancing the safety and performance of mechanical systems.

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Precipitation of α-Dispersoids in Al-Mg-Si-Cu Alloys and Associated Influence on Deformed Microstructure

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Introducing dispersoids to retain the subgrain structure during thermomechanical working is important to mitigate the strength-ductility contradiction of aluminium alloys. Precipitation characteristics of dispersoids, such as size, volume fraction, particle-matrix interface, hold significant importance for their pinning force on recrystallization. This study systematically investigates the precipitation of α-dispersoids in Al-Mg-Si-Cu alloys and associated influence on deformed microstructure with varying Mn and Cr additions. Results indicate that combined addition of Mn and Cr leads to an improved dispersoids precipitation. In response to the resultant enhanced Zener pinning force, the alloy's recrystallization resistance is significantly improved. While notably, the alloy with sole Cr addition surprisingly exhibits better recrystallization resistance compared to the Mn-containing alloy, despite having larger dispersoid size and lower number density. HRTEM results reveal that the α-Al(Cr,Fe)Si dispersoids have a good atomic structure matching with aluminium matrix, the misfit between (002)Al // (3-3-3)α-Al(Cr,Fe)Si is about 4.3%, (020)Al // (2-24)α- Al(Cr,Fe)Si is about 2.4%. In comparison, the α-Al(Mn,Fe)Si dispersoids are partially coherent with the aluminium matrix, with the misfit between (020)Al // (044)α-Al(Mn,Fe)Si being about 8.9% and (022)Al // (008)α- Al(Mn,Fe)Si being 14.6%. The coherent interface of α-Al(Cr,Fe)Si dispersoids provides higher pinning force that effectively impede the recrystallization.

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Influence of Impurities on the Hot Shortness of Brass Alloys

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[1]Elkeme S.A., Oinofyta, Greece, [2]National Technical University of Athens , Zografos, Greece

Brass alloys are critical for numerous modern applications. However, a significant knowledge gap exists regarding the impact of impurities on their processability, particularly regarding hot cracking susceptibility. This issue is exacerbated by increasing recycling rates, leading to a higher concentration of impurities in the alloy pool. This study employs computational methods to assess the tolerance limits for common impurities in brasses. By analyzing impurity segregation at grain boundaries and identifying eutectic-forming elements, this work aims to provide valuable insights for optimizing brass production and minimizing the risk of hot cracking, ultimately enhancing the reliability and sustainability of these essential alloys.

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Microstructural Study of Welded and Repair Welded Dissimilar Creep-Resistant Steels Using Different Filler Materials

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[1]PPC Inspectra, Athens, Greece, [2]University of West Attica, Egaleo, Greece

Introduction
Power generation plants operate under extreme conditions characterized by high temperatures, elevated pressures, and corrosive environments. ASTM A335 Grades P22 (P22) and P91 (P91) are among the most advanced steels used in these applications. Despite their excellent properties, prolonged exposure to operational temperatures and stresses may lead to material degradation. Dissimilar welding between P22 and P91 plays a crucial role in power plant maintenance, enabling cost-effective restoration and extending system longevity. [1-3]. Additionally, repair welding imposes stricter metallurgical requirements to ensure resistance to various failure and corrosion mechanisms. [2-3]. This study focuses on the microstructural characterization of welded and repair-welded joints between creep-resistant steels P22 and P91, using two different filler materials.
Methods
Pipes of 58 mm in diameter with a thickness of 7 mm were welded using TIG welding. Two fillers were employed: a steel-based filler (AWS A5.5: E9018-E9018-B3H4R) and a nickel-based filler (AWS A5.14: ERNiCrMo-3) [4]. A single-V joint preparation was adopted while the heat input was kept below 1.5 kJ/mm. Pre-heating (PRH) and post-weld heat treatment (PWHT) were applied according to ASME B31.1 guidelines [5]. To simulate a repair welding scenario, a rectangular groove measuring 4.0 mm in width and 3.0 mm in depth was machined into the completed weld and then filled with the designated filler materials. A comprehensive metallographic analysis was performed.
Results
The study highlighted the impact of the different processes (dissimilar welding and dissimilar repair welding), as well as the effect of the different filler materials on the microstructure of the welded regions, including both the weld metal and the heat-affected zone, focusing on the formation of different phases, grain size and growth characteristics, and variations in microhardness.
Conclusion
The nickel-based filler material exhibited superior microstructural characteristics in all cases. Repair welding procedures had a significant impact on grain morphology and increased the likelihood of developing a microstructure prone to various failure types or corrosion mechanisms.

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Keywords: Creep resistant steels, dissimilar welding, repair welding, microstructural study.

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Anomalous Fatigue Crack Propagation Behavior in Near-Threshold Region of L-PBF Prepared Austenitic Stainless Steel

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Introduction

Laser powder bed fusion (L-PBF) process produces a specific non-equilibrium microstructure with properties significantly different from those of conventionally processed materials. It was found that rapid solidification results in the formation of the characteristic cell substructure with a very high dislocation density within the cell walls. This configuration offers significant strength enhancement due to the Hall-Petch strengthening. Despite the focus of many researchers on the topic of L-PBF-processed austenitic steels, the number of published articles dealing with fatigue crack propagation is limited, and several aspects of this phenomenon remain unclear. Considering the growth of fatigue cracks to be one of the most frequent failure modes in engineering applications, a thorough analysis of various aspects of fatigue crack propagation behavior in stainless steels produced by L-PBF is still needed.

Methods

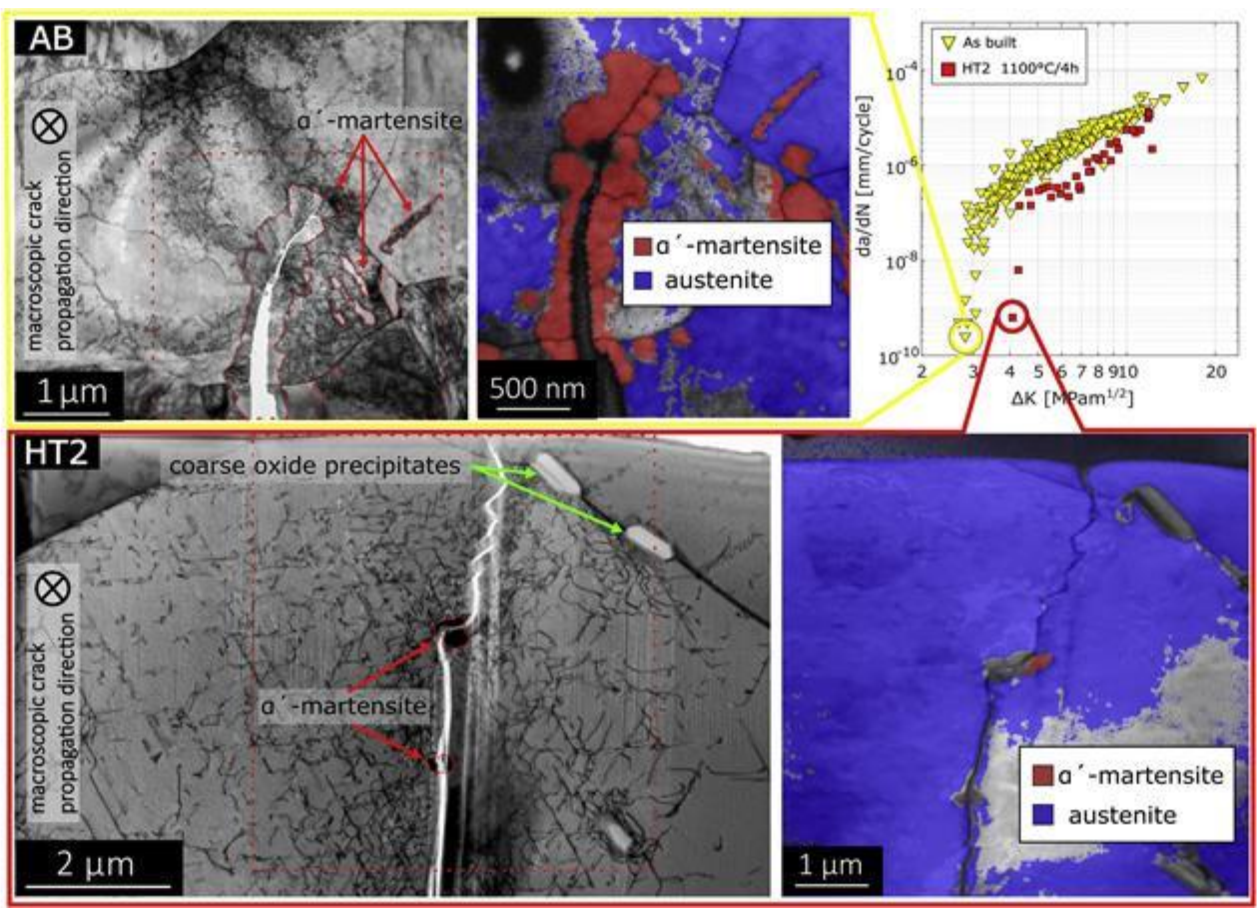
Three types of compact tension (CT) specimens, varying in different orientations of crack propagation direction with respect to the built direction (BD), were used to clarify the possible effect of specimen orientation on the fatigue crack propagation behavior. Subsequently, specimens of one orientation underwent two different heat treatments to shed light on the effect of characteristic L-PBF microstructure on fatigue crack behavior and to clarify the recorded low threshold SIF. Microstructures of all examined states were characterized by means of electron microscopy.

Results

The results showed the absence of the orientation dependence of the fatigue crack propagation behavior. In addition, abnormally low threshold stress intensity factor values were recorded, which were attributed to the absence of crack closure even at low load ratio ($R = 0.1$). In order to explain observed behavior, the specimens of selected orientation were heat treated to relieve build-in residual stresses (HT1) and to create recrystallized microstructure (HT2) comparable to conventionally processed (wrought) stainless steels. It was found that the characteristic microstructure produced by L-PBF is the main reason for the absence of crack closure and the low threshold values at low load ratios. Due to the cyclic instability of the matrix, the macroscopic cyclic softening occurs as a result within the crack tip region. Under such conditions, the formation of the plasticity-induced and roughness-induced crack closure is significantly reduced, and macroscopic resistance to the fatigue crack propagation is low.

Conclusions

Austenitic stainless steel 304L prepared by L-PBF process exhibited significantly lower resistance to fatigue crack propagation compared with its wrought counterparts. The low resistance to the fatigue crack propagation at low stress ratios (R = 0.1), especially in the near-threshold region, was explained by the absence of crack closure effect as a result of the cyclic softening of the austenitic microstructure prepared via L-PBF.



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A Micromechanical Model for the Toughness of Hydrogels

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The fracture of polymeric gels has been of growing interest in the last two decades, in particular in applications to biological tissue. Well established continuum theories that couple large deformations and fluid diffusion have been applied to gels to determine crack tip fields and the energy release rate. Some studies have combined experiment and calculations to determine the fracture toughness of gels and have shown that fluid effects make a substantial contribution to the toughness. Here we adopt a micro-mechanical view to estimate the fracture toughness of gels, defined as the critical (total) energy release rate, and show how the initiation toughness can be written as a combination of contributions from fiber scission and of fluid-solid demixing at the crack tip. This estimate is based on knowledge of a critical stretch and a volumetric strain when fracture is incipient and reveals dependencies on material properties including the solid volume fraction of gels. There have been no known ways to measure the de-mixing contribution directly from experiment, but the results in this paper provides a methodology. We also show how dissipation due to fluid motion as the crack propagates can contribute to the fracture toughness. Detailed results are presented for fibrin gels, which are the main structural component of blood clots. We find that the contribution of fluid mixing with the fibrin network to the initiation toughness for fibrin gels is significant at moderate critical stretches. We also find that fluid flow around a steadily moving crack leads to a contribution to the toughness that is linear in crack speed and fluid viscosity.

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Microstructural Aspects of Fatigue Striation Formation

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Fatigue striation formation in metallic materials is a complex process influenced by a range of factors, including the material's microstructure, external loading conditions, and environmental influences. Fatigue striations, which appear as periodic markings on fracture surfaces, provide valuable insights into the cyclic loading and crack propagation behavior of metals. Several models have been proposed to describe the formation of fatigue striations, each emphasizing different aspects of the underlying mechanisms. Microstructural properties, such as grain size, phase composition, and dislocation behavior, are known to significantly impact the formation and spacing of fatigue striations. Furthermore, micromechanical processes such as crack tip blunting, cold working causing dislocation density, and local plastic deformation play a crucial role in the development of these striations.

The external loading conditions, including load amplitude, frequency, and the presence of tensile or compressive stresses, also contribute to the formation of fatigue striations. Environmental factors, particularly those that prevent repassivation of the crack tip, further influence the process. For instance, corrosive environments can promote localized corrosion at the crack tip, affecting the crack propagation rate and striation development. This complex interplay of factors results in the characteristic striation patterns observed in fatigue fractures.

Despite the complexity of the fatigue striation formation process, empirical data and derivation suggests the existence of a lower limit value for the spacing of fatigue striations. This spacing, which depends on material properties, loading conditions and environmental factors, has a significant influence on the loading cycles determined in the fatigue crack analysis.

Understanding the mechanisms behind fatigue striation formation is essential for improving the fatigue life prediction of metallic materials and designing more durable engineering components.

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Damage-Tolerant Engineered Materials and Structures - What Can We Learn From Nature?

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In the final decades of the 20th century, biologists – together with architects and engineers – established a theoretical basis for the science of form, which has not only impact on biology but also on architecture and materials science [1]. A proven “damage-tolerant design” of nature are biocomposites that contain components with high fracture toughness [2]. As an example, microcracks in the outermost layer of a mollusk shell are steered into and finally trapped in an amorphous organic phase with high fracture toughness, located between calcite building blocks [3]. The transfer of such biological principles into the design of materials and systems on the micro- and nanoscale provides a new interdisciplinary perspective, and it has a huge potential in solving technical problems.

One option of “materials toughening” is the design of composites consisting of glass and metal components, where the metal structures have the function to slow down or even stop the propagation of microcracks in these composites. Since the plasticity of metals is reduced for micro- and nano-scale structures, this size-dependency has to be considered in the design of micro- and nano-structured materials and systems. For copper, the dependency of the interface fracture energy on the metal layer thickness was studied by Lane and Dauskardt [4]. The decrease of the energy release rate for microcrack propagation with the decrease of the size of copper structures (in the μm range) can be explained with the finite number of dislocations and with dislocation confinement. This effect of size-dependent copper plasticity is exploited in the design of guard rings (GRs), i.e. a specially designed metal structure at the rim of microchips with the function to dissipate energy in such a way that the propagation of wafer-dicing induced microcracks is efficiently slowed down and eventually stopped.

As an example, the microcrack propagation through a fully integrated multilevel on-chip interconnect stack in a microchip is demonstrated by positioning a miniaturized micro double cantilever beam (micro-DCB) test in the beam path of a laboratory full-field transmission X-ray microscope [5]. The critical energy release rate, Gc, for crack propagation increases significantly while the microcrack is approaching the GR structure [5], which can be explained by the fact that the Gc value includes not only the breaking of chemical bonds across the interface but also the plasticity of adjacent ductile copper structures.

The combination of micromechanical testing and high-resolution X-ray imaging of opaque materials and 3D nanopatterned structures opens the way for the development of design concepts for novel engineered materials based on their local mechanical properties. 100+ years after Griffith' theorem, it has the potential to contribute essential to the understanding of small-scale fracture mechanics.

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Experimental Investigation of Small Cracks Propagation Under Cyclic Loading

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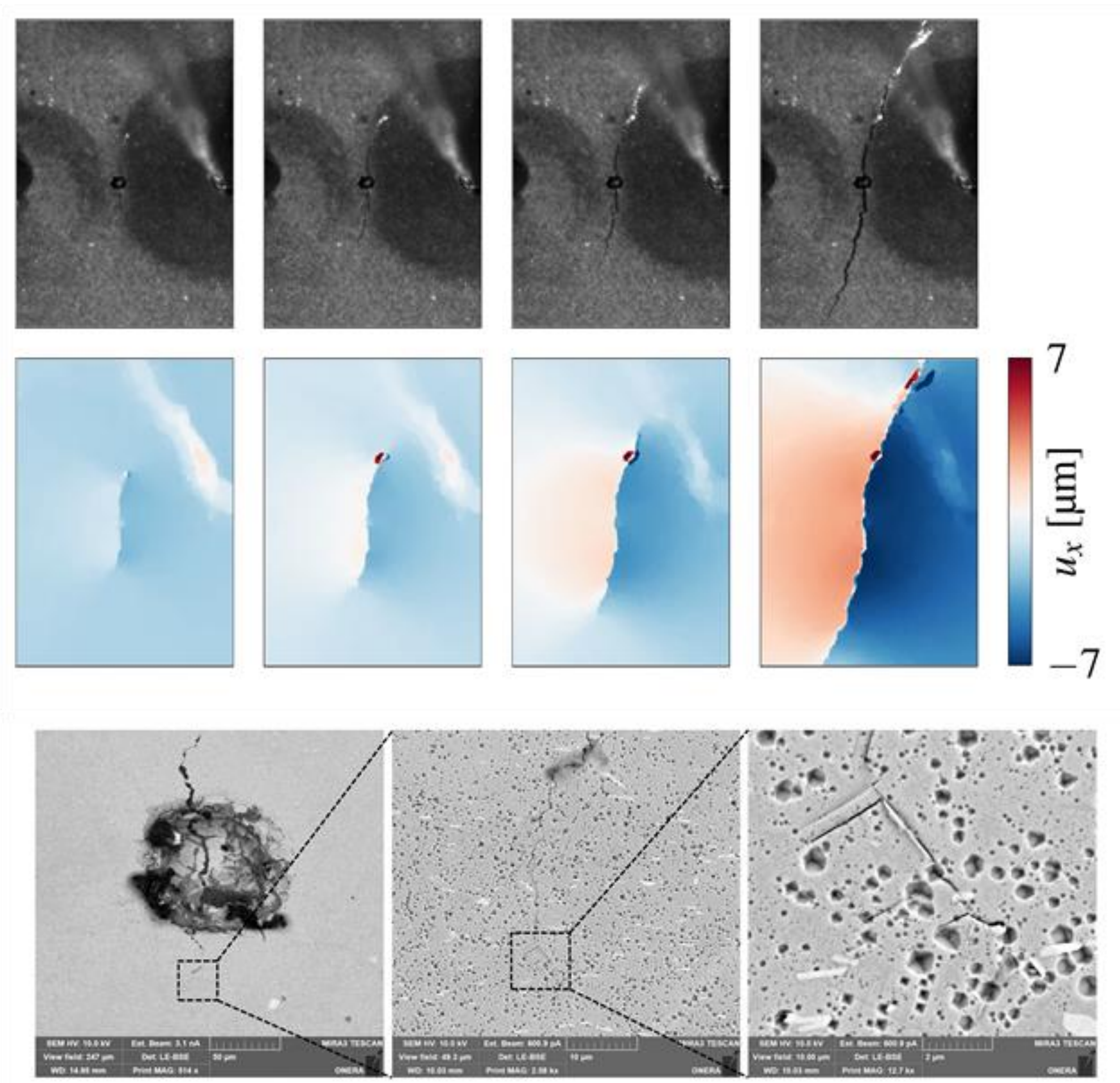
This work focuses on damage tolerance study and fatigue life prediction of aeronautical parts undergoing cyclic loading. The goals are to understand the propagation mechanism of small cracks by predicting their growth speed and path depending on the surrounding microstructural barriers (like twins and grains boundaries). This involves analyzing the interactions between plastic flow and the microstructure, and studying the roles of crystallographic orientations on the crack characteristics. The material of the study is INCONEL718DA, a nickel-based superalloy used in forged high-pressure turbine disks of aircraft turbojets. The cracks are initiated from a micro-defect artificially generated on the surface of the specimen. The study is carried out at room temperature.

To properly account for the influence of the microstructure on the characteristics of small crack propagation, we are considering three grain sizes, obtained by heat-treatments, ranging from conventional size (about 4µm) to a quasi-millimeter size (thus leading to an almost oligocrystalline consideration of the medium). Observation of dislocation mechanism, like stacking phenomena at grain boundaries, are expected. Moreover, we choose to tailor the defect by electro-erosion to avoid significant residual stresses and achieve the smallest defect possible (Ø~50µm) while still bigger than statistically observable natural ones (non-metallic inclusions like nitrides or carbides). Optimum surface treatments for MEB (EBSD) and optical observations (on speckles) are done by mechanical polishing, electro-polishing and chemical etching (cf. figures 1 & 2).

Conventional test protocol and monitoring technics were specifically adapted for small crack study. Tests are conducted from detection of crack initiation near the defect, to long crack propagation regime (with Paris law determination) and up to specimen fracture. Crack tip position is measured by electric potential, optical microscopy and images correlation associated with replica method at known fatigue cycles. The traditional pre-cracking stage is replaced by the determination of an incubation time at constant load. The K-decreasing stage is replaced by the determination of a microstructural propagation threshold at given length and K-increasing load. Those considerations lead to the utilization of a high-frequency fatigue machine (several hundred of hertz) associated with a high-speed camera (short integration time to avoid blurring) in order to have a significant time saving in reaching large numbers of cycles.

In this experimental study, we are starting to evaluate the effects of the surrounding microstructure on the small crack propagation mechanism. We will present preliminary results of the impact of the grains size and their crystallographic orientations on incubation time, microstructural threshold value and propagation law. Ultimately, the goal is to understand the role of the microstructural barriers on the small crack regime.



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Advances in Micro-Mechanical Fracture Toughness Measurements

Dr. Eric Hintsala[1], Dr. Douglas Stauffer[1], Dr. Oden Warren[1]
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Local measures of toughness are important for designing devices that are resistant to failure. However, the majority of quantitative measures of fracture are limited to measuring bulk properties, far removed from the microstructure or device level that determines local toughness values. Nano and micro-mechanical measures of local fracture toughness have evolved from the effort of Nihara and Lawn[1], who independently related indentation toughness to bulk measurements.
Through advances in micro-machining, using focused ion beam machined microscale beam bending specimens, fracture has further progressed with the ability to quantitatively investigate individual interfaces. These methods are still limited in that they are not always occurring in a plain strain condition. Also, the ductility found in many of the cantilever specimens require the use of the J-integral approach. An interesting sample shape evolution is the pre-notched double-cantilever beam, which are self-arresting to allow for detailed post-mortem investigation and can be tested as a function of temperature as shown in figure 1.[2]
Finally, a wedge loaded double cantilevered structure is presented that allows for multiple stable crack growth and arrest cycles, which enables an R-curve measurement in silicon.[3]

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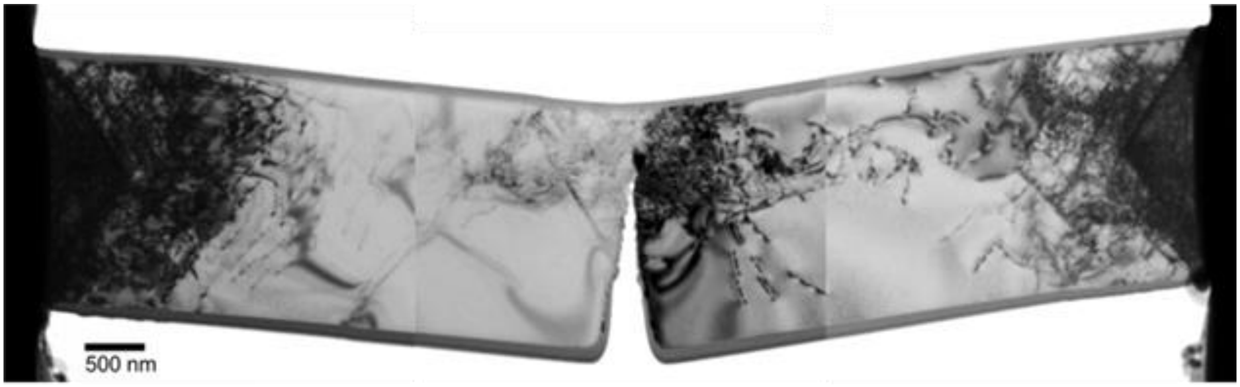

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Local Surface Toughening – Improvement of Stress Resistance by Using TPU

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Bonded joints offer numerous advantages compared to bolted joints when connecting different materials. However, the disadvantages of an adhesive bond like fatigue cracks can quickly become apparent under increased load, a challenge that is particularly prevalent in aviation because of the thin substrate material and the limitation in joint design. To address this issue, critical stressed components in aviation utilize a hybrid approach, incorporating both rivets and adhesive for structural bonding. This strategy aims the benefits of structural adhesive bonding while maintaining the safety associated with traditional bolted joints. Referred to as a fail-safe design, this concept prioritizes damage tolerance and enhanced resilience against manufacturing defects, achieved through a secure double load path. Especially when joining fiber-reinforced composites, bolts weaken the adherends of the joint and only contribute to load transfer when the brittle adhesive fails [1].
This study investigates the impact of local surface toughening [2] on the bond strength of thermoset adhesive joints using additional thermoplastic polyurethane (TPU) as toughening material. The concept is designed to introduce a crack arrest inside a pure bonded structural joint. Structural adhesive Mode I loading conditions are tested through quasi-static Double Cantilever Beam (DCB) test. Single lap joint (SLJ) tests are carried out to determine the influence of the TPU strip on the joint strength of a typical bonded joint combined load condition (Mode I and Mode II). The results show a pronounced influence of the TPU on the joint strength and an increase of over 15% in fracture toughness, indicating a significant improvement in the robustness of the joint and its resistance to failure.
[1] E. Paroissien, et al., Int. J. Adhes. Adhes.,77,p.183-197,(2017).
[2] M.J. Schollerer, et al., J. Adhes., 95:5-7, p.495-514, (2019).

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Works on Fatigue Crack Propagation in Railway Mechanical Components

Dr. Alexis Ratier[1], Mr. Philippe Feraud[1], Dr. Mac-Lan Nguyen-Tajan[1], Mr. Yann Cheynet[1], Mr. François Churlaud[1], Dr. Fabien Szmytka[2], Dr. Habibou Maitournam[2]

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To improve the rolling stock maintenance strategies and to extend the operational domain of existing mechanical components, while guaranteeing a constant high level of safety of the railway circulations, the Railway Testing Agency, which is part of the Rolling Stock Engineering Department of the French railway company SNCF Voyageurs, is studying both the fatigue cracks propagation mechanism and new solutions to strengthen existing mechanical components.

This article presents the two aspects of our approach, around a case study of a rupture by crack propagation of a component whose damage analysis was commissioned by a railway operator to the Railway Testing Agency. We will first present our work on fatigue life and crack propagation assessment, including striation counting and numerical simulations. Striation counting was first used on the exploitable area of the cracking surface shown in Photo 1, to obtain information on propagation speed. These results are compared with those obtained by numerical simulations (Cast3m software), from the thesis of François CHURLAUD.

Photo 1: Case study of a rupture by crack propagation

Then we will present a solution for improving the resistance of a component, based on a heat treatment (High frequency induction hardening) generating compression to prevent the propagation of cracks. The various qualification analyses are presented: hardness, microstructure, scale 1 fatigue tests and residual stresses, as illustrated in Photo 2 by the contour method. Complementary methods of DHD and X-Ray Diffraction have also been used, their results are presented and compared.

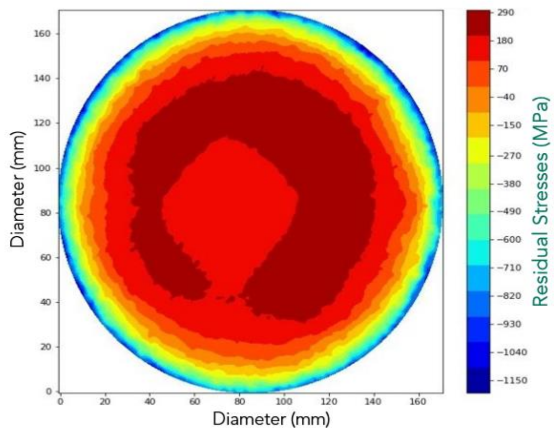

Photo 2: Residual stresses measured by contour method

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Predicting Fatigue-Driven Delamination in Curved Composite Laminates Under Non-Constant Mixed-Mode Conditions Using a VCCT-Based Approach

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Carbon-fibre reinforced polymer (CFRP) laminates are susceptible to both static and fatigue-driven delamination. Predicting this type of failure in curved composite structures, often referred to as delamination by unfolding, remains a critical challenge. This work presents the development of a Virtual Crack Closure Technique (VCCT)-based computational method for simulating fatigue-driven delamination propagation under non-constant mixed-mode conditions. The fatigue delamination growth model follows a phenomenological approach based on a Paris–Erdogan-based power-law relationship, where the delamination propagation rate depends on the strain energy release rate. This methodology has been implemented as a user-defined subroutine, UMIXMODEFATIGUE, for Abaqus, integrating the effects of load ratio and mode mixity conditions while leveraging the mode separation provided by VCCT. The proposed approach is validated against an experimental case involving a four-point bending test applied to an L-shaped CFRP curved beam specimen with a unidirectional layup. Unlike the existing standard configuration, the proposed test campaign introduces a non-adhesive Teflon foil insert at the bend, placed within the midplane layers to act as a delamination initiator, representing a manufacturing defect. In addition to the testing machine, digital image correlation (DIC) is used to monitor delamination length. The simulation method developed accurately predicts fatigue delamination propagation under varying mode mixity at the delamination front. By enhancing the predictive modelling of defects and delamination evolution in composite structures, this approach provides valuable results for timely maintenance and repair actions, helping to prevent catastrophic failures. Additionally, it deepens the understanding of how the mode mixity influences the delamination propagation process.

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Core Shell Rubbers for Toughening and Life Extension of CFRPs

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Introduction
Carbon-fibre-reinforced polymers (CFRPs) are extensively used in high-performance applications; they are, however, prone to impact damage and characterized by friability. Those challenges constitute the motivation of the following research that includes the incorporation of core-shell rubber (CSR) nanoparticles in the matrix of the examined composites as tougheners for the enhancement of CFRPs' mechanical behavior, as well the evaluation of patch repair techniques and subsequent NDT on artificially impaired composites, that simulate EoL CFRP parts or damaged panels.

Methods
The first investigation aimed to compare CFRPs made with reference and resin modified with CSR at 25% w/w. Two types of fabrics were used based on the mechanical test and according to the standard guidelines. CFRPs were fabricated using vacuum-assisted resin transfer molding.
The second investigation evaluated patch repair thicknesses: (a) equal to the original part and (b) half of the original part. Original composites were made with reference resin, while for the patches of the repairing process, resin modified with 25% CSR was used.

Results
Pristine and MX156 reinforced specimens were tested over their mechanical properties through flexural, tensile, impact, fracture toughness and short-beam tests.
The results revealed that MX156 system appeared ideal when ductility and damage resistance are demanded, due to the toughening mechanism and improved strain at failure. Regarding tensile test, despite the lower values compared to reference, MX156 is effective when energy absorption is of primary importance. Furthermore, specimens containing CSR particles revealed improved impact resistance, possibly assigned to their distinctive structural and energy-dissipation properties. Additionally, the modified MX156 resin system displayed noticeable improvement in fracture toughness, absorbing more than twice the amount of energy absorbed by the pristine panels. To conclude, after a specific displacement value, the shear strength of the enhanced panels formed a plateau, defining that CSR nanoparticles act as crack terminators, extending CFRPs' lifespan.

Regarding drop-weight impact test on Reference, Repaired 1:1 and Repaired 1:2 panels, the peak loads of the specimens revealed almost equal values, demonstrating that patch-repair technique used in Repaired 1:1 samples reinstates load resistance. It was also illustrated that CSR-modified resin system, when used in patches, could maintain the structural integrity of the repaired panels under peak loads. Contrarily, the peak loads of Repaired 1:2 specimens were notably lower, confirming the deficiency of the thinner patch to resist impact loads. With reference to energy absorption, the Repaired 1:1 samples surpass the reference ones, illustrating the enhancement provided by CSRs.

Concerning NDT, the C-scan images of the reference specimens outlined severe damage surrounding the impact site, accompanied by deep penetration into the thickness. In contrast, the delamination of Repaired 1:1 samples is significantly reduced, certifying that CSR-modified resin in patches can dissipate energy and crack propagation.

Conclusions

To conclude, MX156 is an effective system that should be used in dynamic or impact-critical applications, while those are energy-dissipating and improved toughness oriented.

Future exploration could include the long-term durability of CSR-modified CFRPs when exposed to extreme environmental conditions, and the optimization of patch repair techniques, investigating alternative adhesives and geometries.

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Lifetime-Centric Engineering Approach for Fiber-reinforced Polymer Springs Regarding Fatigue and Material Degradation

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Introduction

Fiber-reinforced polymer (FRP) composites are particularly suitable for spring applications due to numerous advantages like lightweight design, intrinsic damping, or chemical resistance. In addition to the numerous design advantages, FRP also have some challenges.

While basic material properties of composites such as anisotropy and inhomogeneity are always taken into account in component design, fatigue and degradation are usually only considered in the detailing design steps or trough experimental tests.

The time and stress exposure during the design life lowers the stiffness of the material caused by creep and micro damages. Additionally, the strength degrades depending on the number of load cycles. For components, this means that tolerances can no longer be maintained over the course of use, for example, or even the safety requirements are no longer fulfilled.

The aspect of stiffness loss is far more important for springs, because the spring's function is sensitively affected. If the spring rate is being reduced, the tolerance for the required forces to ensure the assembly function can be compromised. Therefore, fatigue and degradation must be taken into account when designing FRP springs.

Methods

In our recent publications, we published a new, generalized approach for a holistic FRP spring design method. To further develop this method, we want to take the stiffness loss as well as degradation into account in early design stages.

Therefore, assumptions had to be made not only for the material properties, but also the requirements regarding spring function must be defined depending on time and load. Through this connection between requirements and material behavior on a basis of load and time, a generally new aspect is being introduced, offering a design window.

There are engineering approaches in which the basic elasticity variables $E\perp$, $G\perp\parallel$ and $\nu\perp\parallel$ are reduced using reduction factors η, which can be described using analytical relationships. These should be used in the first step to described the changes of the spring characteristics.

Results
To validate this approach, a test database with tape specimens made of GFRP under cyclic torsional load is being used. It could be shown in accordance to the expectations, that the time and load dependencies exist and can be adjusted to the test database.
Furthermore, the suitability for a CFRP volute spring should be analyzed, from which there were a few test samples and experiments existing. The spring was cyclically loaded with pressure force, leading to a high material utilization. It could be shown, that the spring rate and the spring length are being reduced. The expectations were also confirmed and could be modelled using the approach.

Conclusion
The consideration of time- and load-dependent material properties and linking them with equally dependent requirements in the spring design are completely new aspects in the calculation of springs made of fiber-reinforced polymers.
Compared to the design and usage of metal springs, this also opens up new possibilities for adapting spring properties depending on the lifetime phase of the spring. The approach was tested in initial trials and offers starting points for further studies.

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Enhanced Euler-Bernoulli Fiber Force-Based Beam Analysis Using Simpson's Integration

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This work presents an enhancement to the formulation of the Euler-Bernoulli fiber beam force-based model by incorporating Simpson's integration scheme for two-dimensional (2D) stress field integration over the cross-section. This integration is applied to compute the element's general forces (axial force N and bending moment M) as well as the flexibility matrix for both bending and torsional terms. The flexibility matrix is then inverted to obtain the stiffness matrix.

The proposed improvement has been implemented in the open-source computational mechanics code MSolve and compared with the classical trapezoidal rule integration used in ANSYS and OpenSees. Results indicate that the proposed model offers a more robust integration method for the flexibility matrix and, consequently, for the stiffness matrix. Furthermore, the stability of the load-displacement curve in cyclic nonlinear analysis is improved, with the percentage divergence between the two integration methods remaining significantly low. Across all tested examples, the maximum relative divergence is on the order of 5%.

This methodology is applicable to various one-dimensional material constitutive models, including combined nonlinear hardening, the Ramberg-Osgood model, and the Kent-Park concrete model. The effectiveness of the 2D Simpson integration scheme is demonstrated in both uniaxial and biaxial bending cases. Additionally, the framework has been tested under cyclic and monotonic static loading—scenarios known to be particularly challenging in computational mechanics due to numerical instability.

Overall, the proposed approach leads to more stable and accurate simulations in nonlinear structural loading, reinforcing its potential for advanced computational mechanics applications.

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Integrated Strategies for Structural, Thermal and Fire Failure Mitigation in Lightweight TRC/CLCi Composite Facade Panels

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The thermally efficient and lightweight TRC/CLCi composite panels for functional and smart building envelopes, funded by the iclimabuilt project (Grant Agreement no. 952886), offer innovative solutions to sustainably address common failure risks in facade systems. This work specifically emphasizes on strategies for mitigating structural, thermal, and fire-related failures through targeted material selection, advanced design methodologies and rigorous validation protocols. To effectively mitigate structural failures, high-pressure concrete (HPC) reinforced with carbon fibers is utilized, significantly enhancing tensile strength, reducing susceptibility to cracking and improving overall durability. To counteract thermal bridging—a critical failure mode compromising energy efficiency and structural integrity—the panels employ specially designed glass-fiber reinforced pins connecting HPC outer layers through the Cellular Lightweight Concrete (CLC) insulation core that has a density of around 70 kg/m3 and a thermal conductivity in the range 35 mW/m·K comparable to those of expanded polystyrene and Rockwool. These connectors ensure effective load transfer and maintain optimal thermal performance. A central focus of the failure mitigation strategy is robust fire behaviour. The developed panels undergo rigorous standardized fire tests, achieving an exceptional reaction to fire classification of A2. This outcome confirms that HPC layers maintain structural stability and integrity even under prolonged fire exposure, effectively preventing catastrophic failures and ensuring occupant safety. In conclusion, this work highlights explicit failure mitigation strategies—reinforced concrete materials for structural stability, specialized glass-fiber connectors to prevent thermal bridging, rigorous fire behaviour protocols and comprehensive thermal performance validation—to produce a facade system that is robust, energy-efficient, fire-safe, and sustainable for modern buildings.

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A Machine Learning Based Approach for the Design of Ductile Iron in a Critical Raw Material Perspective

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[1]University Of Padova, Vicenza, Italy, [2]Tongji University, Shanghai, China, [3]University of Rome, La Sapienza, Rome, Italy

One of the most important challenges of this century is to guarantee the supply of raw materials that are fundamental for the economy of a country but that at the same time suffer from supply risk because of different reasons such as scarcity, geopolitical instability of supplier countries, lack of possible substitutes, and so on. The European Union (EU) defined a list of such critical raw materials (CRMs) that is updated every three years, and it is extremely motivated to spend a huge effort to find and develop mitigating actions against this issue.
In this scenario, ductile iron (DI) is a strategic material for mass production at low cost and high mechanical performances that however requires some CRMs to be produced such as Si, Ti, Mg, Nb, and Sb. One possibility to overcome this drawback is to find substitutes that could replace CRMs in DI chemical composition without reducing or even improving the mechanical properties of the alloy. To reach this goal, an AI-based model is developed that can predict static mechanical properties of DI starting from the chemical composition. Finally, some low CRMs-content compositions obtained by the model are proposed as an example.

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Interdisciplinary Communication of Fracture Analysis via a New Three Phase Epistemologically Grounded Approach to Fractography

Ms. Deborah Aliya[1]
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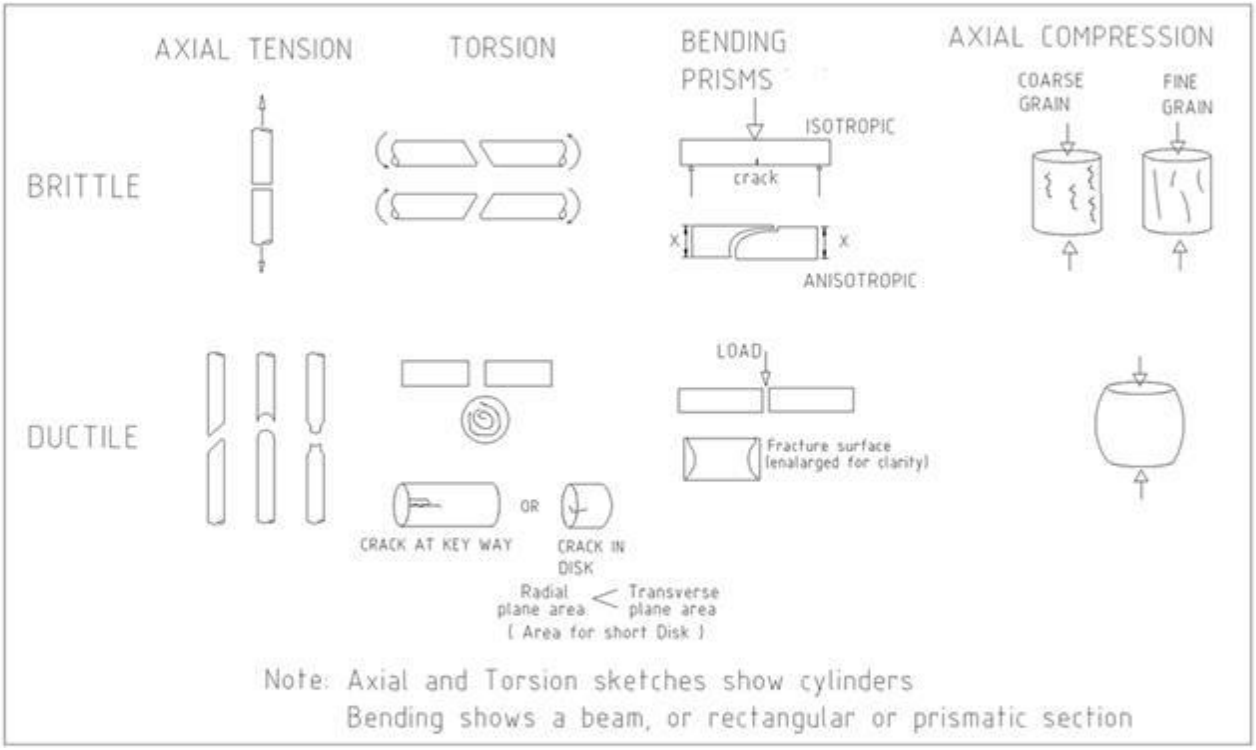
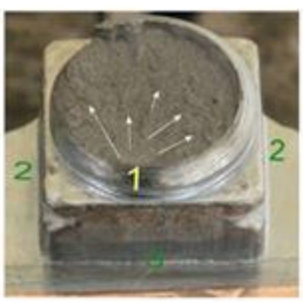
Objective
Metallurgists and Materials Engineers form the minority of the engineering profession. It would thus behoove us to explain why things break in a way that is readily comprehensible to the wide range of people interested in our work. This includes mechanical, civil, and electrical engineers, attorneys, quality engineers, even bean counters, who we may have to convince that it's worth spending the extra money on the material or process that will be less likely to "fail."

Methods
This may readily be achieved by focusing first on how the loading geometry affects the crack orientation, and how the resulting crack orientation is modified by the mechanical behavior of the component. These are features that in many cases are readily visible to anyone with typical human vision. The number of basic choices of loading geometry that is required to convey the basic principles is four, and of the mechanical behavior is two. Combined with a simple explanation of the expected crack location, position, and direction, materials engineering focused failure analysts may readily and clearly explain to a wide range of parties whether there is anything "suspicious" about the crack.

Results
By this method it also becomes possible in many, but not all, cases, to create a clear criterion by which one may differentiate benign discontinuities from defects. Furthermore, this method can be used to extract useful information about the fracture even when the crack surfaces are corroded, damaged, or covered with contaminant / deposit. Once all that useful information is extracted from the macro and meso scales, the usual techniques of determining or confirming the damage mechanism with microfractography and materialography may proceed by standard practice.

Conclusion
Using this method is much more conducive to transparency and building consensus than starting off by explaining phase diagrams, fuming etchants, second phase particles and their dislocation interactions.





A faint fan pattern is highlighted by the white arrows.

Determine Crack DIRECTION Through the Use of:

Particular Features
ridge patterns
coloration
steps
texture
fan patterns
beach marks
ratchet marks

OR

The Smooth to Rough Rule

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Visual Inspection: Holistic Versus Formulaic Approaches

Ms. Deborah Aliya[1]

[1]Aliya Analytical, Inc., Grand Rapids, United States of America

Objective

Visual inspection and background documentation review are the key parallel first steps in a failure analysis. Usually, photo-documentation accompanies the visual inspection. Many people doing "routine" forensic work have a formulaic approach to photo-documentation, especially when this approach is most damaging, as part of forensic investigations. The investigators are often in a hurry, perhaps trying to be considerate of others who need to view the evidence. This is understandable when there are 3 or more parties at a destructive testing party. However, it's unlikely that all potentially relevant features will be noticed when someone takes a series of photos, whether six, 16 or 160, without taking the time to look before they point their cameras. Yes, the new generation of small digital cameras is fantastic. But they don't replace looking at the evidence. In this presentation, some hints to cultivate open-mindedness and the ability to notice relevant features will be presented.

It's important to go beyond the idea that the key purpose of the photos is to prove you attended the inspection.

Methods

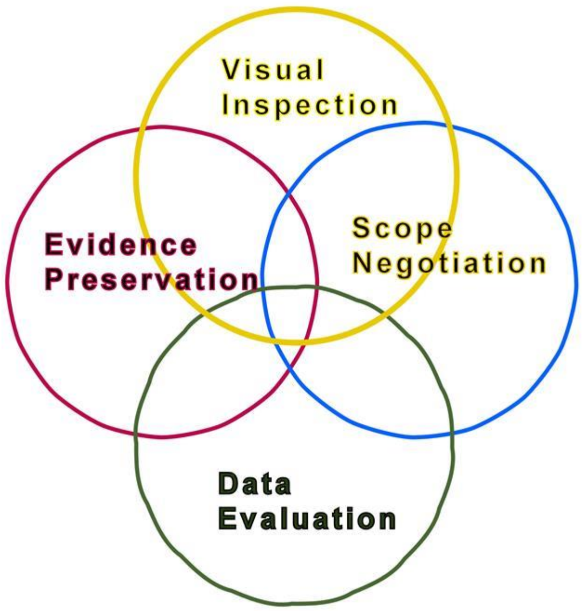
Visual inspection may be accomplished with the unaided human eyeballs/brain/mind, corrected human eyeballs/brain/mind, or, for smaller Subjects, with optical or electron microscopes. The magnification is less the issue than what we are trying to accomplish. The visual examination for failure analysis must be done in two phases: Looking FOR and Looking AT. The first is easier, and is commonly taught by anyone teaching or mentoring in the failure analysis field. Looking at something, to see what's there, is more difficult, because it's not defined.

We must adopt a methodology to facilitate our learning to be open-minded and open-eyed, so we can notice features that would never appear on a list of what others have been able to compile.

Results

With practice the new methodology, published in the Author's book "Constructing Competence in Failure Analysis: a technical and human factors guide, starts to pay off, allowing the failure analyst to notice features that they would have missed in the past.

Conclusion
Even people with many years of experience can learn to master the critical skill of visual examination at a higher level.



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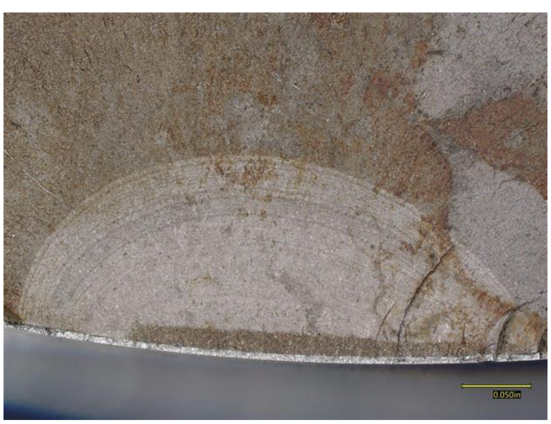
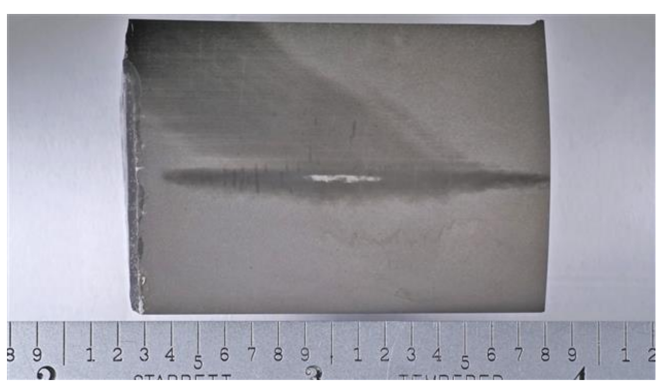
NTSB Investigations of High-Strength Steel Landing Gear Components Fracturing From Fatigue Caused by Excessive Grinding

Dr. Erik Mueller[1]
[1]*National Transportation Safety Board, Washington, United States of America*

The National Transportation Safety Board is an independent federal agency investigating transportation accidents across aircraft, rail, pipeline, marine, highway, and hazardous materials modes. Among these events, the agency has investigated multiple accidents involving fractures of landing gear components during landing. In these cases, the failed components exhibited fatigue thumbnail cracks on the fracture surfaces, initiating at the surface. These investigations discovered that the crack initiation sites coincided with areas displaying marks consistent with excessive heating. These marks, or 'burns', developed during grinding operations from rework of the parts. This presentation will detail how fatigue cracks initiate at these areas of excessive grinding, the fracture morphologies observed, and the diagnosis of the issue in an investigation. The presentation will also discuss safety improvements to prevent the fracture sequence from reoccurring, as well as the challenges of finding areas of excessive grinding and heat inputs to high-strength steel parts during rehabilitation.





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Failure Investigation of Inconel 625 Alloy Boiler Tube

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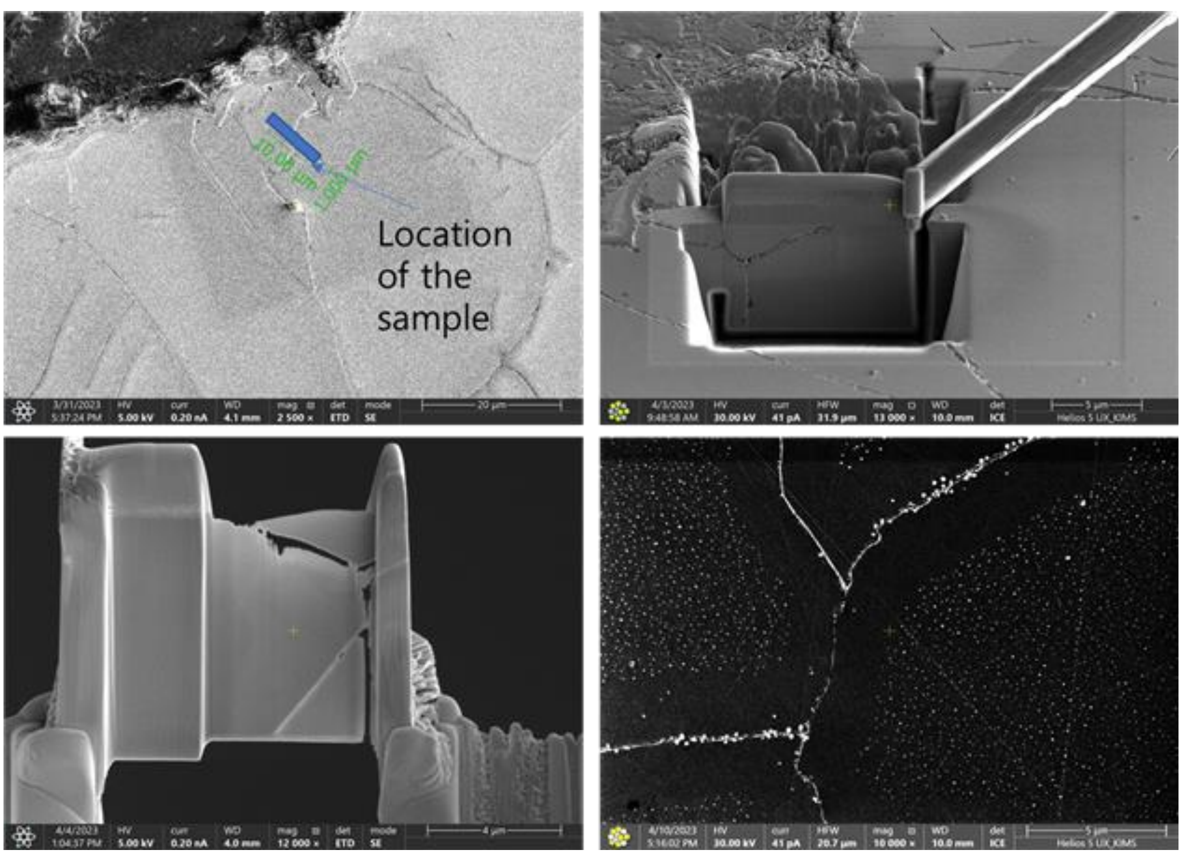
This study investigates the failure of Inconel 625 alloy tube for superheater boiler. The tube had been serviced for two years and the leakage of the tube was observed during the period of regular maintenance inspection. The microstructural investigation was performed to reveal the cause of the crack by utilizing scanning electron microscopy and transmission electron microscopy. It was found that the crack was propagated through the interface of the weld of the tubes. The result of microstructure analysis presents the phase transformation of the Inconel 625 affects on the failure with the combination of stress corrosion cracking environment. Gamma double prime particles and the Ni2(Cr,Mo) precipitates were formed due to the long term high temperature exposure and the formation of Cr-rich carbides at the grain boundaries leaded to generate precipitate free zone (shown in figure 1) which weaken the grain boundaries. And it leads to the stress corrosion cracking at the weld interface. The detail of the investigation will be presented in the conference.



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Research on the Behaviour of Diamond-Based Porous Structures Under Compression

Prof. Katarina Monkova[1], Dr. George Pantazopoulos[2], Dr. Marianthi Bouzouni[2], Dr. Sofia Papadopoulou[2], Dr. Anagnostis Toulfatzis[2]

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Product development through 3D printing has revolutionized the manufacturing industry. With the advancement in technology, 3D printing has become more accessible and affordable, providing an efficient and cost-effective way of prototyping and producing new products. The benefits of 3D printing in product development extend beyond the reduction of costs and lead times. It also enables designers and engineers to explore more complex and intricate designs that were previously not feasible, resulting in innovative product offerings that better meet consumer needs. This has led to an increase in product customization, allowing businesses to offer tailored solutions to their customers not only in an industry (such are automotive, aerospace or aviation) but also in biomedicine and health care fields. The research was focused on the investigation of the mechanical properties of porous structures made by the Direct Metal Laser Sintering (DMLS) of Inconel 718. Two types of basic cell topology, mono-structure Diamond (D) and bi-structure Diamond+ Gyroid (DG), with material volume fractions of 10, 15, and 20 %, were studied within the research to compare their properties under quasi-static compressive loading. The testing procedure was performed at ambient temperature with a servo-hydraulic testing machine at three different crosshead testing speeds. The recorded data were processed, while the stress–strain curves were plotted, and Young's modulus, the yield strength Re0.2, and the stress at the first peak of the local maximum Rm were identified. Uniform compression was succeeded without shattering fracture up to approximately 80 % compressive strain (apart from the Diamond structure which was only slightly compressed due to overloading). The minimum measured load (during the first peak) of 76 kN was recorded at the Diamond+Gyroid structure with 10 % volume fraction at 10 and 100 mm/min testing speeds, while the maximum load exceeding 250 kN was reached by a Diamond 20 % structure; however, the precise value of Fmax couldn't be recorded due to testing machine overloading at all three testing speeds. Overall, it can be stated that testing speed does not significantly affect the maximum force results (variations < 5 %), especially for volume fractions 15 % and 20 %.

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Study of the Strength of Mooring Lines of Floating Wind Turbine on Fatigue With Deterministic and Probabilistic Methods

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Introduction
Majority of the fatigue damage on offshore structures is generally assumed to be caused by relatively frequently occurring moderate sea states, i.e. sea states with significant wave height in the range of 4m - 8m. This study aims to investigate the inter relationship between fatigue damage versus sea state severity, on a moored offshore hybrid structure for wind and wave energy absorption. The examined floating structure encompasses a system of four oscillating water columns (OWC), in a square arrangement, whereas at the center of the structure a floating wind turbine of horizontal axis is supported.
Methodology
There is a plethora of implemented methods in the problem of fatigue such as energy methods, stress methods, strain methods, rainflow method and of course probabilistic methods such as Monte Carlo simulation and probabilistic S – N fields. In this study, the analysis is performed using both a deterministic and a probabilistic method. The spectral-based fatigue assessment method is the deterministic one and attempts to account for the random nature of sea states in a rational manner. The analysis is performed using the sea scatter diagrams of three different locations, Kassos - Sicily - North Sea and then developing the structure's stress response spectrum. The Rayleigh distribution and the number of response cycles of the process are combined to calculate the number of cycles for a constant stress range in a given stress block. The number of cycles to failure corresponding to the stress range in the given stress block are determined from the S-N curve. The effect of the accumulated fatigue damage on the structure is observed by analyzing the S-N curve with single slope. Finally, the linear damage calculation by Miner-Palmgren summation is used to evaluate the accumulated fatigue damage. The probabilistic part uses the Rayleigh and the lognormal cumulative density functions of the stresses, in order to predict the probabilities of survival in a 31 year period, which is the period of the records. After calculating probabilities for all sea states, in the context of the linear theory, the probabilities are accordingly weighed in order to extract a total probability of survival for the general sea states of the three regions.
Results & Conclusion
The fatigue analysis results have asserted the first claim that fatigue damage in the structure is observed to be caused due to the moderate sea states. The percentage 65% to 80% of the accumulated fatigue damage is induced in the structure by the moderate sea states. This is because the moderate sea states are more than the higher sea states and have relatively higher stress ranges than the lower sea states. density function, the probabilities of survival of the structure in the different locations were calculated. The Mediterranean

locations had very close probabilities of survival about 75% while the North Sea location introduced a probability of approximately 25%. The results render also evident that the specific device can operate in the Mediterranean Sea, whereas in the North Sea the probability of survival is reduced significantly.

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Enhancing Characterization and Failure Analysis of Thin Films and Interfaces Through Advanced Surface Analysis Techniques

Mr. Wolfgang Betz[1], Dr. Norb Biedermann[1], Dr. Kateryna Artyushkova[1]
[1]Physical Electronics, Chanhassen, USA

Problems related to surfaces, thin films, and interfaces of materials, such as adhesion, contamination, corrosion, delamination, and friction, significantly impact product performance, safety, and the manufacturing process. Often occurring at the nanoscale, these challenges demand surface-sensitive analytical techniques capable of distinguishing the surface from the bulk material.

Through several case studies, instrument manufacturer Physical Electronics (PHI) will showcase how state-of-the-art surface analysis instruments and analytical methods serve as pivotal tools in enhancing materials characterization and failure analysis. Techniques such as X-ray photoelectron spectroscopy (XPS), hard X-ray photoelectron spectroscopy (HAXPES), time-of-flight secondary ion mass spectrometry (TOF-SIMS), and Auger electron spectroscopy (AES) will be highlighted.

XPS and HAXPES are utilized for quantitative elemental and chemical-state analysis of surfaces as well as buried interfaces tens of nanometers below the surface, which contain key information inaccessible by other analytical techniques. These methods also enable non-destructive measurement of film thickness approaching the thickness of a single monolayer.

TOF-SIMS analyzes long-range molecular structures at the surface. In addition to identifying large molecules, a critical ability in the failure analysis of polymers, TOF-SIMS is capable of detecting species at parts per million to billion with nanometer spatial resolution, a critical tool to detect low-level species that may lead to material failures. TOF-SIMS also offers the capability of depth-profiling large organic molecules in thicker thin films below the surface without degrading their chemistry.

AES provides nanoscale resolution elemental mapping, essential for analyzing nanoscale features that may be responsible for material failure. Compared to the more traditional SEM-EDS (scanning electron microscopy and energy dispersive X-ray spectroscopy) approach commonly used in failure analysis laboratories, AES offers superior spatial resolution and surface sensitivity, making it ideal for analyzing ultra-thin surface layers and small particles.

Scientists and engineers routinely incorporate these advanced surface analysis techniques in their analytical toolbox to characterize and resolve materials failures.

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Failure Analysis of Compressor Plate Valve Seat

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This research deals with a failure of the valve seat which is a part of an air compressor plate valve. It is suction and delivery valve at the first stage of the reciprocating compressor. The compressor served in the engine room of a LNG carrier. Failure occurred during normal operation, before the overhaul recommended by the manufacturer. Failure analysis combined experimental and numerical research. Microscopy, optical and scanning electron (SEM), was used to inspect damaged surfaces, detect possible flaws and microstructure of the material. Optical observation revealed surface cracks that propagated to a failure around the center of the valve seat. These cracks are located on the radial ribs in the suction area. A crack emanating from a deep corrosion pit was also detected, but no failure occurred at that location. Observation of fracture surfaces disclosed the presence of ductile fracture with final overload fracture surfaces and also some areas that contain secondary cracks. In order to gain better understanding of the failure process, a finite element (FE) stress analysis is performed. The stress distribution showed that stresses do not exceed allowable limits and that they are highest near the outer edge of the valve seat, not around the center. The stress intensity factor calculation also showed that their values are below the critical value. However, the values of the stress intensity factor range are large enough to initiate crack propagation. In addition, the loading frequency was 15 Hz, which implies that valve seat was exposed to the high cycle loading. The research results indicate that the cause of the failure are surface cracks originated by improper heat treatment in combination with high cycle fatigue in corrosive environment.

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Failure of Corrosion-Resistant Alloys (CRA): Effect of Operating Environment and Stress

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Corrosion-resistant alloys (CRAs) have been developed to resist degradation by oxidation or corrosion in extremely corrosive environments. CRAs include duplex and superduplex stainless steels, nickel-base alloys, titanium, molybdenum, zirconium and tantalum base alloys. Despite their excellent general corrosion resistance, there are cases where CRAs suffer from localized corrosion leading to failure of infrastructure in the process industry (refineries and chemical industries), with severe consequences regarding downtimes and increased costs from repairs and equipment replacement. In the present work, two cases of corrosion damage of CRAs are presented. The 1st case is concerned with the rapid corrosion of Hastelloy C-22 tubes operating in sulfuric acid environment. One tube failed after few months while a second tube failed just after 42 days in service. The 2nd case is concerned with the damage of a heat exchanger expansion bellows, made from Inconel 600, which experienced stress-corrosion cracking in the shell side, operating in a steam environment. In both cases the CRAs were selected because of their high corrosion resistance, the Hastelloy C-22 being suitable for sulfuric acid and the Inconel 600 being suitable for handling steam, possibly containing chlorides. The two cases were investigated by applying methods of metallographic analysis, SEM/EDS analysis and X-ray diffraction of deposits and corrosion products. in the 1st case, the rapid corrosion of Hastelloy C-22 was caused by the alternate exposure of the tubes to sulfuric acid and spent caustic fluid containing NaOH, leading to Cr-depletion and intergranular corrosion of the alloy. In the second case, the Inconel 600 bellows suffered caustic stress corrosion cracking from carry-over NaOH in the process water (steam). The expansion bellows had not received an annealing treatment to reduce residual stresses, making the material susceptible to this type of corrosion attack. The above cases indicate that the careful control of environmental process conditions and stress is a prerequisite to obtain the maximum corrosion protection in equipment made from CRAs.

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Notes on the Fatigue Life of Welded Structural Nodes of Bus Bodies and Their Assessment, Database of S-N Curves and Service Stress Spectra

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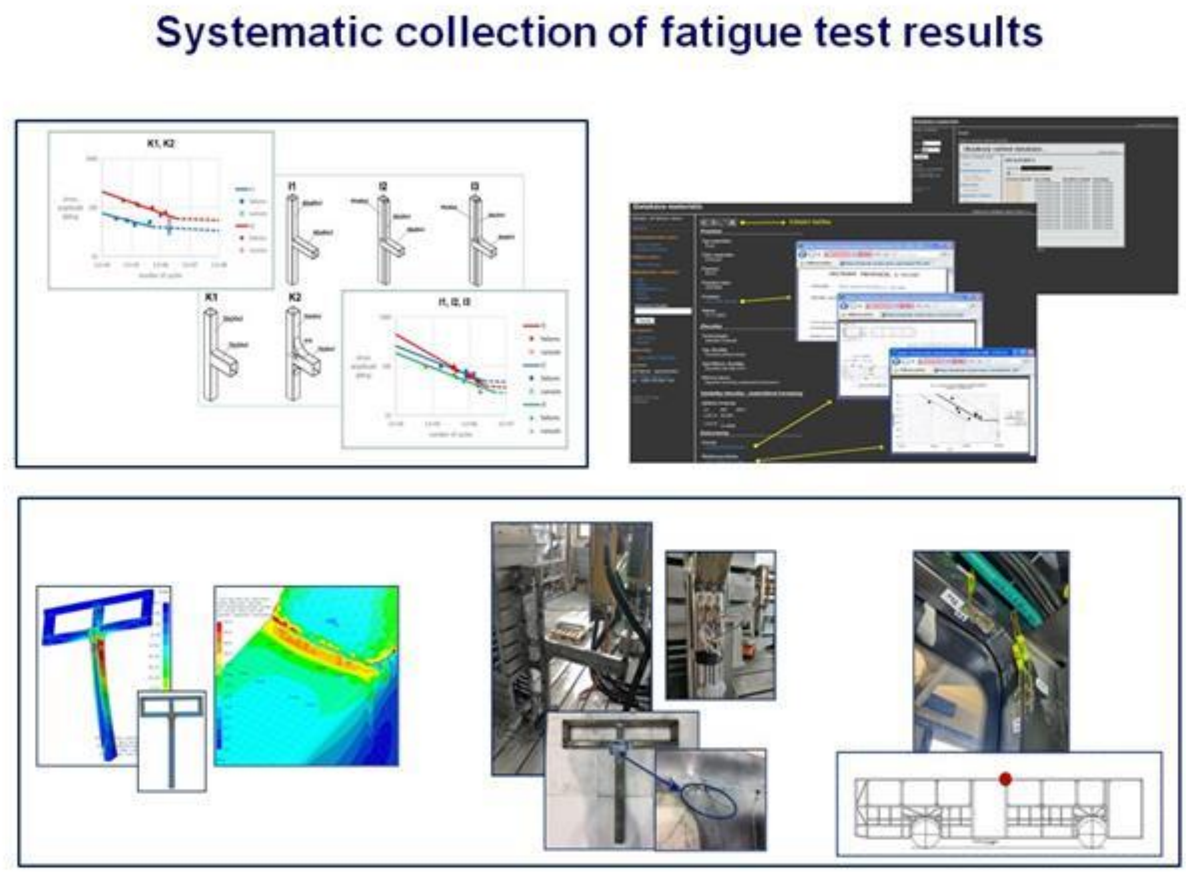
The methodology for designing and assessing the fatigue life of the bodyworks of buses, trolleybuses and currently battery buses (collectively referred to as buses) is continuously evolving. The methodology does not differ much from the procedures used in the classic automotive industry.
Not often, but nevertheless, fatigue cracks sometimes occur in a bus bodywork. Fatigue cracks in the bus bodywork usually do not limit the operability of the vehicle or pose a direct threat to the safety of passengers. If fatigue cracks appear, then they are most often at the welded joints of thin-walled bodywork profiles, which occur mainly in the corners of door or window openings of the bodywork. A fatigue crack weakens the stiffness of these joints, which may be needed for other reasons, e.g. due to the deformation resistance of the bodywork when the vehicle overturns. Compliance with the EHK 66 regulation is demonstrated by calculation or experiment, which assumes the integrity of all body joints. Joints with a fatigue crack do not meet such an assumption.
Bus series are smaller than passenger cars. As a result, the resources for fatigue life verification are also lower for buses. This will be reflected in a smaller volume of experimental activities and the need to use previous experience and qualified estimates. This concerns both the fatigue strength of the critical structural nodes of the vehicle bodywork (most often described by the S-N curve) and their service loading (characterized by the maximum stress amplitude and the stress spectrum = histogram of the frequency of harmonic cycles evaluated by the rain flow method).
If fatigue cracks appear, then subsequent analyses most often identify the following causes:
a) Unstable production technology causes a large scatter of fatigue properties so that even usual service loads exceed the values of the actually achieved fatigue strength;
b) The service stresses, and the aggressiveness of the service stress spectra exceed the values of the fatigue properties of designed and well-made joints;
c) Combination of both factors a) and b);
d) Incorrect estimates of fatigue strength of critical structural nodes (parameters of S-N curves) or erroneous estimates of their service stress (design stress spectra).
Specific examples illustrate the importance of testing the fatigue properties of various variants of welded structural body assemblies. The university research center presents the importance of systematically collecting the results of laboratory fatigue tests together with stress spectra measured in real operating

conditions. Sufficient data allows for more precise calculations of fatigue life and verification of alternative approaches to fatigue expertise. Last but not least, it supports highly valued cooperation with industrial enterprises - bus manufacturers.



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Fatigue Strength Assessment of HFMI-Treated Welded Joints According to the Peak Stress Method

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High-frequency-mechanical-impact (HFMI) is a post-weld treatment for improving the fatigue strength of welded structures, by introducing compressive residual stresses, localized strain hardening and enlarged weld toe radii. The Peak Stress Method (PSM) has been recently extended to the fatigue strength assessment of HFMI treated steel joints, by means of a dedicated analysis procedure and new fatigue design curves, calibrated on experimental data generated from HFMI treated joints tested under uniaxial loading with nominal load ratios R = -1, 0.1 and 0.5. The results were taken from the literature and relevant to structural steels having yield stress in the range 355 ≤ σy < 750 MPa.
In the present work, a validation of the PSM-based fatigue design curves calibrated for HFMI treated welded joints has been performed. To this aim, new experimental fatigue results have been generated by testing HFMI-treated full-penetration butt-welded joints made of S355 structural steel under uniaxial loading with nominal load ratio R = 0. Moreover, further experimental results generated by testing HFMI-treated transverse as well as longitudinal attachments made of structural steels having yield stress in the range 355 ≤ σy < 750 MPa under uniaxial loading have been collected from the literature. The considered dataset has been converted from the nominal stress range to the equivalent peak stress range; then, the obtained results have been compared with the PSM-based fatigue design curves.

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The Peak Stress Method Applied for Assessing the Lifetime of Welded Joints With Reinforcement Ribs Under Constant and Variable Amplitude Fatigue Loadings

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In the framework of the fatigue strength assessment of welded structures, the Peak Stress Method (PSM) is a local approach to rapidly estimate the Notch Stress Intensity Factors (NSIFs) starting from the linear-elastic peak stresses calculated at weld toe and weld root V-notch tips by exploiting 2D and 3D relatively coarse FE meshes. Once combined with the Averaged Strain Energy Density (SED) fatigue criterion, the PSM enables the estimation of the fatigue durability of welded structures made of aluminium alloys or structural steels under uniaxial and multiaxial constant amplitude (CA) and variable amplitude (VA) loadings, in conjunction with PSM-based fatigue design curves which have been validated against more than 2000 experimental data. To promote the adoption of the PSM for the fatigue design of complex industrial structures, an interactive analysis tool known as PSM App has been developed in Ansys® Mechanical, which enables to automate all the analysis tasks required to apply the PSM.

In this investigation, the fatigue strength of complex tube-to-flange welded joints with reinforcement ribs made of S355 structural steel has been experimentally investigated under pure bending, pure torsion and in-phase as well as out-of-phase combined bending-torsion CA and VA loadings. The specimen consisted of a square hollow section tube having 500 mm length, 80 mm side and either 6.3 mm or 8.0 mm thickness, which is welded to a 15-mm-thick flange at both ends. In addition, the tube-to-flange connections were reinforced by 6-mm-thick fillet-welded reinforcement ribs. All the experimental fatigue tests have been carried out using two independent force-controlled 15 kN MTS® servo-hydraulic actuators and a closed-loop MTS® FlexTest 60 digital controller in a standard laboratory environment. In the case of combined bending-torsion loadings, two values of the nominal biaxiality ratio $\Lambda = \tau/\sigma$ have been adopted, i.e. $\Lambda = 1$ and $\Lambda = 1/\sqrt{3}$, τ and σ being the shear and normal nominal stresses calculated at the weld toe of the reinforcement ribs according to the beam theory. Dealing with VA loadings, two p = 0.5 spectra were discretized into six-loading-block programs and applied in a decreasing/decreasing sequence until the fatigue failure of the tested specimen. A total of 33 specimens in the as-welded conditions have been tested under CA loadings in the fatigue life range 3·104 ÷ 2·106 cycles, while 11 additional specimens were tested under VA loadings. All tested joints exhibited crack initiation at the weld toes of the reinforcement ribs and the number of cycles to break-through has been adopted as a failure criterion. In addition, dye penetrant inspections have been conducted to investigate the cracking behaviour and monitor the growth of fatigue cracks.

The fatigue strength of the welds joining tube and flange with the reinforcement ribs has been assessed using the PSM App software. As a result, the PSM always identified the fatigue crack initiation site at the weld toe of the reinforcement ribs in accordance with the experimental outcome and a good agreement has been obtained between the experimental fatigue data and the durability estimations of the PSM.

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Assessing the Shear Properties of the Adhesives by Improved Processing of Torsion Test Results

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Torsion test is known since long as the most effective way to assess experimentally the behaviour of an adhesive under shear. Indeed, it creates a state of pure shear stress, with a simple and non-singular distribution within the elastic range, and allows for tracking the plastic behaviour in case of a ductile adhesive. The output of a torsion test is a recording of the torque-twist curve captured by the machine. Already in 1931, Nadai proposed in his book (Plasticity - A Mechanics of the Plastic State of Matter) a procedure to extract from this curve the stress-strain response of a circular bar of ductile material. However, such a procedure does not generate an explicit shear stress - shear strain formula, which is needed for analytical or numerical modelling. This presentation describes an algorithm, recently developed by our group, to obtain the analytical representation of the shear stress - shear strain curve as a piecewise description. The starting assumption is to have at least three segments, namely: i) the elastic response until yield; ii) the elastic-plastic response that accounts for strain hardening; iii) the descending part describing the damage. In contrast, if the response is more complicated, especially in the early stages that can be non-linear already under low stress, more segments can be added. This representation has a direct physical interpretation as the slopes of the ascending segments are the elastic (in the beginning) or elastic-plastic (after yield) moduli, while their end points are the stress and strain values corresponding to limits (yield, ultimate, etc.).
In general, for a piecewise law with n segments, 2n-1 parameters must be identified. This task was accomplished by creating a Matlab script that minimizes the difference between experimental curve and model. The user can vary the number of segments (up to six) to obtain the best representation.
In the experiments carried out to try the algorithm, different adhesives in the family of structural epoxies were tested, also considering different levels of adhesive layers. The substrate materials were aluminium and steel. The torsion specimens were manufactured in hourglass shape, with the adhesive joint in the reduced section and the ends having an enlarged polygonal cross section to fit into the heads of the machine.
A 500 Nm torsion machine was used for the tests, equipped with a 1% accuracy torque cell and a 4 Arc-min resolution encoder to measure the relative rotation between the heads. However, to obtain the rotation between the faces of the joint eliminating the influence of the substrate compliance, two levers were mounted on the specimen halves close to the bond, and the displacements of their extremes were measured by LVDTs. An angular speed of 3 deg/min was used and each test was repeated thrice.
By applying the algorithm, the model parameters were identified in each case and the correctness of the results was proven by the good fit of the torque-twist curves reconstructed from the model with respect to the experimental ones, accounting for the dispersion bands.

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Determination of Fatigue Crack Size in High-Strength Bolting Assemblies Using Hydrogen-Induced Cracking

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Due to ever-increasing demands on the fatigue resistance of bolting assemblies used in structures like wind turbine towers, available fatigue strength potentials must be used as effectively as possible. For the investigation and consideration of existing potentials, also concepts beyond the well-established nominal stress concept like the notch-strain-approach and the fracture mechanics approach are invoked. To validate these approaches, it is often necessary to precisely determine the size of an existing crack at a certain point in the service life of the tested bolting assembly. However, since the fatigue crack typically initiates in the first load-bearing thread, it is not directly accessible during fatigue testing. In this context, a method for determining the fatigue crack size in high-strength bolting assemblies and the application of the results for the validation of a fracture mechanics model are presented.

In the developed method, further propagation of the original fatigue crack is achieved by hydrogen-induced cracking under constant load, resulting in specimen failure at the location of the original crack. The resulting fracture surface consists of the transcrystalline fatigue crack, an intercrystalline hydrogen-induced brittle fracture surface as well as a transcrystalline ductile residual fracture surface. This characteristic structure allows for the determination of the original crack size. Furthermore, the investigations show that it is also possible to differentiate between fatigue fracture and brittle fracture macroscopically, which further simplifies the procedure.

The described method was used to determine the fatigue crack sizes in high-strength bolting assemblies with a nominal diameter M12. For this purpose, fatigue tests acc. to DIN 969 on a resonance testing machine were stopped at a certain drop of the testing frequency indicating the presence of a fatigue crack. The specimens where then tested acc. to the procedure described above. Static failure at the location of the original crack was achieved reliably and reproducibly. Examination of the resulting fracture surfaces under a scanning electron microscope allowed a clear distinction between transcrystalline fatigue crack and intercrystalline brittle fracture. Therefore, a precise determination of crack depth and shape was possible. In addition, it was found that both can also be determined using a 3D profilometer, taking into account the typical crack initiation pattern at the first load-bearing thread. In some cases, the ductile residual fracture prevented a complete measurement of the original crack on the entire circumference. However, it was still possible to

determine maximum crack depth and general crack shape. The results were successfully used to validate a linear-elastic fracture mechanics model regarding its capability to describe crack propagation in the investigated M12 bolting assemblies.

The presented method allows reliable and reproducible characterization of fatigue cracks in high-strength bolting assemblies and is thus a valuable tool in the authors current work regarding fatigue crack initiation and propagation in bolting assemblies. Based on the investigations described, the validated fracture mechanics model has already been successfully applied to bolting assemblies with a nominal diameter M36 and is currently being used to further investigate crack propagation in large bolting assemblies > M36.

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Failure Analysis of Steel-to-Aluminium Hybrid Welded Joints Under Multiaxial Fatigue Loading

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This study presents a detailed crack path analysis of hybrid aluminium-to-steel welded joints produced using EWM coldArc® welding technology, with a focus on uniaxial and multiaxial fatigue loading conditions. Following fatigue failure of the tested specimens, an in-depth examination of crack initiation and propagation was carried out, with particular emphasis on the critical role of crack initiation in multiaxial fatigue failure.

The analysis identified four principal crack initiation sites across uniaxial, pure torsional, and biaxial fatigue loading conditions: the weld toe, weld start/stop position, weld metal, and the aluminium heat-affected zone (HAZ). Results indicate that the weld toe is the most frequent site of crack initiation, particularly under uniaxial and biaxial constant amplitude fatigue loading. However, under certain loading conditions, crack initiation tends to occur at the weld start/stop position, likely due to localised stress concentrations arising from weld geometry. Notably, cracks originating within the weld metal were relatively rare, highlighting the effectiveness of EWM coldArc® technology in joining thin dissimilar aluminium-to-steel components.

Furthermore, crack plane orientation analysis revealed that shear stresses predominantly govern crack initiation, while normal stresses control crack propagation. A strong correlation was observed between experimental and theoretical crack plane orientations, with crack initiation angle errors generally within ±20% of the maximum shear stress plane angle, and crack propagation angle errors within ±30% of the maximum normal stress plane angle.

These findings provide valuable insights into the fatigue behaviour of hybrid aluminium-to-steel welded joints, with potential implications for improving their structural integrity and durability in engineering applications.

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Dependence of Mode-I Interfacial Fracture Energy of a Fusion Bonded Metal-FRP Hybrid on Parameters of Laser Surface Treatment of the Metal Adherend

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Hybrid materials, particularly those manufactured by combining thermoplastic Fiber Reinforced Polymers (FRP) with metals, are being increasingly utilized in industries focusing on lightweight engineering, especially in the automotive sector. This is due to their high stiffness-to-weight ratio, which is crucial for achieving optimal automobile design and performance. With the advancements of these materials and an increase in their applications, the need to investigate and understand their damage and failure mechanisms increases proportionally. One of the most common failures in such hybrids is delamination at the interface between the adherends, which emphasizes on the importance to characterize their interface properties.
Mode-I fracture energy (GIc) and bonding strength determine the quality of the interface formed between the metal and FRP adherends of the hybrid material. Among other factors, the parameters of the surface treatment carried out on one or both of the adherends significantly influence the quality of the interface. Therefore, it is of ample importance to determine the dependence of interface properties on the parameters of surface treatment method which is a labor-extensive task. Therefore, development of numerical models with modified constitutive relations to model the interface of the hybrid with the associated interface properties as the function of surface treatment parameters is an alternative to tedious experiments.
An effective way to fabricate metal-FRP hybrids is by fusion bonding in a heat assisted press process whereby the matrix of the FRP melts to form an interfacial bond with the metal surface. For this study, fusion bonded steel-glass FRP (GFRP) hybrid produced in a hot press are considered. Laser structuring is selected as the surface treatment method and is carried out only on the steel adherend with 5 different sets of lasering parameters (lasering speed, frequency and hatch distance). The focus is on the determination of the dependence of GIc and bonding strength on the parameters of laser structuring and development of a modified Cohesive Zone Model (CZM) to define this dependence numerically. Hence, fusion bonded steel-GFRP Double Cantilever Beam (DCB) hybrid specimens are manufactured after laser structuring the steel adherends. Mode-I peel tests are carried out on the DCB specimens to determine GIc as the function of laser structuring parameters. Laser parameter dependent bonding strengths are determined by curve fitting. These dependencies are then transformed into empirical equations. A user-defined Cohesive Zone Model is developed for Abaqus CAE by writing a UMAT-Subroutine which utilizes the modified constitutive behavior based on the developed empirical equations. Simulations based on the modified CZM are executed on the parametric model of DCB specimen. Force-displacement behaviors are obtained from the simulations,

compared with those from the experiments and a good correlation is obtained between them. The developed UMAT is validated by peel tests on DCB specimens wherein metal adherends are laser structured with an arbitrary set of parameters. After validation, the modified Cohesive Zone Model is able to predict the quality of the interface between the considered metal-FRP hybrid without the need of further experimentation.

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Numerical and Experimental Investigation of the Physical Effects of the Strength Increase and Disbond Arrest Using Surface Toughening in Composite Adhesive Joints

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Structural adhesive bonds are a desirable joining method for lightweight composite structures. However, one main challenge regarding the certification of primary aircraft structures is that eccentric load transmission in single overlap joints and elongation of adherends cause an inhomogeneous stress distribution along the bonded area. Stress peaks contributing to premature failure occur at overlap edges. The literature addresses many stress-reducing mechanisms such as mixed adhesives along the bondline with a gradient Young's modulus or additional rivets. The surface toughening method is a newer approach, which is more advantageous for fiber-reinforced plastics. This technology involves the local integration of thermoplastic films with higher ductility than the adhesive and adherends. Depending on the position of the Poly(vinylidene fluoride) film along the bondline, disbond arrest or strength increase of structural bonds can be achieved.
In order to facilitate certification and material selection for the surface toughening film, a simulation-based determination of crack arrest and strength increase capability is the aim. For this purpose, an already available accurate progressive damage analysis for structural bonds is extended by the surface toughening material. This work compares predicted and experimental results for strength increase and disbond arrest. For this purpose, Single Lap Shear (SLS) tests and Double Cantilever Beam (DCB) tests are modeled. Cohesive zone modeling for the adhesive layer and hydrostatic stress-sensitive Drucker Prager law for the surface toughening film are used. The simulation results show different accuracies towards the SLS and DCB experimental tests despite similar material laws for the surface toughening material. The SLS model shows a strength increase of 60% while the experiment yields an increase of 84%. The DCB model proves with higher accuracy the disbond arrest. This indicates different physical effects for the strength increase and the disbond arrest effect of surface toughening. One difference in the effects could be attributed to Crazing of the surface toughening film (Whitening due to void formation). Crazing is investigated with scanning electron microscopy (SEM) and detected only in SLS specimens.

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A Fatigue Damage Model for Epoxy Resin and its Application to Fiber Reinforced Plastics

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Introduction
Epoxy resins feature good mechanical properties and a high adhesiveness to many substrates which makes them a widely used candidate as matrix material for fiber reinforced plastics (FRP) and as structural adhesive, e.g. for wind rotor blade applications. Within these applications, epoxy resins are exposed to mechanical loading including cyclic loading conditions. The gradual property degradation of FRP under cyclic loading is related to the successive fatigue degradation of the epoxy matrix. Also, for adhesively bonded joints, the fatigue damage behavior of the epoxy adhesive is crucial, as cracks initiating in the adhesive tend to propagate into the adherends. Thus, understanding the fatigue phenomena of epoxy and developing reliable methods for prediction are key aspects for designing robust FRP structures and composite joints.

Methods
This contribution presents a stress-based progressive fatigue damage model for epoxy considering the non-linearity and the tension/compression-asymmetry of the constitutive material behavior as well as the mean stress effect of the fatigue behavior. The law by Palmgren and Miner is used to consider variable loading amplitudes and a property degradation law, active after damage initiation, enables to account for stress redistribution occurring within the matrix of FRP. SN curves obtained from uniaxial cyclic loading with different stress ratios are used for model calibration (Figure 1). Arbitrary multiaxial stress states are assessed by transferring them to equivalent uniaxial stresses using a procedure based on a pressure-dependent failure criterion. The progressive fatigue damage model is implemented as user-defined material subroutine within the Fortran library MCODAC to be available within Finite Element Modelling software.

For assessment and validation, the model is applied in a micro-scale modelling framework for predicting fatigue behavior of unidirectional FRP subjected to cyclic tension, compression and shear loading. Doing this, the morphology of the composite's micro-scale, consisting of carbon fibers distributed within the epoxy matrix, is modeled by a Representative Volume Element (RVE) with hexagonal fiber packing and periodic boundary conditions.

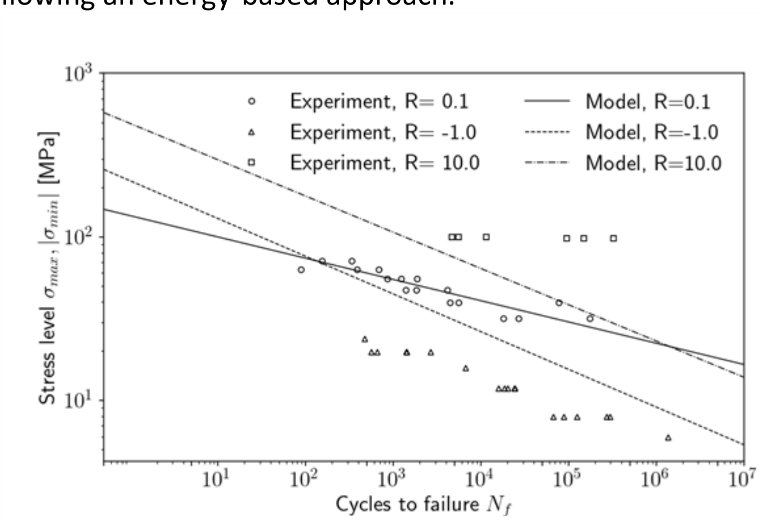
Results
The fatigue damage model of the pure epoxy in conjunction with the RVE approach yields to a qualitatively good prediction of the FRP's fatigue behavior with respect to the mean stress effect and to the crack patterns

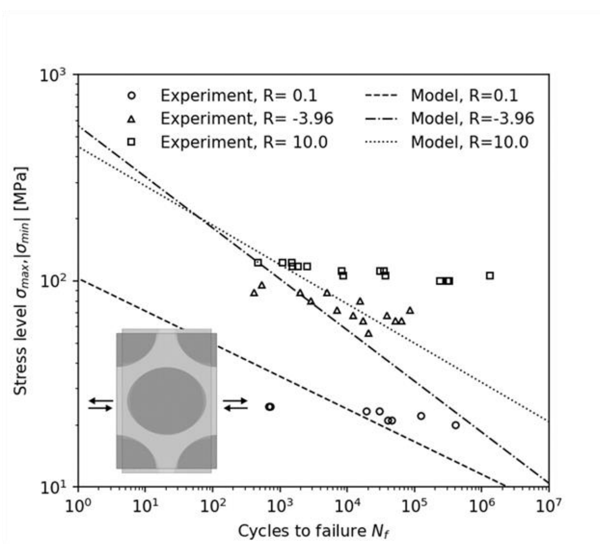
observed under different loading conditions. However, the model overestimates the fatigue life for higher stress levels and underestimates for lower stress levels (Figure 2).

Conclusion

The application of the developed progressive fatigue damage model for pure epoxy resin is demonstrated for predicting the fatigue behavior of unidirectional FRP. From the deviations observed between model prediction and fatigue test data for unidirectional FRP, the following suggestions for improvement of the model are derived:

- Implement a pressure-dependent visco-plastic constitutive model to account for plasticity effects which may accumulate over fatigue life.
- Replace the linear constant life diagram – currently used to capture the mean stress effect – with a non-linear approach to mitigate the fatigue life underestimation at lower stress levels.
- Address challenges concerning the transfer of multiaxial stress states into equivalent uniaxial stresses, for instance by following an energy-based approach.





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A Comparative Study of FEM Modelling Strategies for the Fibre Composite Adherend to Predict the Strength of Bonded Joints

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The increasing importance of lightweight construction in aviation to enhance fuel efficiency has brought fiber reinforced composite structures back into focus. To fully leverage the potential of these structures, adhesive bonding is particularly suitable, as it enables uniform load transfer without weakening the material through drilling. However, adhesive bonds in aviation are subject to a complex certification process. Precise progressive damage analyses, particularly for predicting static strength, are therefore essential for understanding and potentially certifying bonded fiber-reinforced composite structures. The aim of this study is to evaluate FEM modelling strategies to accurately predict the progressive damage behaviour of Carbon Fiber Reinforced Polymer (CFRP) laminates in bonded joints. As damage may not only occur in the adhesive but can also arise within the adherend, it is necessary to model the intra- and interlaminar (damage) behavior of the laminate. Especially with regard to the modelling of fibre composite laminates, many different approaches can be found in the literature. This work aims to provide an overview of the strategies suitable for adhesive joints and to give recommendations for a computationally efficient and precise numerical prediction. The intralaminar behavior of CFRP laminates is modeled using either 2.5D continuum shell elements or fully 3D solid elements, coupled with a material model capable of capturing the matrix's plasticity. This material model incorporates extended 3D formulations of failure criteria and damage evolution based on Cuntze's Failure Mode Concept (FMC), providing a robust framework for damage initiation and progression. Interlaminar behavior is analyzed using either cohesive zone modeling (CZM) with surface-based contacts or cohesive elements, or by neglecting interlaminar effects entirely for comparative evaluation. To evaluate the various modelling strategies, these are compared with various experimental results. This involves comparing samples from material characterisation to single lap shear specimens. This study provides an overview of the quality, advantages and disadvantages of different modelling strategies of fibre composite adherends in bonded joints. In combination with an equivalent study on the modelling of adhesives, this work serves as a basis for further investigations with more complex requirements. Possible applications of these strategies could be bonded fuselage segments, stringer-skin joints or investigations of bonded joints on CFRP hydrogen tanks, as well as many others.

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Precipitation Strengthening in Austenitic Low-Density Steels: The Role of κ-Carbides

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Low-density steels are known for their light weight combined with excellent mechanical properties. Specifically, the addition of aluminum (Al) in the chemical composition increases the lattice parameter and, therefore, decreases the steel density. On the other hand, high manganese (Mn) and carbon (C) contents ensure a fully austenitic microstructure, which exhibits extreme ductility, up to 100%. Upon aging of such alloys, the formation of κ-carbides occurs through spinodal decomposition and short-range ordering. The intragranular formation of these carbides leads to an increase in the yield strength, as it decreases the mobility of dislocations.

In the current work, the goal is to study the formation of κ-carbides both qualitatively and quantitatively in order to better understand their effect on the mechanical properties. A fully austenitic low-density steel with a composition of Fe-28Mn-9Al-1C has been studied after hot rolling and various aging treatments. Various characterization methods have been employed in order to determine the size, shape, and volume fraction of the κ-carbides and how they interact with the austenite matrix and the dislocations upon deformation. Specifically, Scanning Electron Microscopy (SEM) was used to determine the austenite grain size, while High-Resolution Transmission Electron Microscopy (HR-TEM) was used to determine the size and shape of the κ-carbides and their coherency with the austenite matrix. Finally, in-situ heating experiments were performed with synchrotron X-ray diffraction to study the precipitation kinetics and volume fractions. Finally, tensile tests were performed, and the deformed areas of the samples were studied through TEM and Electron-Backscatter Diffraction (EBSD) to determine the interaction of the dislocations with the κ-carbides.

The study shows that the peak aging condition is achieved after 8 h of aging at 550 °C. At this condition, the size of the κ-carbides is approximately 4 nm, and their volume fraction is 14 %, while they are coherent with the austenite matrix. Concerning the mechanical properties, this corresponds to 390 HV, 1015 MPa yield strength, 1150 MPa ultimate tensile strength, and 44 % total elongation. The coherency, size, fraction, and interparticle spacing of the κ-carbides determine the interaction with the dislocations during straining. It is shown that the dislocations glide through the austenite matrix, shearing the carbides and leading to an increase in yield strength. The deformation mechanism is identified as the Micro-Band Induced Plasticity (MBIP), which appears in alloys with very high Stacking Fault Energy.

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Prediction of Different Recrystallisation Textures Under a Single Unified Physics-Based Model Description

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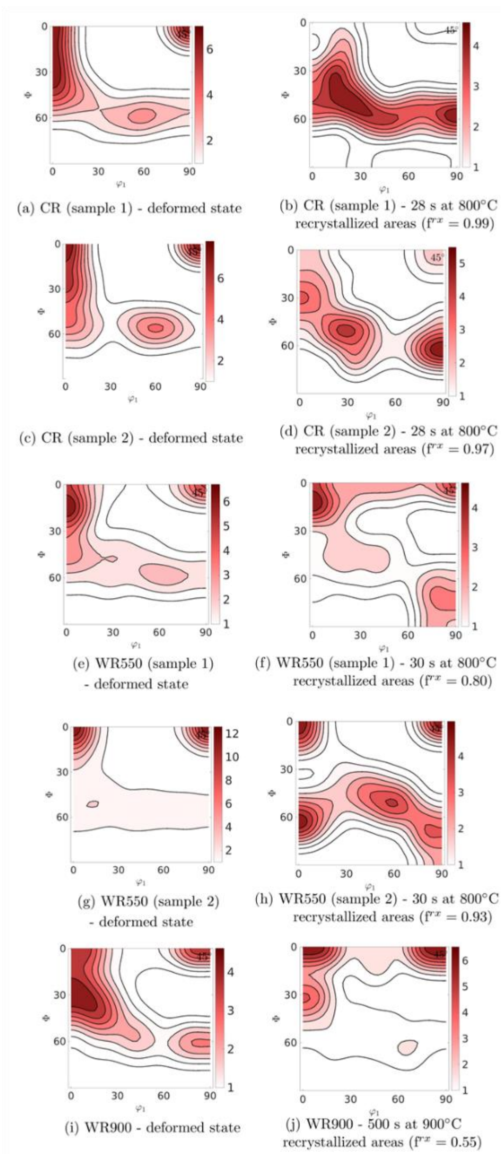
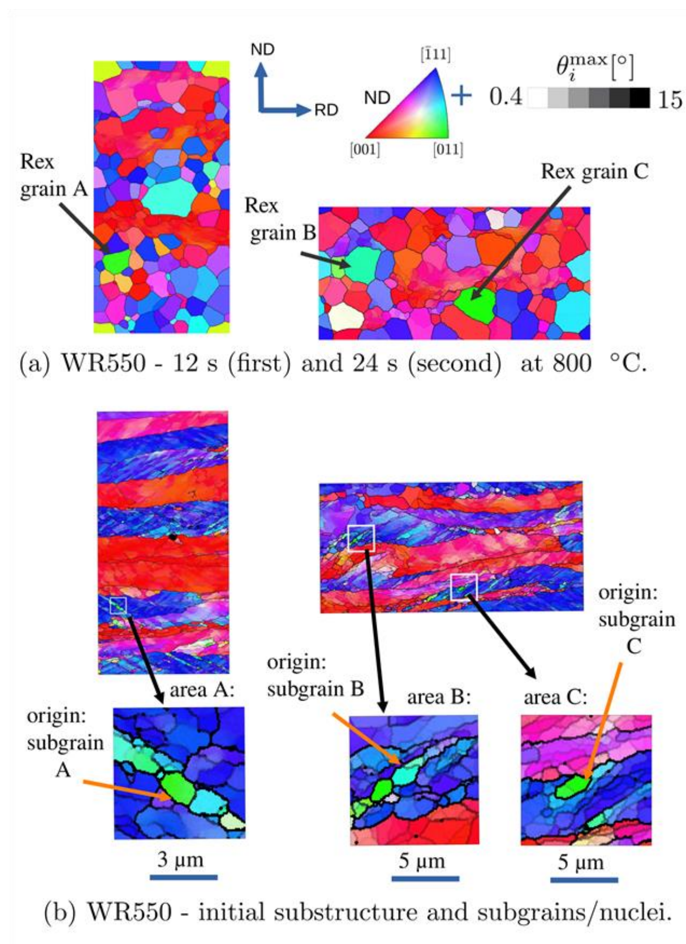
This work investigates the formation of the recrystallisation microstructure and texture of various single-phase ferrite low-carbon steels that were rolled at different temperatures and of which the deformation microstructure
was characterized by high resolution electron backscatter diffraction (EBSD). Three cases are considered: (i) cold-rolled interstitial-free (IF) steel, warm-rolled IF steel at 550 °C and warm rolled Fe-Si steel at 900 °C (below the austenitization temperature due to Si). It is well-known that the deformation texture after flat rolling of single-ferrite low carbon steels exhibits the characteristic α/γ-fiber texture, i.e. < 110 >//Rolling Direction (RD) and < 111 >//Normal Direction (ND), irrespective of the rolling temperature, as long as there is no concurrent phase transformation. However, different recrystallisation textures appear as a function of the rolling temperature. Generally speaking, the γ-fiber recrystallisation texture is obtained after cold rolling, whereas the θ-fiber components (< 100 >//ND) intensify at the expense of the γ-fiber orientations with increasing rolling temperature. This phenomenon is well known, and it is beneficial for widening the range of industrial applications, since the former texture increases the formability while the latter the optimises electromagnetic properties. Nevertheless, the reasons for this behavior
in terms of preferential orientation selection remain as yet unclear. In the present work, recrystallisation microstructures and textures are simulated with a full-field cellular-automaton (CA) description, whereby recrystallisation from its incipient stage is considered as a process of sub-grain coarsening controlled by the well-known physical laws of driving force and kinetics. The simulations integrate in one single model the various conditions that give rise to the observed temperature dependence of the evolving static recrystallisation
texture and microstructure. The different rolling temperatures will give rise to different initial microstructures at the onset of recrystallisation with noticeable variations in short-range orientation gradients in γ and θ-fiber

orientations, respectively. The mere application of local grain-boundary migration laws on the topology of the deformation structure, without imposing any specific nucleation selection criterion, will properly balance the dominance of γ-fiber grains after cold-rolling and θ-fiber orientations after warm rolling.

It is shown that this model, for the first time, explains the experimental results and the yet unresolved contradiction of different recrystallisation textures as a function of the deformation temperature, as shown in Fig. 1. Also, the well-known nucleation of Goss orientations ({110} < 001 >) in shear bands occurring in γ-fiber grains is also
simulated in this single conceptual framework, as shown in Fig. 2.





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Fatigue Crack Formation and Growth in Quenched and Partitioned (Q&P) Martensitic Stainless Steels

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Recent studies have demonstrated the viability of quenching and partitioning (Q&P) treatment for processing martensitic stainless steels, achieving an improved balance of high strength and sufficient ductility. These materials are attractive for various industrial applications. However, despite their importance for structural applications, their fatigue performance has not been thoroughly investigated.
As is well known, high-cycle fatigue life is controlled by fatigue crack initiation, whereas low-cycle fatigue life is governed by fatigue crack propagation. This study focuses on fatigue crack initiation and growth in Q&P-treated martensitic stainless steels with complex hierarchical microstructures, as well as the interaction between fatigue cracks and microstructural constituents.
Three steels with different alloying element contents underwent Q&P processing, resulting in multiphase microstructures with a high retained austenite content. High-cycle fatigue tests and fracture surface analyses were conducted using SEM and EBSD techniques. The results show that prior austenite grain boundaries, MnS inclusions, and TiN particles have minimal influence on fatigue crack initiation and growth. However, fatigue cracks predominantly initiate and propagate along martensite packet and block boundaries, with TiN inclusions potentially attracting propagating cracks, leading to their fracture. Microplastic deformation at the fatigue crack tip increases local KAM values and induces localized transformation of retained austenite grains. Strategies to enhance fatigue resistance in these materials are discussed.

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Damage and Microstructure of In–Field Loaded Rails From Macro-to Nano-Scale

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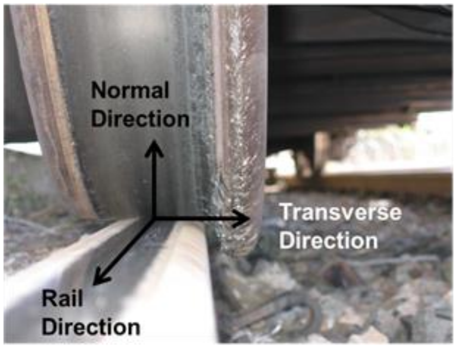
Structural changes on the surface of R260Mn-grade railway steel, developed during wheel/rail contact, were investigated using optical microscopy, electron backscatter diffraction (EBSD), transmission Kikuchi diffraction (TKD) in a scanning electron microscope (SEM), and transmission electron microscopy (TEM). The microstructures of the heavily deformed and phase-transformed surface layer, known as the white etching layer (WEL), and the underlying deformed layer were characterized at different length scales. Ferrite grain fragmentation and grain alignment in the normal direction (perpendicular to the traffic direction) were characterized using the abovementioned methods. Substructures with misorientations less than 5° were identified by analyzing local misorientation maps (kernel average misorientation, KAM). Retained austenite was detected in the WEL using XRD, EBSD, and TKD. The detection of retained austenite, the formation of a specific "shear" BCC texture on the surface, and the ultrafine grain structure suggest a mixed mechanism for WEL formation, where both martensitic transformation and severe plastic deformation occur.
Keywords: RAILWAY STEEL, DAMAGE, WHITE ETCHING LAYER, MICROSTRUCTURE, TEXTURE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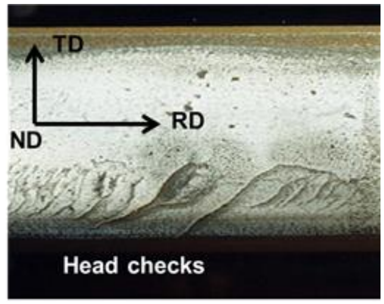
Transverse Direction
Rail Direction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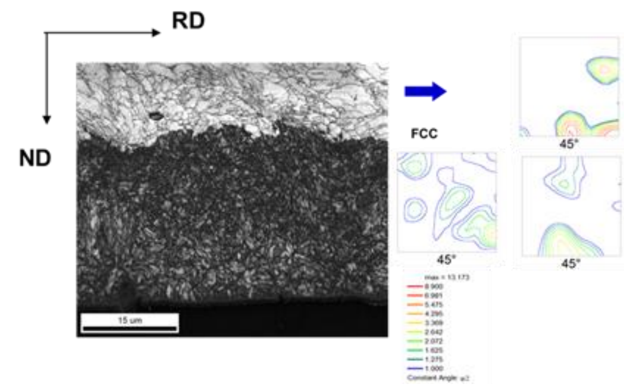
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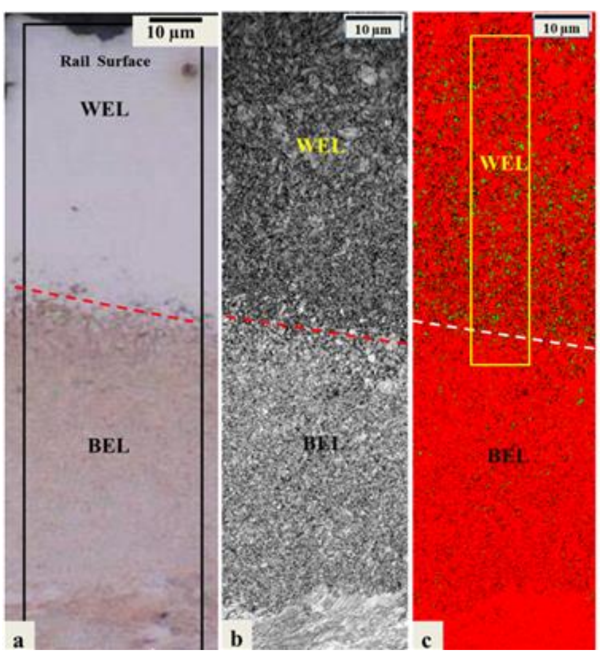
10 μm
Rail Surface
WEL
BEL
a
10 μm
WEL
BEL
b
10 μm
WEL
BEL
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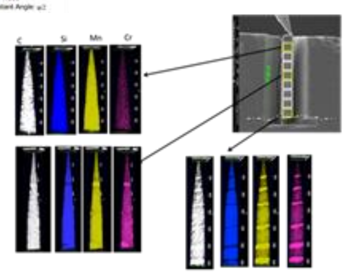
C
Si
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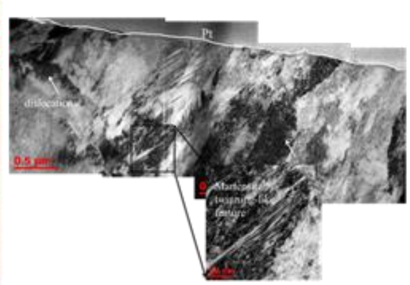
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Microstructure Engineering Through Ultra-Fast Annealing: Innovations in Alloy and Processing Design of Advanced High Strength Steels

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The application of high heating rates during annealing has been the focus of several studies in recent years. The reason behind such interest from both academia and the automotive industry is the potential to produce complex microstructures in a single-step annealing process. The Ultra-Fast Annealing (UFA) process minimizes the overall annealing time by applying very high heating rates (100-1000 °C/s) via induction and minimal soaking times before quenching. Simulation of heating and soaking via Thermo-Calc® and DICTRA show that such short heating times strongly affect the diffusion range of carbon and other alloying elements, such as chromium, manganese, and molybdenum, which are commonly found in Advanced High Strength Steels (AHSS). Hence, UFA leads to heterogeneity in the chemical composition, with areas rich in carbon and areas depleted from it. This change in the carbon content affects the Ms and Mf temperatures locally and, thus, the microstructural constituents after quenching. Such constituents include martensite and retained austenite in the carbon-rich areas, ferrite and bainite in carbon-depleted regions, and cementite, which has not dissolved completely due to the short heating times.
The current work is focused on the microstructure engineering of AHSS to optimize their mechanical properties. Microstructure characterization is combined with computational modeling to offer a deeper understanding of the diffusion processes and phase transformations as a means to predict microstructural changes and design novel thermal treatments for lean-alloyed steels. Advanced characterization techniques are employed, such as Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), Electron Backscatter Diffraction (EBSD) and transmission EBSD (t-EBSD). Combining these methods with tensile tests gives an overview of the interaction between the treatment, microstructure and properties of different AHSS. The application of high heating rates can be expanded to more complex thermal treatments, such as those used to produce Transformation Induced Plasticity (TRIP) steels and Quench & Partitioning (Q&P) steels. An overview of UFA treatments on different AHSS alloys is given in this work, and its potential as an alternative thermal treatment to produce lean alloys with improved technological properties while reducing energy consumption.

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Cleavage Fracture Micromechanisms of Advanced High Strength Steel and its Heat-Affected Zones

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Advanced high-strength steels (AHSS) offer excellent strength and toughness, being greatly valued for structural applications. However, under severe service conditions (e.g., high strain rates and low temperatures) and welded parts, body-centred cubic steels like AHSS can transition from ductile to brittle behaviour and welding-induced heat-affected zones (HAZ) may present low-toughness microstructure. Therefore, identifying cleavage failure mechanisms in AHSS and their HAZ is essential for integrity assessment and optimal material design.

This study investigates the microstructural features governing cleavage fracture in an 80 mm thick commercial S690QL AHSS and its most critical types of HAZ. Fracture toughness was evaluated using crack tip opening displacement (CTOD) tests at – 100 °C (lower-shelf region of the ductile-to-brittle transition curve). Cleavage fracture micromechanisms were studied using scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), and electron backscatter diffraction (EBSD) on fracture surfaces and their transverse section.

The mid-thickness of the as-received steel plate demonstrated the highest susceptibility to cleavage fracture, due to the larger fraction and size of cubic Nb-rich inclusions, frequently distributed as clusters and associated with defects such as voids and cracks. To assess cleavage fracture micromechanisms in HAZs, Gleeble thermal simulations were carried out on the steel's mid-thickness section (the most sensitive region of the 80 mm thick material). In both coarse-grained HAZ (CGHAZ), predominantly composed of auto-tempered martensite, and intercritically reheated CGHAZ (ICCGHAZ), composed of granular bainite, brittle martensite-austenite (M-A) constituents were observed acting as dominant crack initiation sites, despite the presence of Nb-rich inclusions. However, the small size of M-A (smaller than 1 μm) prevented unstable crack growth, making matrix phase properties the primary factor controlling fracture progression. Thus, CGHAZ exhibited lower fracture toughness than ICCGHAZ. Moreover, the morphology and internal structure of M-A constituents played a crucial role in crack propagation. M-A constituents with internal substructures with high misorientation angles and high internal plastic strains acted as effective barriers to crack growth, arresting secondary cracks and delaying fracture.

Lastly, a rapid cyclic heat treatment (RCHT) was proposed to enhance cleavage fracture toughness through grain refinement. This approach significantly increased the fraction of high-angle grain boundaries, providing additional barriers to crack propagation. RCHT refined the microstructure of the middle section of the S690QL steel by 55%, improving its cleavage fracture toughness. With grain refinement, alternative crack initiators such as oxide inclusions and carbides began to play a role alongside the detrimental Nb-rich inclusions. RCHT improved cleavage fracture toughness by up to 2.6 times in specimens where Nb-rich inclusions initiated fracture and up to 8.5 times in those where oxides or carbides acted as initiation sites, demonstrating its potential for mitigating cleavage fracture susceptibility in S690QL AHSS.

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An Average Strain Energy Density Method for Accurate Fatigue Predictions in Additive Manufactured Lattice Structures

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Lattice structures are well known for their tunable mechanical properties and lightweight capabilities. However, to fully develop the potential of these additive manufactured structures in the industrial environment, a complete understanding of the mechanical properties is required. Among all, one of the most challenging properties to address is fatigue resistance. This phenomenon is localized and strictly dependent on the singular geometry, application and loading condition of each lattice structure. To address this challenge, this work will focus on the development of a methodology to accurately predict the fatigue life of lattice structures thanks to a combination of finite elements simulations and energetic approaches. The work leverages the understanding gained in the fatigue prediction of welded joints to apply the average strain energy density (ASED) on additive manufacturing products [1]. This energetic procedure takes the moves for an initial material characterization and requires the identification of the so-called critical radius. Once this material properties is defined, the lattice structure undergoes a finite element simulations to identify the critical locations where the energetic state is accessed and the most critical ones are determined [2].
It is well known that fatigue life of lattice structures is deeply impacted by the material selection, the manufacturing process and the manufacturing induced defects inside the component. For this reason, two different lattice structures analysis are presented: the first one is conducted on L-PBF Ti6Al4V specimens and the second one on PA12 MJF specimens. These two components are characterized by diametrical different properties, the former being a metal additive manufacturing component, characterized by a complex surface geometry while the latter being a polymeric lattice structure with an as-built geometry adherent to the as-designed one. The analysis shows the difference between the two selected lattice structures, highlighting the influence of manufacturing induced defects and stating once again the need of accessing the as-built geometry of additively manufactured lattice components. Despite the differences, the proposed methodology is found to provide accurate predictions on both selected configurations, displaying the capabilities of energetic based approaches in the estimation of the fatigue life.

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An Update on the Direct Quenching and Partitioning Route for the Realization of Tough, Ultrahigh Strength Steels

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[1]University Of Oulu, Oulu, Finland, [2]Outokumpu Oyj, Tornio, Finland

Direct quenching and partitioning (DQ&P) route has come a long way, since the first experiments were successfully conducted using 0.2C (high) Si and/or Al steels. The specific objective was to develop a steel with yield strength ≥ 1100 MPa, combined with good tensile ductility and adequate low temperature toughness. Right from establishing appropriate composition and process designs through comprehensive physical simulation, emphasis was principally placed on ensuring a cost-effective processing route amenable for subsequent industrial hot strip production. Whilst the martensitic matrix has the potential to provide the required strength, a small fraction of retained austenite finely divided between the martensitic laths imparts improved work hardening characteristics and uniform elongation without loss of impact toughness. Ausforming in no-recrystallization regime resulted in extensive refining and randomization of the martensite packets/laths besides fine division of interlath austenite, thus resulting in an all-round improvement of mechanical properties, including low temperature toughness and uniform elongation. Fractographic studies of tensile-tested DQ&P specimens revealed quasi-cleavage mode of fracture with the intermittent presence of shallow dimples corroborating the TRIP-induced improved tensile elongation. On the other hand, the constrained nature of austenite-to-martensite transformation required higher energy to drive the crack forward resulting in appreciable improvement in fracture toughness. Significant progress has since been made to extend the processing route to medium carbon steels but required significant changes in processing route to realize desirable microstructures and properties. The key research strategy encompasses studying structural refinement approaches, phase transformation characteristics, accompanying microstructural and fracture mechanisms using advanced metallography as well as analytical techniques.

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Advanced Strategies for Strengthening and Repairing Historic Structures of Religious Buildings in Areas Subject to Mining Influence

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Introduction

The paper deals with the problem of existing religious buildings in areas of mining impacts. These impacts relate to the kinematic forces transmitted from the mining subsoil to the structure of the buildings. Under the conditions of mining operations, the referenced forcing results from deformation-like impacts or may result from mining tremors. The above-mentioned mining impacts caused extensive states of damage to structural elements in sacred objects. They threatened the safety of use of these objects.

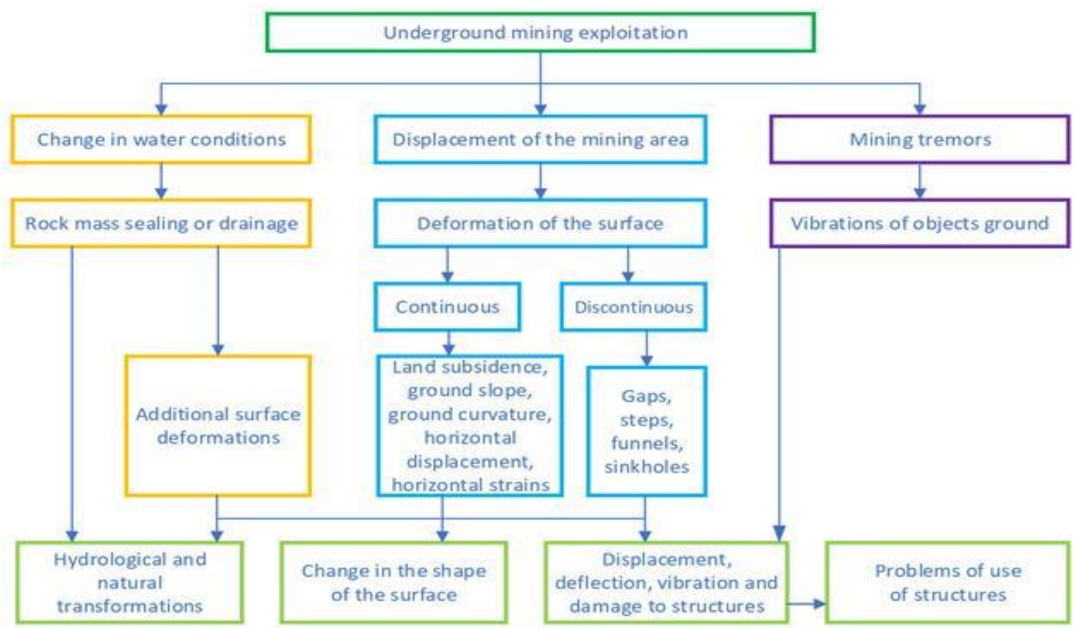
The paper will discuss examples of sacred objects that have undergone a diagnostic process for determining the state of damage, the causes of its origin and proposals for effective protection. The latter aspect, i.e. the protection of the existing building substance, was carried out in two groups of activities. The first concerned the strengthening of structures against the projected effects of mining operations. The second group of activities was related to the removal of the effects of the mining exploitation that had taken place and the implementation of repairs to enable the continued safe use of buildings.

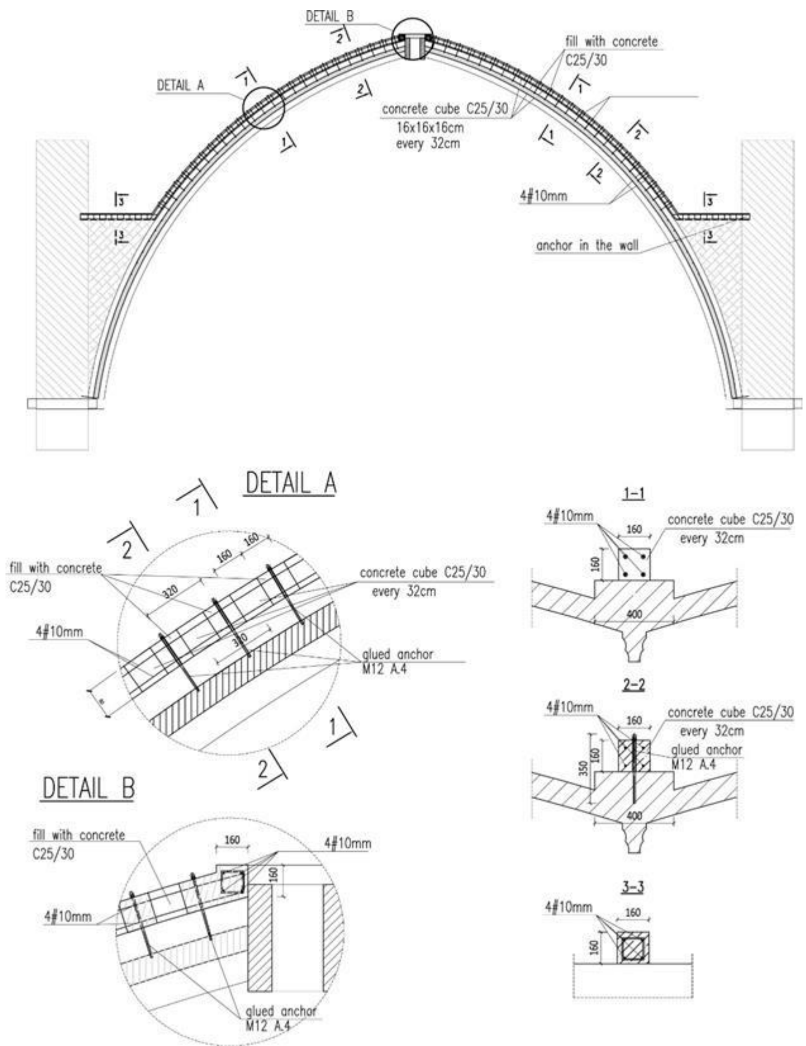
Methods

With regard to the technical age of the sacred buildings presented in this paper, the impacts generated by underground mining operations have appeared relatively recently. During the technical life cycle of sacred buildings, the methods of structural reinforcement also changed. The types of structural reinforcement of sacred objects, described in the paper, are a special case dedicated to the use in mining areas. The strengthening methods presented in the paper are up-to-date both in terms of the materials used and the technology of execution. They ensure the protection of structures from mining loads and allow the use of objects in accordance with their intended purpose.

The strengthening and repair measures of historic religious buildings referred to in the paper were verified under in situ conditions, during the technical supervision carried out. This supervision consisted of fixed-time inspections of the structures, during which their state of damage was inventoried. The whole process was part of a strategy to protect existing sacred buildings from the dangers of the negative impacts of mining activities.

Summary
The paper presents modern solutions for strengthening the structures of existing religious buildings. The influences resulting from the impacts of ongoing mining operations on the structures of the buildings in question are comprehensively presented. The authors presented the types of mining impacts on the land surface and its buildings. They pointed out the importance of periodic assessments of the technical condition of existing buildings, including an inventory of damage. The morphology of structural damage to the buildings in question was presented. Criteria were formulated, the exceeding of which determines the intervention of a structural nature in the buildings in question.
The results of the assessment of the technical condition of historic religious buildings, together with decisions on how to repair and reinforce them presented in the work, can provide generalized guidelines for how to deal with objects of this type under mining influences.




DETAIL B
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fill with concrete C25/30
concrete cube C25/30
16x16x16cm
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DETAIL A
fill with concrete C25/30
concrete cube C25/30
every 32cm
4∅10mm
glued anchor M12 A4
DETAIL B
fill with concrete C25/30
4∅10mm
glued anchor M12 A4
1-1
concrete cube C25/30
every 32cm
2-2
concrete cube C25/30
every 32cm
glued anchor M12 A4
3-3

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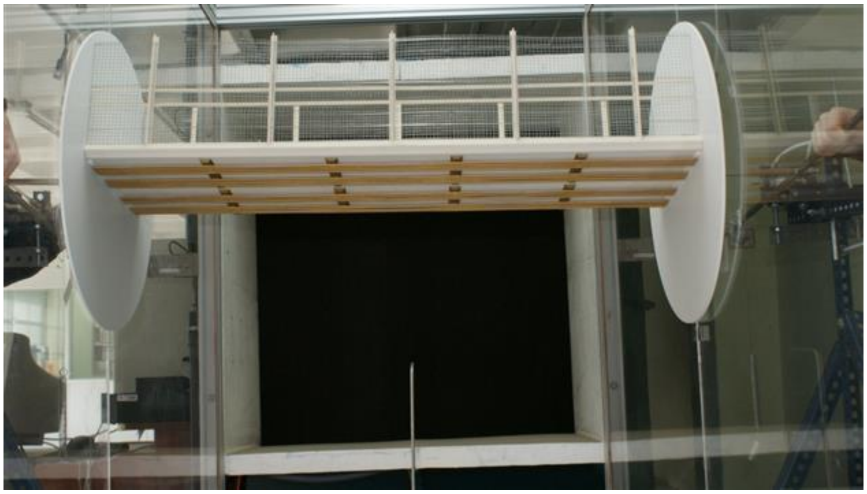
Studies of Aerodynamic Failures in Slender Multi Span Stress Ribbon Bridges

Prof. Santiago Hernández[1], Prof. Aitor Baldomir, Prof. Jose Angel Jurado, Prof. Luis Romera, Ms. Antia Troche
[1]*University of Coruna, A Coruna, Spain*

Stress ribbon bridges are very slender structures that are used in many different locations, from urban areas to mountainous places. They are composed by a very thin deck usually 0.30 cm deep supported by a set of cables subject to prestressing forces. A common ratio between deck depth and span length is 1/450, which is a very small value in comparison with other structural schemes as continuous beams or portal bridges. The first realization of this typology had only a single span but over the years some designs with several spans have been built and the length of the spans has increased. Nowadays it reaches up to 150 m for the single span Plovdiv Bridge in Bulgaria and up to 300 m for the two spans Lake Hodge Bridge (USA). They are preferred for pedestrian or sometimes bicycle traffic. Their construction involves a number of operations that modify the structural system and therefore the structural analysis must take into account this circumstance carrying out an iterative process to identify the prestressing forces of the cables that produce finally the desired geometry of the bridge. Due to the slenderness their performance under wind flow must be studied as aerodynamic failures as flutter or torsional divergence can occur leading to the collapse of the bridge.
In this paper a three span stress ribbon bridge in the city of Cuenca (Spain) will be presented. It is formed by three span of 72 m each one supported by very tall piers with a total length of 216 m. The bridge has the special and pioneer feature that having cables made of carbon fibre instead of the usual steel wires. The paper will describe the geometry of the bridge, the construction steps and the iterative structural analysis procedure. A figure attached to this abstract shows a view of the bridge under construction.
Due to its slenderness, a quite complete set of aerodynamic studies was worked out to find out its safety against the mentioned aerodynamic failures. Flutter was studied using a hybrid approach: first, a sectional model of the bridge deck was tested in a wind tunnel, as shown in the attached figure, to obtain the flutter derivatives. Afterwards a computational analysis of a FEM model of the full bridge subject to the aeroelastic forces that are function of the flutter derivatives was made. This approach leads to a nonlinear eigenvalue problem that finally provided the wind speed that produces the flutter failure.
Torsional divergence was also studied. The torsional aerodynamic coefficient CM, of the deck was obtained in a wind tunnel test and several static analysis were carried out to obtain the flexibility matrix of the bridge. Afterwards a matrix relationship between the angle of attack of wind flow and the twisting moment was formulated using the equation□□=FT·M, where □ is the angle of attack, FT, the flexibility matrix and M the vector of twisting moments. This expression leads to an eigenvalue problem that provided the wind speed producing torsional divergence.



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Analysis of a Faulty Designed Detail of an Flyover Bent That Could Have Been the Cause of a Construction Disaster

Dr. Bartosz Sobczyk[1], Prof. Mikołaj Miśkiewicz[1], Dr. Łukasz Pyrzowski[1], Prof. Jacek Chróścielewski[1]
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The aim of this paper is to emphasize the critical importance of meticulous design with attention focused on even small details, since even a tiny mistake can lead to significant damage or catastrophic failure. Therefore, the paper explains the root cause of substantial damage that occurred in the bent caps of a flyover substructure and proposes an efficient repair solution.
The analyzed flyover is located in northern Poland, in a busy city center. It is a multi-span structure supported by multiple reinforced concrete abutments and bents. Each bent consists of two columns topped with a cap beam which is equipped with cantilever ends. All substructure elements were cast on site. The loads from the superstructure are transferred to the bent cap by three bridge bearings: two at the cantilever ends and one at the mid-span of the cap.
After proof load tests, numerous vertical and inclined cracks appeared on the external surfaces of the bent caps, raising concerns about the structural integrity of the flyover. This situation prompted a detailed investigation into the safety of the structure and the adequacy of its original design.
To address these issues, advanced nonlinear static numerical simulations of the flyover were conducted. The bridge response was analyzed under both standard design actions and the specific loads it had sustained prior to the observed damage. Preliminary results, obtained through conventional design procedures, revealed that the cap beam could not carry the typical design loads. This indicates a clear design error. The beam was under-reinforced, especially in its cantilever regions. Further detailed nonlinear local simulation of cap beam behavior showed that the beam had nearly reached its ultimate load capacity during the proof tests, as its steel reinforcement had accumulated considerable plastic strain. The cantilever ends were identified as the most vulnerable areas. Immediate repair measures were therefore necessary.
In the course of the local analysis, it was essential to employ a nonlinear material model capable of capturing the initiation and propagation of cracks in concrete elements. The Concrete Damage Plasticity model provided accurate predictions of the observed damage patterns, closely resembling the ones observed on site.
Because the flyover had not yet been opened to traffic, a simple, fast, and effective repair strategy was adopted. First, the superstructure was temporarily lifted by installing hydraulic jacks on the damaged bent cap. This action altered the load paths, enabling the cap to safely carry the dead load of the superstructure during the subsequent repair stages. Next, additional concrete was cast around the existing bent elements to form a solid pier wall, thereby significantly enhancing the load-bearing capacity of the substructure. Finally, the superstructure was lowered onto the original bearings.

This case study illustrates that faulty design of just one detail can jeopardize the safety of the entire structure. By presenting the response analysis and repair solution, this work emphasizes the necessity of paying rigorous attention to the design and detailing of every structural member. This will help to prevent similar failures and ensure long-term structural safety.

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Preventing Failures of Improperly Maintained Prefabricated Multi-Family Buildings – Diagnostic Methods and Decision-Making Process

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Prefabricated large-panel multi-family buildings, which have been in use for decades, pose a significant challenge in terms of technical diagnostics and ensuring their safe operation. These structures may be exposed to various risks arising from systemic errors made during the design and construction phases, the natural degradation of materials, and operational errors as well. Particularly difficult to assess are buildings that have been used in a way inconsistent with their design assumptions, as well as those that have remained out of service for a long time.

The authors present a comprehensive research and decision-making process aimed at identifying and assessing risks in prefabricated large-panel buildings. The study uses structural inspection methods, non-destructive (NDT) and semi-destructive (SDT) diagnostic techniques, which enable the determination of material parameters and the assessment of individual structural elements. A key aspect of the analysis is data obtained from previous studies of large-panel buildings, allowing for the degradation mechanism identification and the evaluation of the actual structure durability.

One of the modern tools used in the research is 3D laser scanning, which enables a detailed assessment of the building's geometry, identification of deformations, and determination of potential hazards related to the loss of structural stability. The combination of in situ inspection data, material test results, and point cloud analysis provides a comprehensive overview of damage and deformations, allowing for an in-depth evaluation of structural integrity.

The decision-making process regarding the further safe use of the building considers technical, economic, and environmental aspects. The test results provide the basis for determining the necessary scope of modernization and structural strengthening works, to ensure continued safe operation of the facility. In extreme cases, where the degradation of load-bearing elements significantly exceeds permissible safety standards, the possibility of building demolishing is considered.

The findings and conclusions presented contribute to the broader discussion on the durability and modernization of large-panel buildings. They highlight the necessity of systematic diagnostics for such structures and emphasize the need for modern assessment methods, which are crucial for making justified decisions regarding their continued use or demolition.

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Analysis of the Impact of Structural and Architectural Facade Detail Degradation on the Structural Condition of Historic Buildings: Application of Digital Twins and Photogrammetry in Risk Assessment

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Building facades, providing both an aesthetic and protective function, are particularly vulnerable to environmental factors such as changing weather conditions, pollution, moisture, and material corrosion. Degradation of facade structure, including both losses of architectural details and weakening of structural facade elements, can lead to significant structural problems, affecting the stability of the entire building. Loss of the facade integrity increases mostly moisture penetration, which in turn can lead to damage to internal layers, reinforcement corrosion, and weakening of the other structural elements.
To effectively protect facades and their details, it is necessary to apply modern, non-invasive diagnostic and documentation methods. 3D laser scanning allows for contactless and precise mapping of facade surfaces, damage identification, and degradation monitoring. Photogrammetric facade inventory provides very precise view of the facade without the need for scaffolding. It enables the identification of structural problems that often play a crucial role in the renovation concept, and which may not be visible from the ground level. Photogrammetry is an excellent complementary method to 3D scanning, as it reveals traces of damage that are superficial indications of more serious structural and conservation issues.
Using 3D scanning and photogrammetry, enables the reconstruction of an exact copy of the analyzed historic object. The creation of digital twins allows not only for the accurate reconstruction of damaged decorative elements but also for analyzing changes in the facade structure, which is crucial for assessing the technical condition of the building.
This study demonstrates that the use of technologies such as 3D laser scanning and photogrammetry in facade diagnostics constitutes an effective tool for supporting the protection and conservation of buildings. There are discussed methods of data acquisition and analysis, as well as the benefits of virtual models enabling effective planning of renovation measures that also help prevent building failure or partial destruction. In particular, the importance of protecting architectural and structural details as key elements influencing the durability and

stability of the entire structure is emphasized. The research results and conclusions confirm that the integration of traditional and modern technologies in facade protection can significantly contribute to preserving buildings in their original state, ensuring their longevity and safe use.

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Monitoring and Detection of Damage in Historic Brick Structures Using Non-Destructive Methods

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Monitoring of historic structures at regular time intervals enables the assessment of existing and detection of new damage in brick masonry. This allows for the early recognition of defects propagation and the same enables immediate intervention, such as detailed structural assessments and necessary repair measures. The long-term use of buildings leads to the degradation of both load-bearing and non-load-bearing brick elements. Deterioration is the result of the natural aging process of buildings and the influence of environmental factors, which can lead to particularly dangerous excessive moisture in the wall and development of biological corrosion. In brick masonry structures, signs of deterioration typically include cracks, material losses, and spalling of mortar and bricks. These defects can lead to irreversible changes and reduction in the load-bearing capacity of the wall. Crack pattern analysis is a key aspect of masonry assessment, considering the layout and direction of the cracks. It is particularly important to determine whether the cracks propagate only through the mortar or whether the bricks are also cracked. Another factor is the analysis of the depth of the cracks.

For structural condition monitoring, early damage detection, and technical assessment of masonry, the use of non-destructive technique (NDT) including 3D laser scanning technology is proposed. 3D laser scanning enables highly accurate and rapid identification of damage, deformations, and material losses. It is particularly useful for historic brick buildings, which are often characterized by complex and unique architectural and structural solutions. The application of 3D laser scanning allows for the acquisition of high-quality geometric data of all building elements and their processing into a detailed 3D digital representation. Therefore, in addition to other NDT methods, there is a proposal for the innovative use of 3D scanning in the analysis of the geometry and depth of cracks in masonry structures.

The obtained point cloud allows for precise identification of dimensions and inventory of all types of defects and damages of masonry surfaces. Consequently, this technology enables detection of new defects and monitoring of existing defects propagation. This, in turn, supports further technical assessments, effective building maintenance, conservation efforts, and the planning of necessary repair actions.

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Structural Condition Assessment of Historical Timber Using Digital Approach and Non-Destructive Techniques

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Timber is a fundamental material in historical construction, widely used in architectural heritage sites. However, its long-term durability depends on various factors, including environmental conditions, biological decay, and mechanical loads. Traditional diagnostic methods, such as invasive mechanical testing, can compromise the integrity of heritage structures, making non-destructive testing (NDT) a preferred approach for structural assessment. Nevertheless, the reliability of NDT methods requires validation through comparative analysis with destructive testing results.
This study investigates the structural condition of historical timber elements by integrating non-destructive techniques, mechanical testing, and digital analysis. The primary objective is to establish a correlation between NDT results, density measurements, and mechanical properties obtained from undamaged samples of century-old timber. By comparing these methods, the research assesses the accuracy and applicability of NDT techniques in evaluating the stiffness, strength, and degradation of wooden structures in situ.
In addition, the study explores the potential of terrestrial laser scanning (TLS) and digital image processing to analyze the geometric characteristics of degraded timber cross-sections. By combining 3D laser scanning data with computational geometry methods, a more detailed and automated approach to shape recognition, material loss assessment, and structural integrity evaluation is developed. This method enhances precision in identifying deformations and estimating load-bearing capacity, supporting effective conservation strategies. The findings contribute to the advancement of heritage preservation, structural reliability assessment, and predictive maintenance of historical wooden buildings. The proposed methodology combines traditional engineering techniques with modern digital tools, offering a comprehensive, minimally invasive framework for evaluating timber elements in architectural heritage conservation.

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The Influence of Corrosion of Steel Reinforcement on the Shear Strength of Existing Structure and 2nd Degree Pre-Earthquake Inspection

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Corrosion of steel reinforcement is recognized as one of the predominant degradation factors in the durability of Reinforced Concrete (RC) structures, affecting negatively both the loadbearing capacity and ductility of corroded RC members. In the light of structures' aging, preearthquake inspection methods have been established to assess the seismic capacity and structural adequacy of existing RC structures.

Based on existing experimental results on corroded reinforced concrete columns, of typical geometry and reinforcement of conventional buildings of the previous 50 years, in this work the degree of degradation of the seismic behavior of columns with corroded steel reinforcement was studied and a comparison was made with the guidelines of the 2nd degree pre-earthquake inspection. In particular, the cyclic behavior of RC columns in reference and corroded conditions has been studied imposing gradually increasing deformations at the top of each column (drifts) and a simultaneous imposition of a constant axial load equal to 350 kN. Each column had a square cross section of 30x30 (cm) with 4 reinforcing rebars of nominal diameter Φ16 in each corner and wide stirrups (Φ8/250mm), as a representative RC element of an existing old structure.

Experimental results indicated the adverse effect of corrosion in mechanical behavior of RC members is significant, as shear resistance recorded an intense degradation of 30% (from 66 kN in non-corroded conditions to 46 kN in corroded conditions, as shown in Figure 1) for a corresponding corrosion level between 14% and 20% of its longitudinal reinforcement. Besides the reduction of the load-bearing capacity, in terms of deformations, premature failure was recorded due to the steel corrosion from 5.0% drift to 2.5% drift, sharply reducing by 50% the service life under cyclic loading and transforming the failure mode from ductile to brittle. Comparing the experimental outcomes with the guidelines of the 2nd degree preearthquake inspection, the experimental results showed a 30% reduction in shear strength for approximately 16% mass loss (cross-sectional loss) of the steel reinforcement, while the 2nd degree pre-earthquake inspection guidelines propose. a maximum of 10% drop in shear strength for 40% area uniform reduction of cross-sectional area of reinforcement. Furthermore, the 2nd degree pre-earthquake inspection does not refer to the type of corrosion damage (uniform or pitting corrosion), which greatly influences the rate of degradation of the structural behavior of RC elements, as has already been shown by experimental results. The guidelines do not also quantify the corrosion damage of stirrups, which is directly linked with the steel-concrete bond mechanism and the confinement and the shear resistance of RC elements. To be precise, the laboratory accelerated corrosion had been imposed solely on the longitudinal reinforcement and not in parallel on the transverse (stirrups), which had certainly been corroded inductively only by its contact with the longitudinal reinforcement; the actual degradation of the shear strength Is therefore expected to be more severe. Taking into account the abovementioned, the 2nd degree pre-earthquake inspection overestimate the bearing capacity of the existing corroded RC structures.

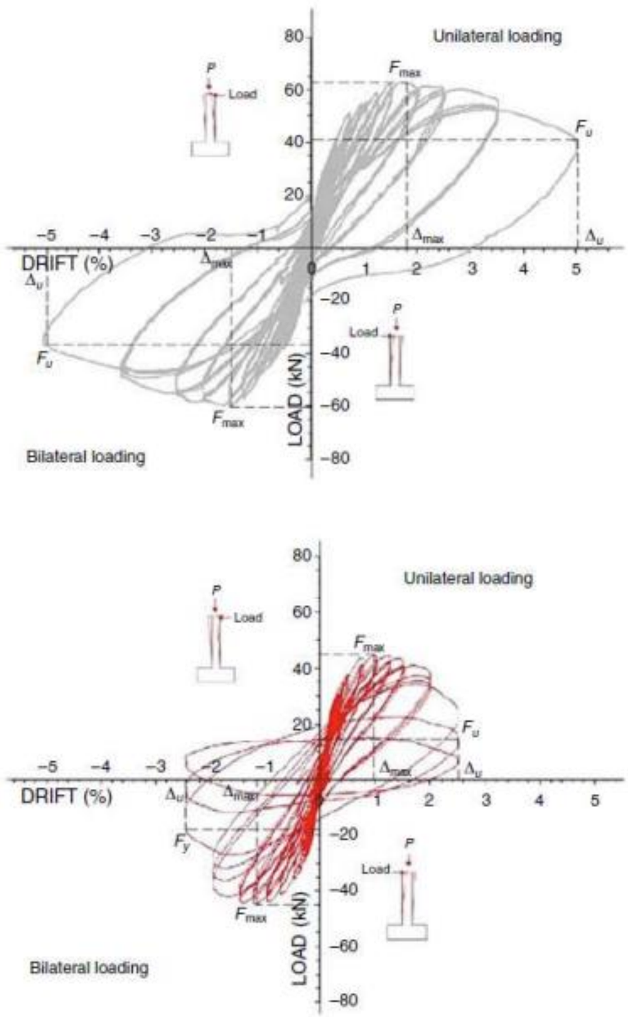

Figure 1. Non-linear cyclic response of RC column in reference conditions (up) and corroded conditions with 16-20% mass loss of reinforcing bars (down) [1].

[1] Apostolopoulos, C., Drakakaki, A. and Basdeki, M. (2019), "Seismic assessment of RC column under seismic loads", International Journal of Structural Integrity, Vol. 10 No. 1, pp. 41-54. https://doi.org/10.1108/IJSI-02-2018-0013

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Slip Effect on Rotational Capacity (Chord Rotation) of Corroded RC Members Due To Pull Out of Steel Reinforcement

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It is known that the pull-out of steel bars in the anchorage area has a direct effect on the deformation of Reinforced Concrete (RC) members and, especially in the case of columns, leads to an increase in the chord rotation angle and the displacement at their top [1]. Various studies have shown that corrosion of steel reinforcement deteriorates the conditions at the interface between steel and concrete resulting in the development of slip and hence the pull-out of the rebar from the concrete [2-3]. Since to date, the influence of corrosion on the deformation of RC members with corroded steel reinforcement has not been adequately introduced within the regulations, in the present paper a study of the influence of steel reinforcement slippage due to corrosion on the chord angle of the RC member was carried out. For this purpose, the manuscript was based on the results of experimental pull-out tests on RC specimens, with concrete class of C20/25, with a longitudinal steel bar of class B500c, of nominal diameter of 16mm, artificially corroded at different levels and taking into account the presence or absence of transverse reinforcement (through stirrups), as proposed in the provisions of the fib Model Code 2010. The experimental results confirmed that the increase of corrosion level of steel reinforcement led to bond strength loss and relative slip between steel and concrete, which was increased from 1 mm in non-corroded conditions to 3 mm even in low corrosion levels, up to 5% steel mass loss. This slippage of corroded reinforcing bars from the anchorage leads to proportional increase of term of chord rotation due to pullout resulting in additional increase in the displacement of the column's top. The experimental results provoked on the basis that the length of the concrete specimen is equivalent to 30 cm. Thus, it is worth mentioning that in the case the length of the corroded rebar extends to a multiple value, namely 2×30cm=60cm or 3x30=90cm, the resulting relative slip will be equivalent. This fact will certainly cause issues that will further increase both the rotation and the predicted displacement of the free end of the column, which is calculated according to the regulations by ignored the corrosive factor. In this framework, the need to check the extent of the corroded bar's length could also be emphasized herein. As a conclusion, the present study highlights the great importance of the contribution of the resulting slippage of the steel reinforcing bar due to corrosion in the calculation of the limit chord rotation (column - beam), a term which is of major importance in the assessment of the structural integrity of old RC structures as introduced as a adequacy requirement by both Eurocode 8-3 and the Greek Code of structural Interventions (KAN.EPE).

Keywords: Steel corrosion, Slip, Anchorage, pull out, chord rotation

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Recent Development of Advanced Surface Engineering to Combat Failure

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The ever-increasing requirements for high performance, high productivity and high-power efficiency, many industry systems and engineering components operate under demanding application conditions, such as intensive loads, high speed, high temperature and harsh environments. It is well-known that most of engineering components can degrade or fail in service through surface related phenomena and hence most of these challenges can be addressed through developing advanced surface engineering technologies.

The present talk is a synthesis of a few strands of recent surface engineering research at the University of Birmingham to combat such surface related failure as wear, corrosion/oxidation and fracture including (1) surface modification of high entropy alloys combat corrosion and wear; (2) development of high entropy coatings for wear protection; and (3) development of CrSi coating to against surface failure of TE materials and blacks. Finally, the future research directions are outlined.

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Microstructure Characterisation and Property Evaluation of a Plasma Nitrided High Entropy Alloy Coating

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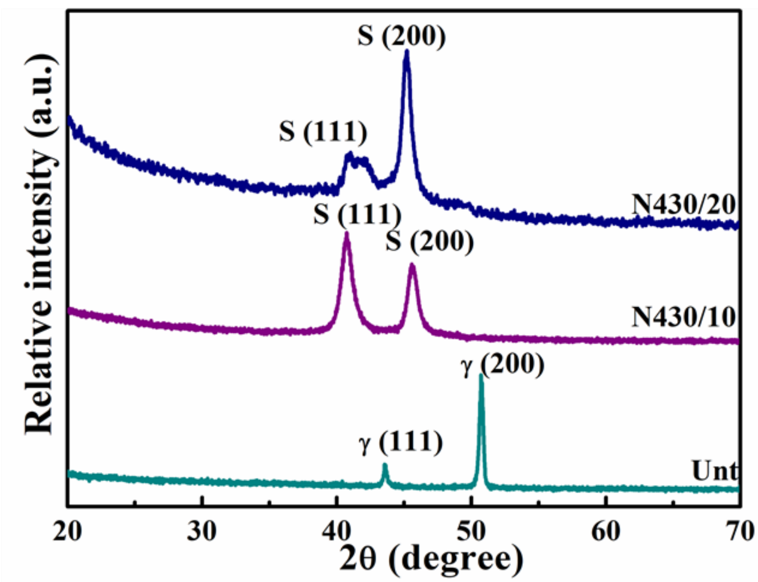
High entropy alloys are newly developed materials, which consists of five or more than five principal elements in equal or near-equal atomic percent. The alloys have attracted great attentions because of their unique compositions, micro-structures, and adjustable properties. HEA alloys mainly composed of a single solid solution phase with excellent mechanical properties and corrosion resistance, high temperature oxidation resistance etc.. However, HEA alloys are expensive materials, and perform poor tribological properties,which limited their industry application. Recently, HEA coatings were developed to give special surface properties of the HEA alloy to the carbon steel or low-cost alloys to meet the requirements of the working environment. This research reported a study on plasma surface nitriding of a CoCrFeMnN HEA coating layer on steel matrix for improved wear resistance without degrading the excellent mechanical properties of a HEA coating.
The results revealed that it is feasible to alloy the surface of multi-component CoCrFeMnN HEA material with nitrogen by plasma nitriding at 430℃. The research work has discovered for the first time that expanded nitrogen saturated austenite or S-phase can be formed in FCC structured multi-component CoCrFeMnN HEA coating layer. The hardness of multi-component CoCrFeMnN HEA coating surface can be effectively increased from 194 to 1465 HV0.025 by low-temperature plasma nitriding due to the formation of the S-phase layer. The tribological properties of the plasma nitrided HEA coating layer are significantly improved as evidenced by reduced CoF from 0.8 to 0.3 and increased wear resistance by more than 26 times due to the significantly increased harness and the change of the dominating wear mechanism from adhesive wear for the untreated material to mild abrasive wear for the nitride surface.


S (200)
S (111)
N430/20
S (111)
S (200)
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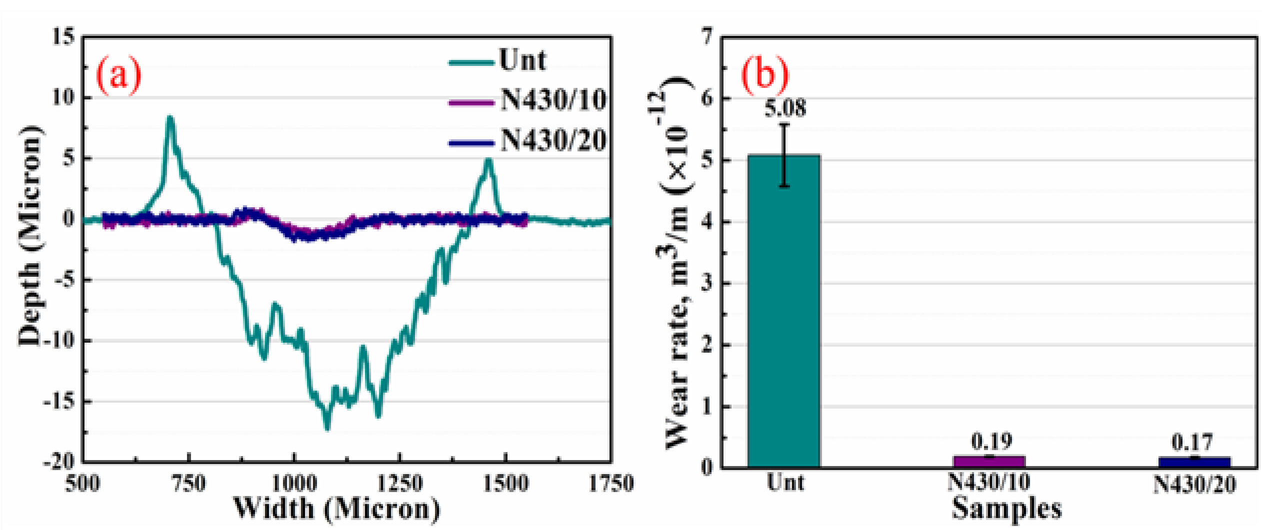
Unt
Relative intensity (a.u.)
20
30
40
50
60
70
2θ (degree)


(a)
Unt
N430/10
N430/20
Depth (Micron)
15
10
5
0
-5
-10
-15
-20
500
750
1000
1250
1500
1750
Width (Micron)
(b)
5.08
0.19
0.17
Wear rate, m3/m (×10-12)
7
6
5
4
3
2
1
0
Unt
N430/10
N430/20
Samples

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Microstructure and Thermomechanical Properties of Electroplated Cu-Carbonaceous Nanocomposite Coatings for Advanced Interconnects in Power Electronics Applications

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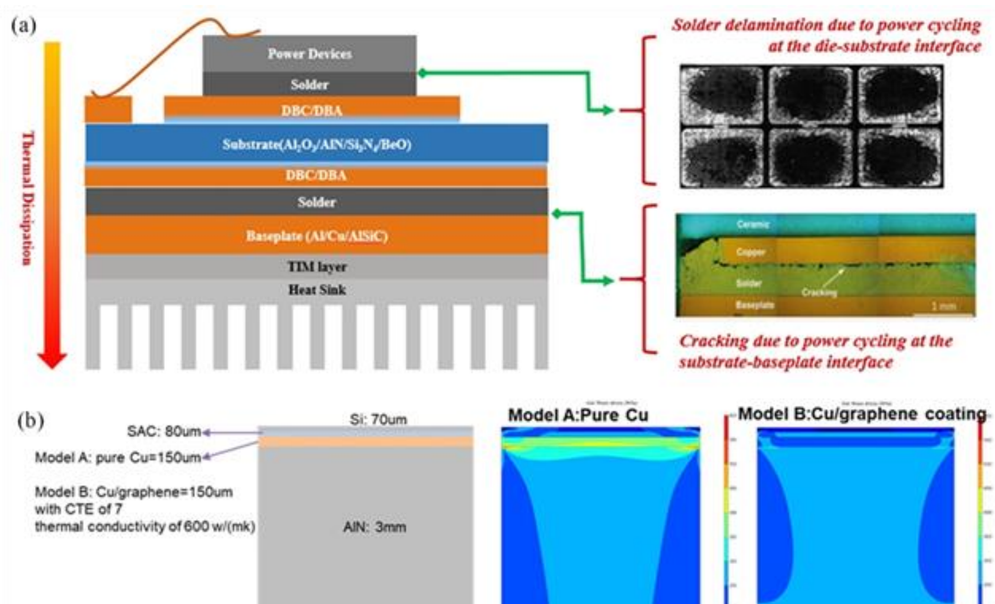
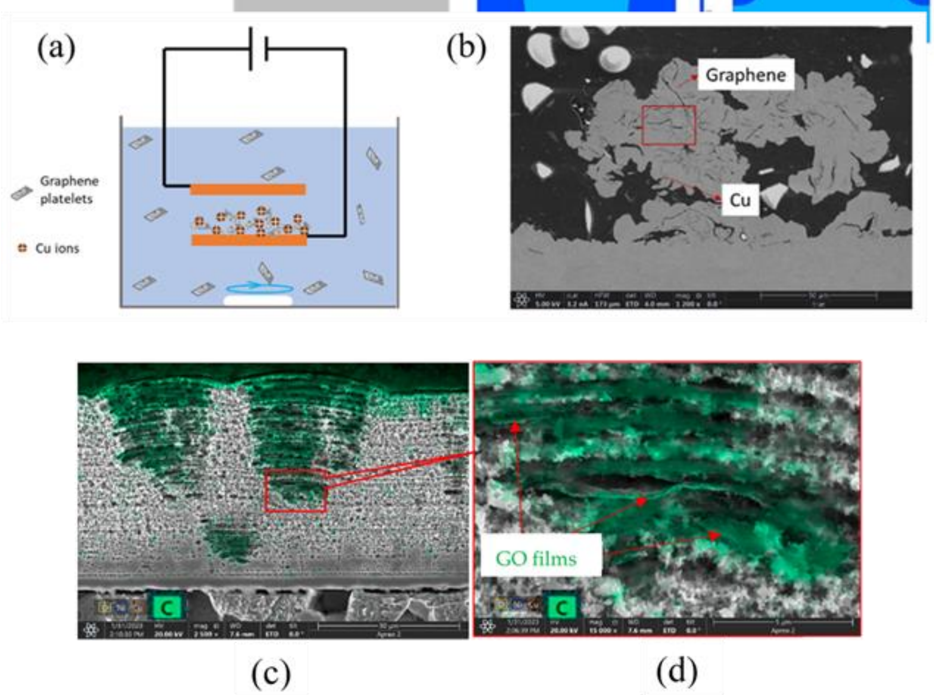
There has been a marked rise in high-temperature (>250ºC) electronics applications with the emergent wide-band gap (WBG) devices such as SiC and GaN, which face serious reliability implications. Figure 1(a) shows a power module commonly encountered in the automotive and aerospace industries.
One of the most significant challenges under elevated temperature loading is the mismatch in the coefficient of thermal expansion (CTE) at die-substrate and substrate-baseplate interconnections, where high internal stresses are likely induced, ultimately leading to fatigue failure, as illustrated in Figure 1(a).
Cu- Carbonaceous (e.g. Cu-graphene) nanocomposites have emerged as promising candidates for electronic interconnections with a tuneable CTE and enhanced thermal and electrical conductivity due to the presence of carbonaceous materials. However, it is difficult to technically incorporate carbonaceous materials into metal-based coatings. This paper presents two innovative processing routes in order to blend graphene into copper: pulse-reversed sediment electroplating and electro-brush plating. The initial endeavour aims to develop a new family of functional Cu-based carbonaceous composite coatings for high-temperature power electronics integrations.
As identified by the modelling shown in Figure 1(b), Cu-Graphene can bridge CTE to effectively reduce the thermomechanical stresses accumulated along the interface. A significant reduction in CTE mismatch directly correlates to lower induced stress, particularly along the solder/substrate interface. Figure 1(b) indicates that a ~10 ppm/K difference in CTE between pure Cu (16.5 ppm/K) and Cu/Graphene (7 ppm/K) yields a 36 % reduction in average von Mises stress across the Cu/Graphene solder-substrate interface. Such reductions in internal stresses can markedly elevate the reliability and lifetime of the system.
In this study, Copper-graphene nano-platelets(GnPs) composite coatings are deposited using the sediment electroplating process as shown in Figure 2(a), where GnPs are incorporated into the microstructure through magnetic stirring during electroplating as confirmed through Raman spectroscopy (Figure 2(b)). Graphene is often described as anisotropic, exhibiting excellent thermal conductivity (TC) and negative CTE in the in-plane direction, but not so obvious in the through-plane direction. The CTE of the Cu-GnPs in the in-plane and through-plane directions varies as such adjustments can be made by altering their orientation and distribution accordingly, in order to bridge the CTE gap between semiconductor die (e.g. SiC at 2.77 ppm/K) pure Cu (16.5 ppm/K). This demands key processing routes to intentionally integrate graphene into Cu matrix in coatings as

currently the GnPs are prone to accumulate on the coating surface with little penetration. Recently, electro-brush plating promises the incorporation of GO (Graphene Oxide) into Cu shown in Figures 2(c) and 2(d). This work utilises the electrodeposition process to enable the formation of tuneable CTE Cu- Carbonaceous (e.g. Cu-GnPs and Cu-GO) nanocomposites coatings for the enhancement of interconnect reliability. This can be achieved by analysing the CTE and TC of these coatings and exploring the fundamental mechanism about the interface network between the carbonaceous materials and Cu matrix through revealing 3D nano-scale microstructure, for instance using Tri-beam System.





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Effect of Different Metal-Reinforcement Phases on PEO Discharge and Coating Growth Behavior of AZ91 Mg-Matrix Composites

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The strength and ductility of Mg alloys were improved through the introduction of metallic reinforcement phases, such as Ti, Nb, Mn, Cu. However, the effect of different metal-reinforcement phases on the PEO discharge and coating growth behavior of Mg alloys has not been systematically studied. In this work, AZ91/Ti, AZ91/Nb, AZ91/Mn, and AZ91/Cu) were subjected to PEO treatment in an alkaline silicate electrolyte. The influence of these metal-reinforcement phases on voltage evolution, coating morphology, phase composition, and corrosion resistance was investigated. The results showed that the PEO discharge and coating growth behavior of composites were affected by the properties of metal-reinforcement phase oxides. Factors such as stability, Pilling-Bedworth ratio (PBR), and conductivity of the metal-reinforcement phase oxides influenced the barrier layer's insulation. The differences in conductivity and bandgap between Mg matrix oxides and metal-reinforcement phase oxides altered the PEO discharge behavior of the composites. Specifically, for AZ91/Ti and AZ91/Nb, although the voltage rise rate did not change significantly compared to AZ91, a short voltage delay platform emerged at the initial stage of PEO. The difference in conductivity and bandgap between reinforcement phase oxides (TiO_2 or Nb_2O_5) and MgO caused continuous discharge above the reinforcement phase, resulting in a "volcanic" local morphology centered on the discharge channel. In contrast, the coating surfaces of AZ91/Mn and AZ91/Cu exhibited "nodular" protrusions mainly composed of reinforcement phase oxides. Current leakage in these "nodular" areas significantly reduced the voltage rise rate. The Ti and Nb-reinforcement phase participates in PEO discharge, forming TiO_2 and Nb_2O_5 in the coating, respectively. The Cu and Mn reinforcement phases, while not directly participating in the discharge, gradually dissolve under the discharge at matrix and are incorporated into the coating as Cu_2O, $CuAl_2O_4$, and Mn_2SiO_4, respectively.

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Enhanced Mechanical Properties of Metals Processed by Surface Mechanical Rolling Treatment

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Surface mechanical rolling treatment (SMRT) is a process by repeated and deep rolling at a high strain rate, which results in a nano-grained thin layer on the surface of the processed workpiece. The thickness of the gradient nanostructured layer reaches an order of hundreds of micrometers and the hardness can be several times as high as that of the coarse grained (CG) core. SMRT processed materials have higher fatigue strength and higher fatigue ductility than their CG counterparts. Residual stresses formed by the process has an influence on the fatigue properties of the SMRT processed materials but such an influence is secondary as compared with the influence of the microstructure changes resulted from the SMRT process. Nanocrystallization and the degree of improvement on mechanical properties are dependent on the type of materials and temperature. The mechanical properties of 1045 carbon steel are less impacted by the SMRT process while 316L stainless steel displays the most significant improvement of fatigue strength and fatigue ductility. 316H stainless steel shows a little improvement of the fatigue properties after SMRT process at room temperature but a significant improvement at high temperature in both fatigue and creep properties. The strain-life fatigue curve of the SMRT samples displays a distinguishable kink point which demarcates surface and subsurface fatigue crack initiations. It is experimentally confirmed that the kink point in the strain-life curve and the associated cracking behavior are due to the high residual stresses induced by the SMRT process. Unlike the traditional surface treatment processes, the microstructures induced by the SMRT process are retained at high temperature.

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Development of TiAlCuN Coatings With High Erosion, Cavitation and Antibacterial Properties for Marine Applications

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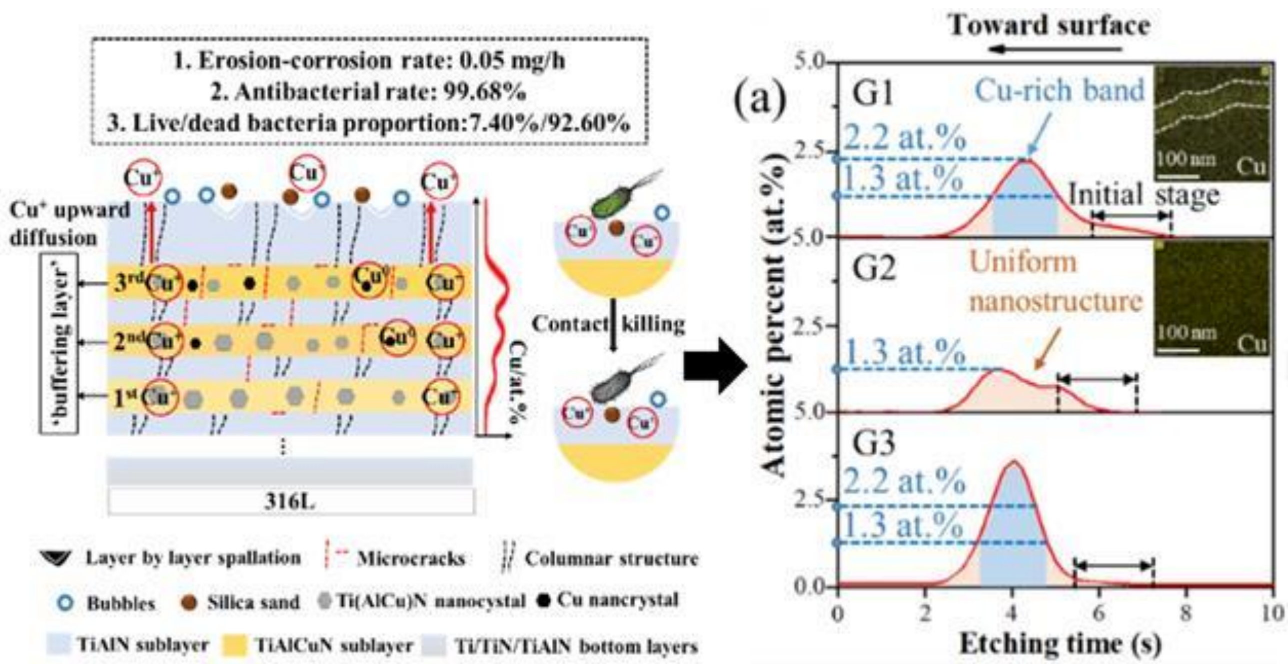
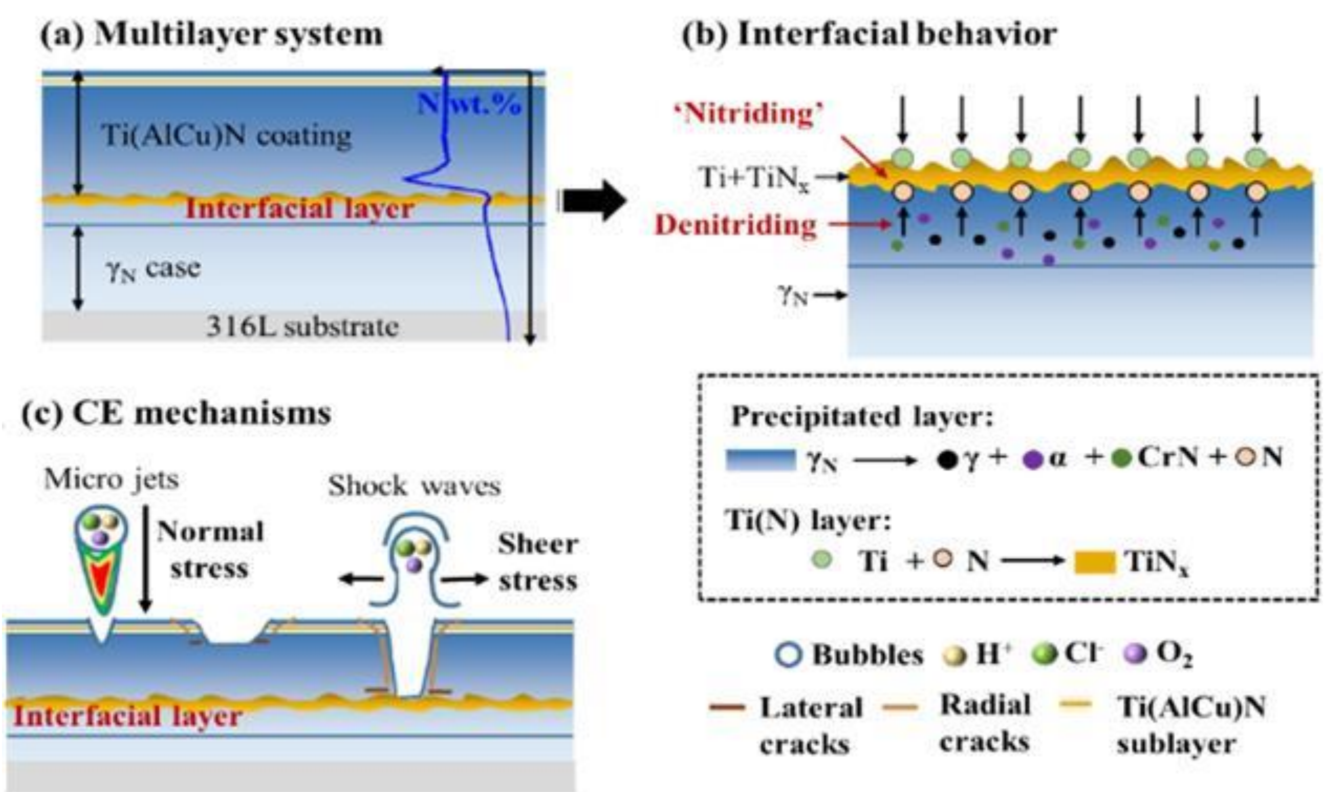
In marine hydrodynamic systems, metal components face significant threats from cavitation, sand erosion, and bacterial fouling. Although TiAlN hard coatings have been well developed to combat wear and corrosion, they still hardly satisfy the diverse requirements for marine environments. In this study, we have successfully developed a Cu-doped TiAlCuN coatings with controlled existence through periodically addition near the topmost surface. The TiAlCuN coatings possess excellent erosion-corrosion resistance and antibacterial property against E. coli with an antibacterial rate of 99.68 %. Furthermore, we have systematically studied the performance of duplex surface treatments combining plasma nitriding and Ti(AlCu)N coatings. The duplex treated surface not only exhibits high load-bearing capacity, coating adhesion, mechanical properties and corrosion resistance, but also demonstrates the superior performance against cavitation erosion in both distilled water and simulated sea water conditions. The interfacial behavior has been thoroughly investigated and a possible 'denitriding - nitriding' alloying mechanism is proposed. These findings not only offer practical solutions for enhancing the marine properties of metal parts but also provide insights into design for PVD nitride coatings.


1. Erosion-corrosion rate: 0.05 mg/h
2. Antibacterial rate: 99.68%
3. Live/dead bacteria proportion:7.40%/92.60%
Cu⁺ upward diffusion
'buffering layer'
3rd
2nd
1st
Cu/at.%
316L
Contact killing
Layer by layer spallation
Microcracks
Columnar structure
Bubbles
Silica sand
Ti(AlCu)N nanocystal
Cu nancrystal
TiAlN sublayer
TiAlCuN sublayer
Ti/TiN/TiAlN bottom layers
Toward surface
(a)
G1
Cu-rich band
2.2 at.%
1.3 at.%
Initial stage
G2
Uniform nanostructure
1.3 at.%
G3
2.2 at.%
1.3 at.%
100 nm
Cu
Atomic percent (at.%)
Etching time (s)


(a) Multilayer system
Ti(AlCu)N coating
N wt.%
Interfacial layer
γN case
316L substrate
(b) Interfacial behavior
'Nitriding'
Ti+TiNx
Denitriding
γN
(c) CE mechanisms
Micro jets
Normal stress
Shock waves
Sheer stress
Interfacial layer
Precipitated layer:
γN → γ + α + CrN + N
Ti(N) layer:
Ti + N → TiNx
Bubbles
H⁺
Cl⁻
O₂
Lateral cracks
Radial cracks
Ti(AlCu)N sublayer

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Low Temperature Nitrogen Diffusion Treatment of Specialty Austenitic Alloys for Surface Hardening and Enhanced Wear Resistance

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Low-temperature nitrogen diffusion treatments are widely used to enhance the surface hardness and tribological properties of austenitic stainless steels (SSs) without compromising (and even improving) their corrosion resistance. Such outstanding performance originates from the formation of a nitrogen-enriched expanded austenite (γN) case on the alloy surface, which is the key in ensuring their surface integrity in corrosion applications. However, current understanding of γN is often limited to the low-temperature nitriding studies on 304 and 316 SSs. Apart from 304/316 SSs, special austenitic SSs were employed for corrosion applications, including the high-Cr and high-Ni super-austenitic SSs with excellent corrosion resistance and the high Mn austenitic SSs that offer cost and strength advantages. These alloys are widely used in marine, chemical, and energy industries. In addition, given the rapid alloy development, a wide range of austenitic high entropy alloys have been studied, which shows superior mechanical and corrosion properties than 304/416 SS that has the potential to be adopted in the future.

After the well-known 'Cantor' alloy, different strands of face-centred cubic (FCC) high entropy (HEAs) and composition-complex alloys (CCAs) are being rapidly developed, exhibiting superior combination of mechanical strength and toughness. However, these FCC HEAs typically exhibit low yield strength and relatively poor surface hardness, which are prone to scratch/wear damage in applications. In particular, the surface hardness and wear resistance of the Cr-containing, corrosion-resistant FCC HEAs could be potentially improved by nitriding treatment at low temperatures < 450 °C without deteriorating its corrosion resistance. In particular, the influences from the high (equimolar) concentration levels of the matrix elements (such as Ni, Cr and Co) to the material surface nitriding response remain ambiguous, that challenges the development and adoption of the nitriding technique for these new alloys in the surface heat-treatment industry.

To this end, in comparison with the classic 316 austenitic SS, two austenitic medium entropy alloys (MEAs) – i.e., a ternary FeCrNi and a quandary FeCoNiCr one – were plasma nitrided at the typical low-to-intermediate treatment temperatures at 430-480 °C. Compared with the nitrogen level at 16-32 at.% in the 430 °C nitrided 316 SS, the nitrided case in FeCoNiCr HEA shows N concentrations at 20-28 at.%. However, the nitrided cases in the ternary FeCrNi MEA exhibits significantly higher N concentration at 30-36 at.%. Moreover, analogous to that in γN-304/316, cellular Cr-nitride precipitates were observed at the grain boundaries of in the nitrided case in FeCoNiCr HEA after nitriding at 450 °C for 10h. Intriguingly, finely dispersed Si-rich nanoprecipitates were observed in the nitrided case in FeCrNi MEA (the 0.5 wt.% Si most likely introduced from the alloy casting process) when nitrided at 430-450 °C. These works pave the way to the development of nitriding process to enhance the wear/corrosion performance of MEAs/HEAs and further nitriding studies on composition-complex alloys.

Keywords: Plasma nitriding, expanded austenite, surface hardening

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Influence of Different Shot Peening Treatments on the Fatigue Behaviour of Modern Leaf Spring Steels

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Introduction

Shot peening under pre-stress ("stress peening") has been widely used to improve fatigue lifetime of steel leaf springs in heavy truck applications. The application of both improved steel grades and modified stress peening treatments is therefore a key factor for battery electric trucks suspension concepts. The successful implementation of such measures is expected to allow for weight reduction, cost savings and increased range with larger batteries. The influence of stress peening treatments on surface layer states in newly developed leaf spring steel grades in comparison to conventional spring steels was assessed and the service life of various steel grades was characterized.

Methods

Four experimental casts of newly developed leaf spring steels were developed and characterized using chemical analyses, microscopy, and dilatometry. Quenched and tempered specimens of the casts underwent shot peening under pre-stress at different temperatures in a warm peening module with a bending pre-stresses. The setup combined inductive and continuous flow air stream heating with a hydraulic bending load device. Various pre-stress conditions, shot peening intensities, and temperatures were applied to study their effects. To evaluate surface layer states, X-ray residual stress, full width at half maximum (FWHM), and roughness measurements were conducted. Fatigue behavior was assessed using laboratory-scale specimens in alternating and 4-point bending tests.

Results

The developed steel grades have improved significantly after the application of the different shot peening treatments. Residual stress magnitudes and penetration depths in pre-stress direction reached a maximum of approximately -2000 MPa and a depth of 0.6 mm, respectively. Warm peening alone did not significantly enhance the fatigue behaviour in the HCF range. Instead, a pronounced negative influence of shot peening intensity was found and could be attributed mainly to the resulting higher surface roughness. Conventional stress peening, warm stress peening and double stress peening led to comparably improved results, while the most pronounced effect could be attributed to the selected steel grades.

Conclusion

The newly developed leaf spring steels demonstrated high suitability for shot peening applications, achieving high residual stress magnitudes and penetration depths as important factors in spring applications. Conventional, warm, and double stress peening yielded comparable results, with the steel composition playing a decisive role in surface layer formation. Furthermore, shot peening intensity proved to be a dominant factor in high temperature stress peening, primarily influencing surface roughness. Fatigue behavior was assessed using laboratory-scale specimens in alternating and 4-point bending tests. The findings highlight the importance of optimized material selection and peening parameters to achieve enhanced performance in fatigue-loaded applications.

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Advanced 3D Simulation of Surface Shot Peening

Dr. Christos Gakias[1], Dr. Efstratios Giannakis[1], Mr. Paschalis Adamidis[1], Dr. Stefan Dietrich[2], Prof. Dr. Volker Schulze[2], Prof. Georgios Savaidis[1]

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Introduction

Shot peening is a widely used surface treatment process where small spherical particles impact the surface of a component, inducing localized deformation and creating a compressive stress layer. These stresses, extending up to 300-400 µm in depth, significantly enhance fatigue life. This study focuses on calculating and predicting the residual stresses generated by optimized shot peening processes for leaf springs.

Methods

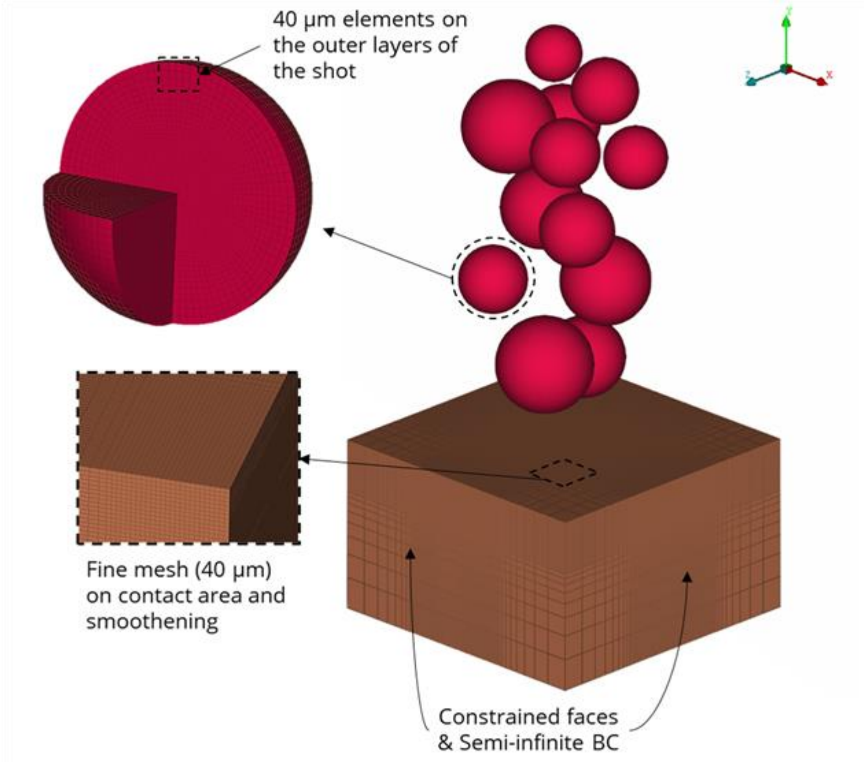
An advanced Finite Element Method (FEM) model was used to calculate compressive residual stresses. Material modeling techniques, including strain rate and temperature sensitivity, along with stochastic parameters, were employed to simulate various process scenarios.
The model incorporates a dynamic/explicit calculation scheme and elastic-plastic material behavior. The shot peening process was modeled sequentially, addressing each stage separately, including the main peening process, component release, and the application of pre-tension, where applicable.

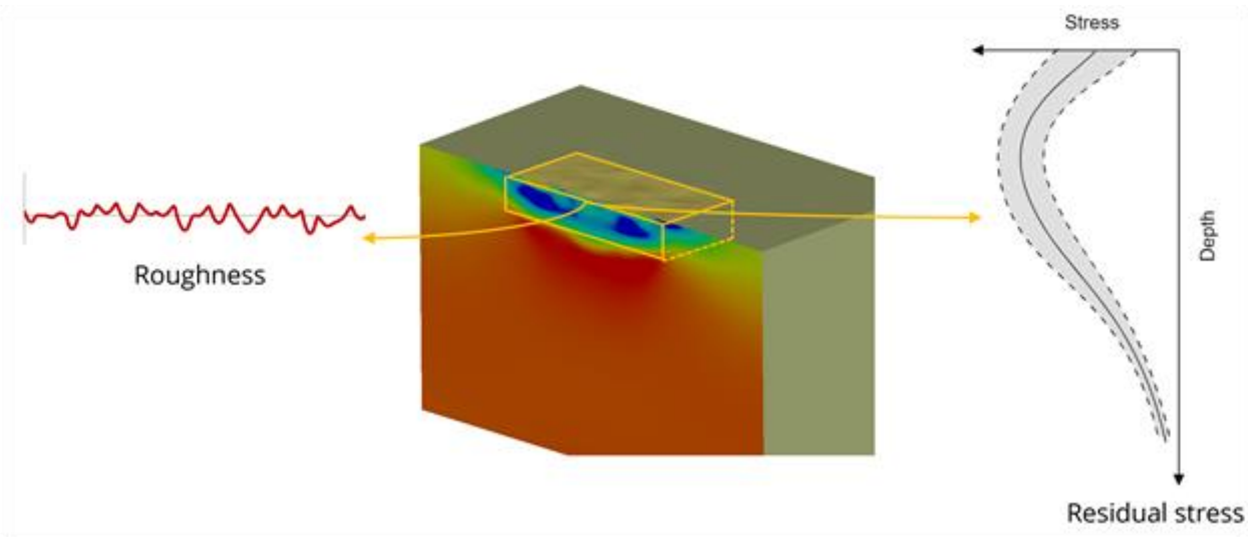
Results

Multiple peening scenarios were simulated, investigating the effects of elevated temperatures and pre-stress application. Key parameters, such as the compressive residual stress field and surface roughness—critical factors for fatigue life—were extracted from the simulations. The results were validated against experimental measurements of residual stress and roughness obtained from tested automotive leaf springs.

Conclusions

The FEM model demonstrates strong agreement with experimental data, accurately reproducing the shot peening process and enabling the evaluation of various process modifications. Parametric studies revealed that process optimization, through the use of elevated temperatures and pre-stress, can further improve compressive residual stress profiles, surface roughness, and ultimately, the fatigue life of leaf springs.


40 μm elements on the outer layers of the shot
Fine mesh (40 μm) on contact area and smoothening
Constrained faces & Semi-infinite BC


Roughness
Stress
Depth
Residual stress

E23

Plasma-Induced Healing of Cracks on Yttria-Stabilised Zirconia

Fangzhou Shi[1], Behnam Dashtbozorg[1], Xiaoying Li[1], Hanshan Dong[1]
[1]University Of Birmingham, Birmingham, United Kingdom

This talk reports novel low-pressure plasma induce crack healing phenomena of yttria-stabilised zirconia (YSZ). The plasma-induced restoration process is visualised by surface and transverse imaging using a combination of optical and SEM imaging with in-situ laser milling. XRD and Raman mapping of restored cracks reveal that plasma treatments lead to significantly greater tetragonal to monoclinic phase transition surrounding indents, which enable cracks to close beyond the inherent passive transformation toughening behaviour of YSZ. The findings of this study can help to pave the way towards future repair of damaged YSZ surfaces.

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Mechanical Durability Assessment of CFRP Liquid Hydrogen Storage Tanks for Aviation

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[1]*Delft University of Technology, Delft, Netherlands*

The use of liquid hydrogen as a fuel is widely regarded as a key technology for the future of clean aviation. However, realizing this potential requires advancements in the enabling technologies. One of these is the fuel storage, where the requirements of lightness and thermal isolation lead to the development of linerless, double-walled composite storage tanks. For such applications, the durability has to be guaranteed, while the weight and thicknesses are optimized to ensure the required gravimetric efficiency for flying, considering the greater volume needed to store the same energy with respect to conventional fuels. One common issue that affects laminated vessels is the onset of ply damage that reduces the permeation barrier of the tank walls, leading to reduced system performance followed by potentially hazardous scenarios.

In this work, developed within the European project COCOLIH2T, the damage development and the performance degradation of a composite shell containing liquid hydrogen is analysed and a framework is set for evaluation during in-service conditions. The main factors contributing to the laminate damage during the tank operations are the cryogenic temperature environment, the internal pressure, and inertial sloshing loads of the fuel itself.
Information about evolution of transverse cracks, characterized at different temperatures in quasi static and repeated loading conditions, is used to define the strength characteristics of the plies, while the permeation barrier performance is obtained through leak test measurements of integer laminates at different temperatures.

Recent experimental results published in the literature in these key areas, e.g. [1], have been utilized in this work to validate the model on a laminate scale, enabling the application on a tank scale. The leak performance index is predicted for various laminate configurations of the tank, this serves as a damage indicator, reflecting the presence of crack damage. It is then compared to a threshold value to identify an acceptable range of laminate designs. The several aspects taken into consideration are presented, such as the definition of the tank laminate, the generation of distributed crack damage as result of the load conditions, and the impact of those damage configurations on the leak rate of the overall tank itself. The limitations of this methodology and the extension of obtainable results using the available data are also reported.

The presented strategy allows for the identification of critical features during the design phase of cryogenic composite storage vessels, while its validation lays the foundation for more sophisticated long-term damage tolerance durability assessments.

The COCOLIH2T project is supported by the Clean Hydrogen Partnership and its members. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or Clean Hydrogen Joint Undertaking. Neither the European Union nor the granting authority can be held responsible for them.

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Buckling of Wide Rectangular GLARE Fiber-Metal Laminates Subjected to Compression

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Introduction
Hydrogen is a promising solution to the energy crisis, since it is a possible alternative to the fossil fuels. Laminated composites have been studied and used extensively as main materials for hydrogen storage, which is a critical issue [1]. Considering that further research is required to improve the potential of hydrogen storage, the future research should focus on advanced materials by developing multifunctional materials and hybrid composites, such as Fiber-Metal Laminates (FMLs).
FMLs are hybrid composite structures consisting of alternating metal layers and fiber-reinforced preimpregnated (prepreg) layers. FMLs have exceptional mechanical properties and they are mainly applied in the aerospace and automotive industry [2]. Most FML structures are thin-walled, since weight saving is of critical importance in aerospace and automotive engineering. Consequently, the buckling behavior of FMLs is of great interest for mechanical engineers. The purpose of this article is to study the elastic buckling behavior of simply supported GLARE (GLAss REinforced) plates compressed by two equal and opposite forces.
Method
The main objective of the present study is the calculation of buckling coefficients of thin GLARE plates and the construction of diagrams of these coefficients as a function of their aspect ratio. The calculation of the critical buckling load is carried out numerically using the eigenvalue buckling analysis [3], and the convergence of the numerical results is always checked. The numerical procedure has been validated through comparisons between numerical and corresponding analytical results regarding aluminum plates [4] (Figure 1) and FMLs [5].
Results
It is found that the elastic buckling strength of the considered materials increases as their metal volume fraction increases. It is also found that the diagrams of the buckling coefficients versus the aspect ratio of aluminum and GLARE plates present a very similar trend.
Conclusions
This article deals with the elastic buckling of simply supported GLARE plates subjected to compression by two equal and opposite forces. The finite element method is employed along with eigenvalue buckling analysis in order to calculate the critical buckling load of the laminates. The results of this study will help aerospace and automotive engineers to obtain insight into the buckling behavior of advanced hybrid materials which can be used in several demanding modern applications.

Figure 1. Numerical versus analytical critical buckling load of simply supported aluminum plates.

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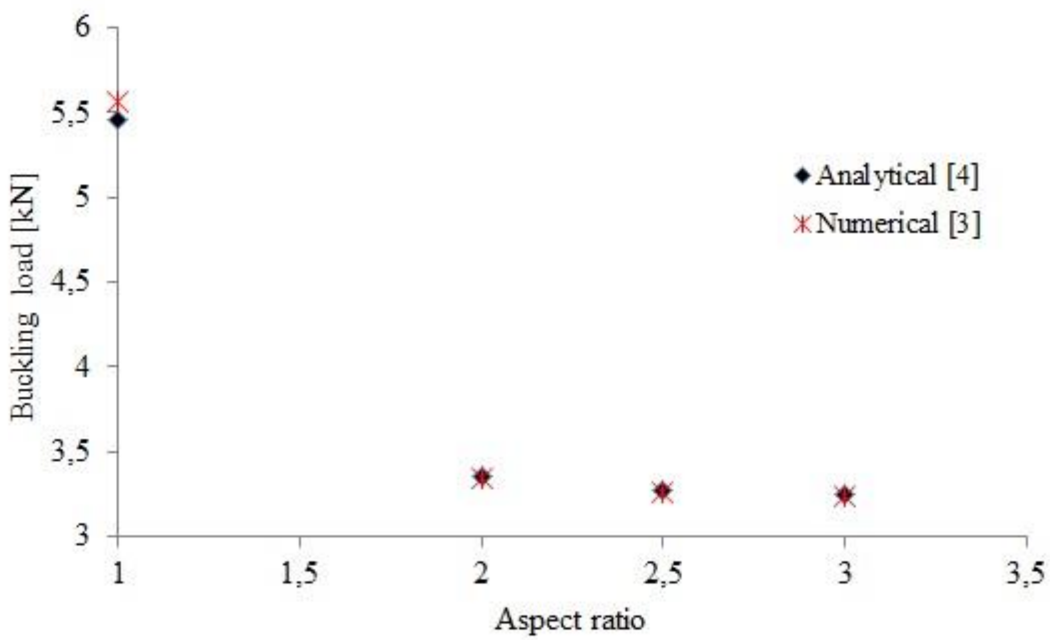

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Effect of Stress Triaxiality, Strain Rate and Pressure on Hydrogen Embrittlement of X70 Steel Studied by Mini Specimens and Synchrotron Tomography

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As a result of climate change, low-carbon power sources are being studied. Most of the green energy sources are volatile, relying on external conditions, making them hard to fully rely on. Storing the excess energy generated and using it when it's needed is still a great problem with today's energy storage technology. To try to solve this problem, hydrogen gas produced from water is under consideration as a form of energy storage.

Hydrogen gas that can be used in both the industry, to generate heat, or to produce electricity. There is already infrastructure in place to transport natural gas used for similar purposes. A reimagination of today's infrastructure to be repurposed to best optimize the transition, could make it cheaper, faster and with less waste.

The repurpose of current infrastructure is beeing studied. Hydrogen can be difficult to work with for most materials. It can permeate through most metals and change the mechanical properties, causing losses in ductility and toughness.

For this work, the effect of a hydrogen atmosphere is studied for an X70 pipeline steel, as well as how different mechanical and gas charging parameters influence the material. The material was collected from a pipeline used for the transport of natural gas. Smooth and notched mini-specimens are tested. The specimens are charged with a hydrogen gas of 6.0 quality inside a pressure chamber and tested in-situ. The extensometry measures are made with Edge Tracing (ET) techniques to ensure accurate measurements without the need for mechanical devices inside the gas chamber.

The tensile testing was done for a gas pressure of 240 bar and compared to tests in air. During the tensile test different strain rates (10-4 and 10-5 s-1) were applied and different mini-specimen geometries were compared to see the effect of triaxiality in the results. The hydrogen gas has a strong effect leading to the loss in radial contraction, showing the material embrittlement.

The strain rates also significantly impact not only the loss of ductility but also the reproducibility of the experiments. The displacement of 10-4 s-1 results shows a dispersion in the radial contraction data, going from 18 to 29%, while for the tests in air the radial contraction surpasses 40%. For the displacement of 10-5 s-1 the tensile tests were more repeatable, ranging from 17 to 19% radial reduction before failure.

The specimens were analyzed with SEM microscopy and synchrotron microtomography to better understand the fracture. Whilst the material tested under air showed classical ductile damage mechanisms with the highest void volume fraction in the specimen center, as expected, hydrogen charged samples showed surface cracks. These were identified as brittle by fractography of the broken surface and by the microtomography results.

The analysis of the brokens samples shows that there is a difference between the strains rates of 10-4 s-1 and 10-5s-1. While for the samples at 10-4 s-1 the crack growth is mostly initiated at the surface, with the center of the sample saying ductile. The samples at 10-5s-1 have the whole surface embrittled.

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FGM Sandwich Curve Beam Under Thermomechanical Loads for the Hydrogen Mechanical Applications

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A class of advanced composite materials developed in 1984, were created by the gradual change of the chemical composition and/or microstructure from one material to another which gives a smooth change of the material properties in one or more directions [1-7]. These types of materials are called functionally graded materials (FGM)and they are employed in applications in the fields of Aerospace, Automotive, Biomedical, Defense, Marine, Machinery, Optoelectronics etc [3-6].
In this study a curved sandwich beam with FGM face sheets and core from homogeneous material under thermomechanical loads is investigated. The finite element method (FEM) will be used to solve the problem. Plane isoparametric 8 node elements are used, where the gradient of the material properties is incorporated in the formulation of the element. The effect of the thickness and volume fracture index (VFI) (Fig.1) of the FGM face sheets on the stress and on the temperature, fields are studied. The results are valuable in the design of hydrogen mechanical applications as the FGM sandwich curved beam could be part of hydrogen storage tanks.

Figure 1 the normal stress σxx stress distributions through the length of the cross section for different values of VFI.

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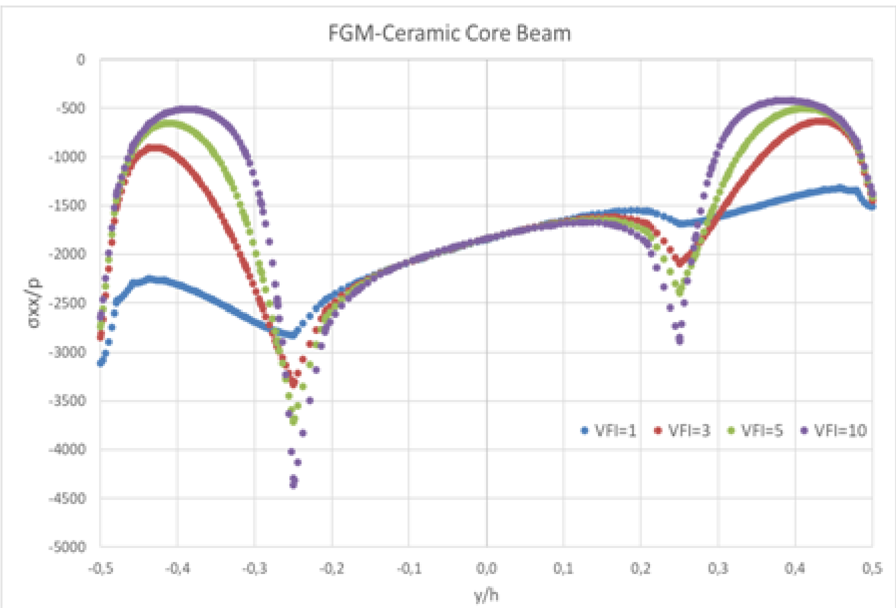

E22

Early Detection, Evaluation and Continuous Monitoring of Hydrogen Induced Cracking in Oil & Gas Vessels

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Hydrogen Induced Cracking (HIC) poses a significant threat to the integrity of carbon steel vessels operating in aggressive hydrogen-rich environments, particularly severe wet H_2S service. This damage mechanism can initiate at relatively low temperatures due to the accumulation of atomic hydrogen at microstructural imperfections and impurities, transforming into non-diffusible molecular hydrogen that expands and may result in cracking. Progressing from small planar cracks and stepwise cracking to stress-oriented HIC, undetected damage can lead to catastrophic and sudden vessel failure, while late-stage detection necessitates costly decommissioning or operational limitations.

Over the past two decades, significant advancements in ultrasonic testing (UT) have dramatically improved the detection and characterization of HIC at early stages. The strategic implementation of advanced Phased Array Ultrasonic Testing (PAUT) and Time-of-Flight Diffraction (ToFD) techniques, now enables timely identification of HIC damage for vessel owners to implement proactive mitigation strategies of its presence. High-quality data from these UT inspections forms the basis for robust Fitness-for-Service (FFS) studies, determining safe operational parameters for damaged vessels. Furthermore, periodic UT re-testing and trend analysis facilitate the monitoring of damage progression, triggering subsequent FFS assessments and potential operational adjustments. Complementing UT, long-term Acoustic Emission (AE) monitoring provides real-time insights into the dynamic behavior and evolution of HIC damage. The synergistic application of PAUT and AE establishes a powerful framework for predictive maintenance, minimizing downtime and mitigating failure risks.

This paper presents our experienced approach to HIC management from the perspective of an inspection and monitoring provider. We detail the application of state-of-the-art UT inspection techniques, supported by illustrative results, data processing methodologies for accurate sizing and characterization, and specialized data analysis workflows designed to inform FFS studies. A key contribution of this work is a novel adaptation of Acoustic Emission monitoring, incorporating real-time alarm criteria specifically developed for the early detection of potential damage progression in severely HIC-affected areas. The study contributes towards the goal of failure prevention in critical oil & gas engineering structures, including vessels, columns, and reactors.

Keywords: Acoustic emission, Hydrogen Cracking, Ultrasonic Testing, Structural Health Monitoring

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An Advanced Stochastic 1D Inverse Finite Element Method for Strain Extrapolation With Experimental Validation

Mr. Jacopo Bardiani[1], Mr. Emanuele Petriconi[1], Mr. Georgios Aravanis[1], Dr. Andrea Manes[1], Dr. Claudio Sbarufatti[1]

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The Inverse Finite Element Method (iFEM) is a powerful technique for reconstructing displacement fields from strain measurements, making it particularly suitable for structural health monitoring applications. Traditional iFEM implementations rely on deterministic formulations, often requiring a dense network of strain sensors to achieve accurate reconstructions. However, practical constraints, such as sensor placement limitations and cost, necessitate the development of robust extrapolation techniques to infer strain in unsensed regions.
This paper presents an advanced stochastic 1D iFEM framework that incorporates uncertainty quantification in the strain extrapolation process. The proposed approach extends classical iFEM formulations by integrating a stochastic modeling technique to improve strain predictions in sparsely instrumented structures. Unlike conventional deterministic methods, this framework assigns weights to extrapolated strain values based on their associated uncertainty, enhancing the reliability of displacement reconstruction.
The methodology is validated through both numerical simulations and experimental tests, demonstrating its effectiveness in accurately reconstructing displacement fields with limited strain data. The experimental validation involves structural specimens instrumented with strain sensors, where the proposed method is used to infer missing strain data and compute displacement fields. The results show that the stochastic iFEM approach outperforms traditional interpolation techniques, providing improved accuracy and robustness under varying loading conditions.
The findings highlight the potential of stochastic iFEM in real-world structural health monitoring applications, particularly for cases where direct measurements are sparse or partially unavailable. The incorporation of an uncertainty-aware strain extrapolation framework enables more accurate and reliable predictions, making the method well-suited for practical deployment in aerospace, civil, and naval engineering applications.

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Estimation of the Size of a Growing Crack Through Strain Sensing Under Uncertainty

Ms. Anastasia Valma[1], Dr. Nicholas Silionis[1], Prof. Konstantinos Anyfantis[1]
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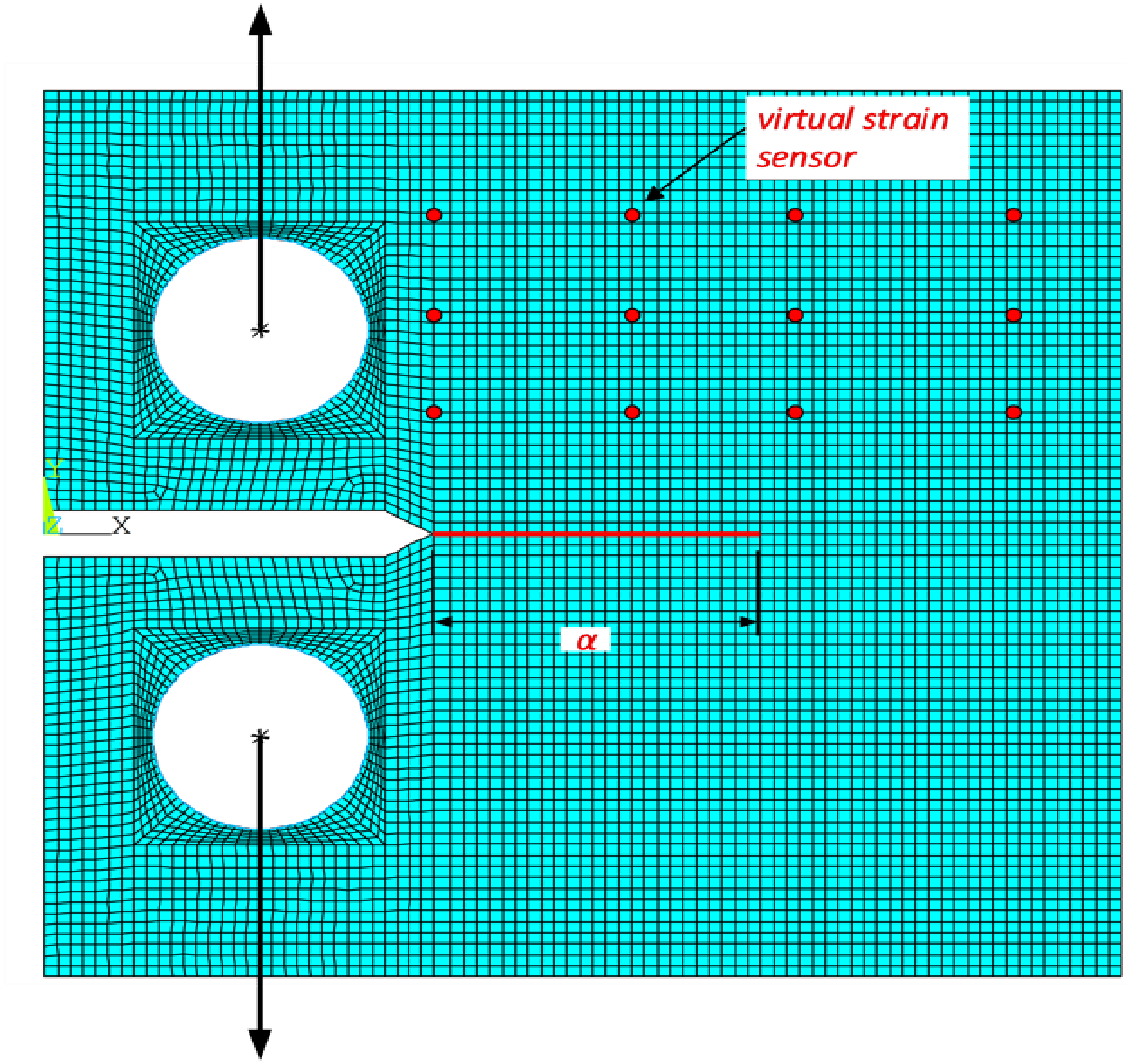
Marine structures and in particular ship hulls suffer from fatigue cracks that develop in highly stressed details mostly due to wave loading. Remote monitoring of the extension process of an identified crack is meaningful at its early stages and is in principle feasible by means of Structural Health Monitoring systems. It is well known, that a growing crack leads to a strain redistribution in the vicinity of the crack tip. Such characteristic may be used as a feature in a diagnostic method. The challenge is to process sensor readings in order to back calculate the responsible crack size under variable sources of uncertainty.
A probabilistic approach that is based on Maximum Likelihood Estimation is employed to tackle the inherent ill-conditioning of the problem at hand in the presence of noisy signals. The method is demonstrated on a simple test geometry, where strain sensors are virtually mounted at different locations and measure the response during the operation of the structure (see Figure 1). Causal relations between the crack length and respective strain features were modeled through surrogates that were generated from regression models on Finite Element simulated data.
Having set up a pool of potential locations for sensor placement, several feature combinations were tested and the corresponding accuracy of the estimation was evaluated over the crack length range that is of monitoring interest. The method allows for integrating the information encoded in several strain features which is useful in an optimal sensor placement problem under given levels of noise in the sensor readings.


virtual strain sensor
α
Y
Z
X

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Reduction of the Estimation Error in Load Inversion Problems: Application to an Aerostructure

Mr. George Panou, Mr. Sotiris Panagiotopoulos, Prof. Konstantinos Anyfantis[1]

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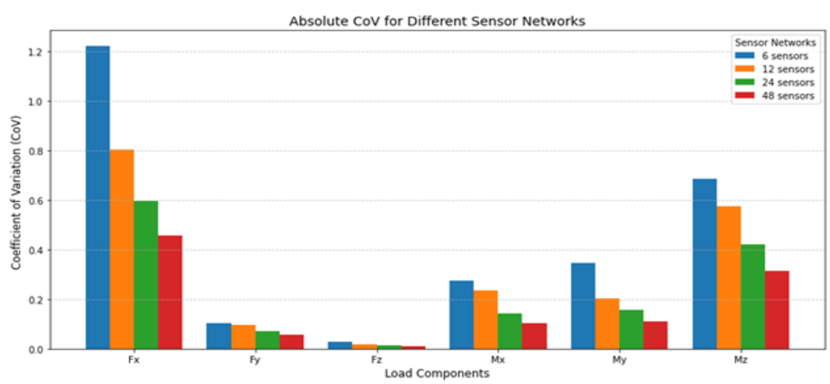
Structures in critical industries, such as aerospace engineering, operate under complex and uncertain environmental and loading conditions. These challenges have driven the need for developing methodologies that facilitate continuous monitoring of structural health and performance to ensure safety, prevent failures, and extend operational lifespan. This study presents a Structural Health Monitoring framework grounded in the concept of digital twinning. The proposed approach emphasizes the identification of loads on foil structures through strain measurements. Load identification is fundamentally an inverse problem, where the objective is to determine unknown loads (inputs) based on known responses (outputs) using a system model. Unlike direct problems, inverse problems are typically ill-posed and highly sensitive to uncertainties in measured responses. These uncertainties, which may arise from sensor noise, modeling inaccuracies, or environmental factors, can significantly affect the reliability of load identification. Even minor errors in response measurements can lead to substantial deviations in the identified loads. This study investigates two demonstrative case studies: a straightforward model of a cantilevered aluminum plate and a more advanced case featuring a composite UAV fin.

The study confirmed that Optimal Sensor Placement is critical in reducing load identification errors. By integrating the D-optimality criterion with genetic algorithms, the method effectively identified sensor locations and configurations that maximize information gain, minimizing uncertainty in the reconstructed loads. The genetic algorithm-based optimization demonstrated adaptability even in complex design spaces, such as the fin structure, which comprises multiple components with varying material properties. Additionally, the calibration matrix approach proved effective in accurately and consistently estimating applied loads, even in the presence of noise in strain measurements.The results demonstrate that the proposed methodology is effective for load identification and shows great potential for advancing Digital Twin development (Figure 1).



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On the Development of a Deep Learning-Based Surrogate Model for Fleet-Wide Probabilistic Modeling

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High-fidelity numerical models are standard for obtaining detailed insights into the mechanical behavior of complex engineering systems for Structural Health Monitoring (SHM) purposes. Nevertheless, their computational cost can be prohibitive, requiring significant resources for large-scale applications. This computational burden becomes even more severe for the case of fleet-wide modeling. Particularly, when dealing with a fleet of assets, differences inevitably arise between individual units, since engineering structures are inherently stochastic; even when these are nominally identical. This is formally related to the concept of Uncertainty Quantification (UQ), which typically relies on multiple model evaluations to capture the expected diversity in the system response. To effectively address these challenges, the development of probabilistic surrogate models constitutes an appealing alternative for stochastic approaches to SHM.

In this work, a specific class of deep generative models known as conditional variational autoencoders (CVAEs) is proposed for reconstructing the boundary response field on a critical region of monitoring interest, while accounting for various sources of uncertainty. CVAEs extend classical autoencoders by incorporating probabilistic modeling, typically using deep neural networks to encode knowledge into a latent space that follows a known distribution and is conditioned on input parameters [1] (see Figure 1). The conditional relationship allows CVAEs, during inference, to generate target response quantities while explicitly associating these responses with observed structural and/or operational conditions. On top of this, their probabilistic structure enables fleet-wide modeling by capturing the effects of service load variations and/or manufacturing inconsistencies on the overall system, without explicitly modeling each individual drone.

The proposed method is demonstrated on a relatively small, research UAV platform. A validated high-fidelity Finite Element (FE) model coupled with a panel aerodynamic model have been employed to generate synthetic data at specific region(s) of interest for training and testing the deep learning model. Ultimately, the authors view the proposed approach as a valuable tool in contexts where both UQ and modeling structural interactions at the system-subsystem level are desired at low computational cost, with global-level information being encoded implicitly into the response field of the target region.

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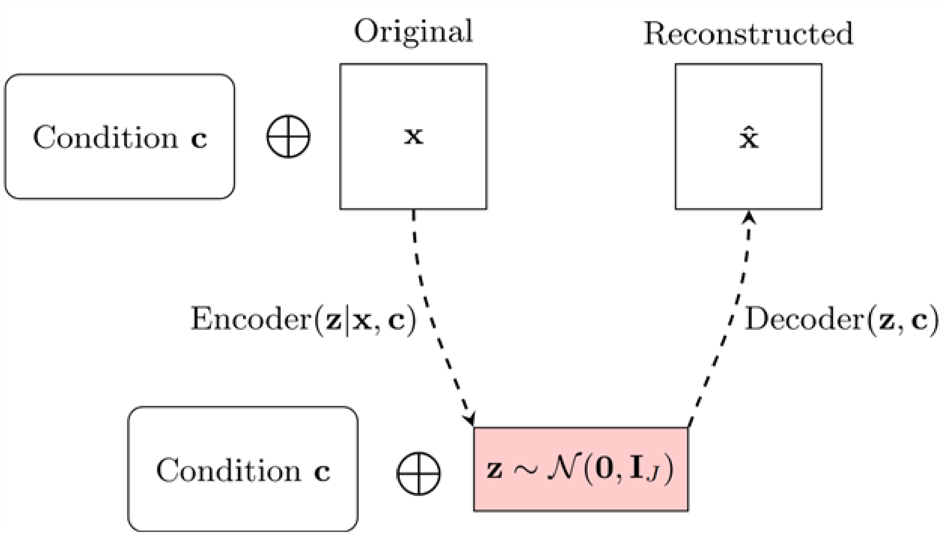

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Digitalization and Thermodynamic Simulations for Impurity Management in Recycled AlSi7Mg0.3 Alloys

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The transition from primary to recycled aluminum offers a significant opportunity to reduce CO_2 emissions, as recycling requires only a fraction of the energy needed for primary aluminum production. However, the recycling process introduces impurities that can impair material performance, particularly in terms of corrosion susceptibility and mechanical properties.[1,2] Addressing these challenges requires a comprehensive digital twin framework to predict the mechanical and corrosion behavior of recycled aluminum in automotive applications. As part of this agenda, the digitalization of impurity management in AlSi7Mg0.3 alloys is crucial and can be achieved by combining high-throughput thermodynamic simulations with supervised machine learning. This approach enables the evaluation of intermetallic precipitate formations caused by impurities such as Fe, Mn, and Cu. Although thermodynamic simulations are computationally intensive, high-throughput simulations of phase fractions serve as the foundation for building a comprehensive database. Machine learning expands upon this database, facilitating an in-depth investigation of precipitate formations and their effects on mechanical and corrosive properties. The findings inform the optimization of Mn/Fe ratios, enhancing mechanical performance while minimizing corrosion susceptibility. This contributes to the sustainable design of recycled aluminum alloys, aligning with circular economy principles and the goals of sustainable materials engineering. We acknowledge the financial support from the Technology Transfer Program Lightweight Construction – TTP LB (Grant No: 03LB3091A).

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Ecodesign Through Advanced Materials Digitization

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The European strategy for twin green-digital transition requires the creation of digital environments, like Open Innovation Platforms (OIP), to facilitate innovation and foster the collaborative development of new products. These effors aim to drive circular, sustainable, and net-zero-emission European economy. To support this transformation, regulations such as Ecodesign for Sustainable Products Regulation (ESPR) [1] mandate the implementation of Digital Product Passports (DPPs) across selected industrial sectors. DPPs, designed to track product sustainability metrics along distributed value chains, are expected to enhance product circularity, carbon footprint reduction, and environmental impuct from materials performance.
This presentation will showcase use the VIPCOAT OIP [2] as a digital framework for collaborative innovation-by-design process in the development of advanced protective coatings for aerospace industry. By integrating predictive modelling tools, the platform enables support the decision-making along the value chain. We will discuss the potential expansion of the OIP and its accumulated knowledge to other applications, as well as strategies to support European industry — particularly small and medium enterprises (SMEs) — in leveraging DPPs and strengthening their digital maturity. There aspects are the overarching obhectives of DigiPass CSA project [3].

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Modelling the Microstructure of Active Protective Coatings Based On 3D Image Data

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Corrosion is a persistent challenge in aerospace engineering, so corrosion control remains a principal part of the design process of aircraft. Active protective coatings play an essential role within corrosion prevention schemes, offering two modes of protection at once: passivation (by acting as a physical barrier), and reactive self-healing. These coatings contain corrosion inhibitor particles which pacify damage through a mechanism called leaching. Namely, the particles dissolve upon contact with moisture and form a mixture that covers the exposed area to protect it. The performance of a coating depends heavily on this process - despite its importance, however, the exact way that leaching unfolds on the microscale remains obscure.

One of the aims of the H2020 project VIPCOAT (GA 952903) is to facilitate development of new coatings. It contributes to these efforts by creating an open innovation platform with models designed to assist engineers and accelerate durability tests. Understanding the underlying mechanisms is crucial for the fidelity of the models. Previous research points to the importance of the microstructure of the coatings (i.e., the size, shape, and spatial distribution of inhibitor particles) on the leaching process. To inspect the microstructure, we imaged coating samples non-destructively in 3D by nano- and microcomputed tomography using synchrotron radiation; the resulting volume images were then used to analyze the particle morphology, as well as study the progress and effects of leaching.

We used the insights gained from observing the microstructure to construct stochastic geometric models of active protective coatings. Two types of models were created: a complex polyhedral model, matching the inhibitor particles more tightly, and a rougher cuboid model, designed for interactive real-time use via the VIPCOAT Open Innovation Platform. These models are intended to generate synthetic data for leaching simulations. Furthermore, we analyzed the pore space formed after inhibitor particle dissolution. We observed the pore space on two scales: the finer scale observations allowed us to track gradual changes in the coating due to leaching, e.g. identifying pathway formation between pores, while we used the coarser observations to model the leaching kinetics by quantifying the leaching fronts.

Active protective coatings are the current state of the art of corrosion prevention, and coatings containing hexavalent chromate particles are still a staple in the aerospace industry. However, since these particles are toxic and carcinogenic, considerable effort is invested into designing a safer, environmentally friendly, and efficient replacement. Understanding the factors that control the leaching is key for performance optimization of new coatings. Our research yielded new insights into the leaching mechanism, which informed our mathematical models of coatings. Our findings and models can guide the design of new coatings and thus decrease the time, labor, and material resources needed in the development process.

Figure 1: From left to right: an observation of a lithium sulfate coating, the polyhedral model, the simplified cuboid model.

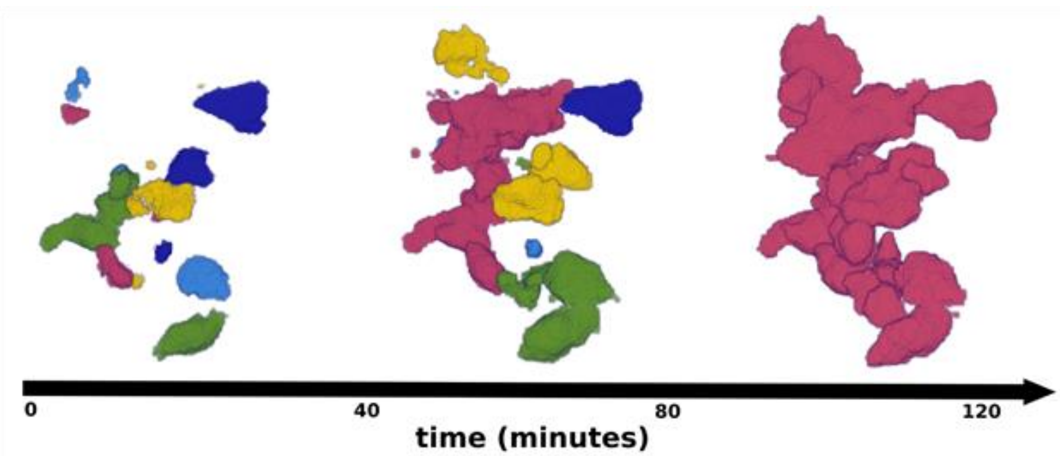

Figure 2: A cluster of pores growing more connected, finally coalescing into a single large pore.

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Influence of Anodizing on the Fatigue Crack Growth Resistance of Artificially Aged AA2198 (Al-Cu-Li) Specimens

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Anodizing is a widely used surface treatment that enhances durability in terms of increased scratch and wear resistance as well as higher corrosion resistance. Anodizing is an electrochemical process that forms on the surface of the aluminium alloy a durable and protective oxide layer. The anodized layer provides additionally excellent bonding for paints and coatings, contributing to enhanced aesthetic and functional properties. Given the growing demand for high-performance materials in the aviation industry, anodizing offers a cost-effective solution to extend the lifespan of Al-Cu-Li alloys while maintaining their mechanical integrity. On the other hand, anodizing has been criticized to decrease the mechanical properties of conventional Al-Cu aluminium alloys, e.g. AA2024 that is still used in the aeronautical sector. The present experimental investigation sheds light on the effect of anodizing and artificial ageing on fatigue crack growth resistance of the third generation Al-Cu-Li alloy AA2198. Compact tension C(T) specimens were used for fatigue crack growth tests in accordance with ASTM E647 requirements from AA2198-T3 sheets of 3.2 mm nominal thickness. To simulate various ageing tempers corresponding to under-ageing (UA), peak-ageing (PA), and over-ageing (OA), the specimens were first subjected to different artificial ageing heat-treatment. As a second step, the following three (3) different anodizing processes: (i) Chromic Acid Anodizing - CAA, (ii) Sulfuric Acid Anodizing - SAA and (iii) Thin Film Sulfuric Acid Anodizing – TFSAA, were exploited at the premises of Hellenic Aerospace Industry (HAI) to perform anodization on different C(T) specimens of the three (3) different ageing tempers, namely UA, PA and OA. Fatigue crack growth diagrams in terms of $d\alpha/dN$-ΔK curves are presented to showcase in twofold: the influence of the anodization type as well as of the prior ageing on the fatigue crack growth resistance of AA2198.

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A Conceptional Digitalisation Framework

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Information handling is steadily increasing, making it necessary to handle data more efficiently and automatically using computers, thus defining a need for digitalisation, which affects experimental data and computer-generated data.
The core idea is to use ontologies defining a standard, computer-processable language for data and their production. The paper will describe how to combine modelling and ontologies to construct a generic framework for integrating experimental and simulated data and making the data available for post-processing via a common data space. The approach automates various elements, removing the need for user interaction and thus reducing the possibility of failure, increasing reliability and ease of use by the researcher.

We combine several concepts:
- Public ontologies that capture the terminology of items,
- a method to represent models in terms of fundamental physical and information-processing entities [CWA],
- systematically built ontologies capturing the equation space describing the fundamental entities [TOPO],
- semantic networks to construct data pipelines.

We will introduce:
- The approach of constructing models using fundamental entities a building blocks, in contrast to a unit-type or component-type approach,
- the generation of a systematically built equation ontology for controlled physical systems with reactive distributed chemical and biological species,
- the utilisation of equation ontology being linked to public ontologies to generate a domainspecific language,
- capturing the process model in a knowledge graph, making the models searchable for AI applications,
- generating parsers for experimental data,
- knowledge-graph approach to capture metadata documenting experiments,
- the utilisation of the generated data models and parsers to establish the desired data pipeline from experiment and simulation to a common data space.

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UNIVERSITY OF LIFE SCIENCES), KLEIN Peter (FRAUNHOFER ITWM), KONCHAKOVA Natalia (HELMHOLTZ - ZENTRUM HEREON), MANENTI Flavio (POLITECNICO DI MILANO), PREISIG Heinz (Chair - Project leader NORWEGIAN
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The Effect of Corrosion-Induced Hydrogen Absorption of the Al-Cu-Li Alloy and the Al-Cu-Mg Alloy AA2024 on Mechanical Property Degradation

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In earlier works[1],[2],[3] it has been demonstrated that exposure of the Al-Cu-Li alloy AA2198 and the Al-Cu-Mg alloy AA2024 to corrosive solutions, including one designed to simulate accelerated atmospheric corrosion (EXCO, according to ASTM G34 standard), led to remarkably different responses with regard to tensile properties degradation. The loss of strength properties (yield stress, ultimate tensile strength) was pronounced for the AA2024 for long exposure times where the pitting corrosion as well as exfoliation mechanisms take place, but little change of those properties was observed for the AA2198 alloy. The yield stress was, for example, degraded for both alloys, although the Li-containing AA2198 showed high resistance, with only 4,3 % degradation observed after 24 hours of EXCO exposure. In comparison, the Al-Cu-Mg alloy (AA 2024 T3) showed a yield strength degradation of 21,0 % after the same exposure. Additionally, significant differences between the two investigated materials were noticed on the corrosion-induced degradation percentage of elongation at fracture; the AA2198-T3 was found to be more corrosion resistant especially at short exposure times and minimal surface attack was observed after 48 h of EXCO exposure. The degrading mechanism of the tensile mechanical properties of the alloys at short exposure times is believed to be the hydrogen embrittlement phenomenon since no evidence of pitting or other corrosion was noticed in some cases, but the fundamental reasons for these differences were not fully explored at the time.

In the current work, the individual contributions of hydrogen absorption and sub-surface intergranular corrosion attack (IGC) on the relative tensile mechanical property's degradation of the two alloys are studied. Thermal Desorption Spectrometry (TDS) is used to evaluate the extent of diffusible hydrogen absorbed by the two alloys at different levels of corrosion exposure (EXCO, according to ASTM G34 standard). Both short (e.g., 2 h) and long (e.g., 24 and 48 h) corrosion exposure times to EXCO solution were selected to search for

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differences in the level of absorbed hydrogen with increasing exposure time, since noticeable differences were revealed in the corrosion-induced degradation percentage of the mechanical properties from the tensile test results of previous works of the authors[1,2]. Each sample was placed in a TDS chamber and heated at a controlled rate of 5°C/min up to 600°C and soaked there for a further 300 s. The desorption rate of hydrogen was recorded as a function of temperature. The role of various trap sites is studied and discussed. Furthermore, the extent of tensile property degradation and hydrogen absorption after cathodic charging of the alloys, i.e., in the absence of sub-surface intergranular attack, is studied to compare the effects of hydrogen absorption only (i.e., cathodic charging) to that of hydrogen absorption plus intergranular corrosion (EXCO exposure). A cathodic potential of -1 V relative to an Ag/AgCl reference electrode was selected. The samples were immersed in the electrolyte under continuous potential control for 24 and 48 h. The temperature of the solution was maintained at an average temperature of 58 °C throughout the charging process to ensure consistent test conditions. TDS is again utilized to study the trapping site behaviour and scanning electron microscopy (SEM) work is used to evaluate fractography and intergranular attack.

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Modeling of the Corrosion-Induced Damage and Assessment of the Residual Mechanical Properties of Artificially Aged AA2198

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The increasing demand in aviation industry for lighter metallic structures with improved mechanical performance, damage tolerance and corrosion resistance enhanced the use of Al-Cu-Li alloys. Their advantages are attributed to their precipitation hardening system, including δ (Al3Li), θ (Al2Cu), T1 (Al2CuLi) and S (Al2CuMg) phase. Nevertheless, these phases influence the alloys corrosion, due to the different electrochemical characteristics between them and the matrix [1 , 2 , 3]. Their size and population alters significantly during natural ageing of the alloys. For the simulation of natural ageing, isothermal artificial ageing heat-treatment is performed to accelerate the thermo-mechanical transformations. This process affects the alloys metallurgical structure, residual stress-state and corrosion initiation and propagation mechanisms. 2xxx series Al alloys have higher corrosion resistance when artificially aged at certain tempers, e.g., T6 for AA2024 [4]. Hence, it is of major importance to investigate the effect of artificial ageing on corrosion behaviour and damage on newly developed Al-Cu-Li alloys.

The material used was a wrought AA2198-T3 of 3.2 mm nominal thickness. Rectangular specimens [10 mm x 20 mm] were machined from the sheets and exposed to artificial ageing for different times which correspond to under-ageing (UA), peak-ageing (PA) and over-ageing (OA) temper. Exposure to EXCO solution [e.g., ASTM G34 standard] was performed for different times to investigate the effect of artificial ageing on the evolution of corrosion-induced damage. Corrosion damage was modeled both as surface notches and as pitting distribution on the specimens deteriorated surface. A three-dimensional parametric finite element model was developed using ANSYS to take as an input the size and shape of corrosion products. The model considers the randomness of size and shape of the corroded products and the size of the hydrogen embrittled zone. The evolution of damage during loading is predicted using a progressive damage modelling scheme. The model can assess the residual mechanical properties of corroded structures and provide useful information concerning the mechanics of damage evolution from the deteriorated surface to the hydrogen embrittled zone and to the pristine material. The latter is enhanced with a fully parametric theoretical investigation with respect to the pitting damage and depth of hydrogen embrittlement as related to corrosion exposure time.

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The Dependence of Ageing Condition on Hydrogen Embrittlement and Grain Boundary Attack in Exco-Exposed AA2024-T3

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In earlier work, it has been demonstrated that both the plain-stress fracture toughness (KR-curves) and tensile ductility of the AA2024-T3 alloy are degraded by simulated atmospheric exposure, by immersing in an EXCO solution for times ranging from relatively short (2 hours) to long (48 hours) durations [1,2]. The degradation has been shown to be associated with both H embrittlement and grain boundary attack of the sub-surface zone, resulting in the development of sub-surface cracking upon tensile straining. For an EXCO exposure time of 2 hours, the depth of the sub-surface zone with the grain boundary attack was found to be in the order of 100 micron for the standard T3 condition. For this exposure time, a total of 5,7 ppm of diffusible hydrogen was found to be absorbed in the sample, and all the absorbed diffusible hydrogen was removed by a solution heat treatment [3]. The extent of mechanical property degradation, both in terms of KR- curves and tensile elongation, has been found to be dependent on the ageing condition, with the peak aged condition giving rise to the smallest level of degradation [4]. The reason for this trend has not been fully explained.

In the current work, the relative contributions of H diffusion and sub-surface grain boundary attack on the ageing -related mechanical property degradation were investigated. Two durations of EXCO exposure, 2 hours and 48 hours, were utilized.

Thermal Desorption Spectrometry (TDS) was employed to investigate the extent of hydrogen absorbed and the trapping sites associated with it, while the extent of grain boundary attack and secondary cracking were investigated metallographically, all as a function of the ageing condition. The depth of sub-surface grain boundary attack, as well as the density of secondary cracks adjacent to the primary crack in EXCO-exposed KR – CT samples were furthermore quantified. The degradation trends observed regarding the ageing-dependent degradation were explained with reference to the change in the trapping sites with the progression from under-aged to over-aged conditions. Fractography of the degraded KR – CT samples were conducted using Scanning Electron Microscopy.

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Integration of Machine Learning (ML) and Fuzzy Inference Systems (FIS) in the Risk Assessment of Buildings Affected by Industrial Impact From Underground Mining

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The present work refers to the serious problem of the static and dynamic environmental impacts of underground mining on building structures. These impacts manifest as kinematic excitations acting on the building foundation level. In the case of buildings in mining areas, these are usually continuous surface deformations, discontinuous deformations, and mining tremors. The effects of such impacts can be the occurrence or intensification of existing damage such as cracks or scratches, as well as an accelerated process of material deterioration of load-bearing or finishing elements. In order to minimize the risk of failure in a large number of buildings, a suitable tool must be used to effectively monitor this process, e.g., as a function of long-term (continuous deformation) and frequent (tremors) mining impacts. The necessity to properly assess the effects of mining influences usually concerns a large number of buildings and must be carried out in a relatively short period of time.

The deterioration process is also influenced by other factors, such as the quality of maintenance of a given building or its technical age; such an assessment is a complex and multifactorial issue.

The experience gained during previous statistical research allowed the adaptation of innovative machine learning (ML) techniques and the construction of a prototype decision-making system.

It was assumed that the main goal would be to create a rule-based inference system. At this stage, an additional assumption was made regarding the method of data processing in such a system so that it could work even in the case of uncertain information. This formulation of the problem makes it possible to identify a family for further analysis of the Fuzzy Inference System (FIS). Uzgodniono, że zostanie użyta specyficzna forma tak zwanego Mamdani FIS. It is an expert system in which the parameters of fuzzy sets and the relations between them are arbitrarily determined by the user. However, this type of operation for multivariate processes is not possible due to the obvious limitations of human perception.

This problem was solved by creating a computational procedure integrating the use of an ML tool in the form of SVM (Support Vector Method), derivative-free optimization (DFO) as a genetic algorithm (GA), and an intermediate FIS system called TSK (Takagi-Sugeno-Kang).

In the established calculation procedure, the SVM method allowed for the construction of a regression model, which was further the basic information source, i.e., the core of the acquired knowledge transferred further to the TSK system and finally to the Mamdani FIS. The genetic optimization method was applied twice throughout the procedure. The first time was to tune the hyperparameters of the SVM model, and the second time to adjust the positions of fuzzy sets in the Mamdani system. All this made it possible to build an expert system reflecting the process of building deterioration described in the multifactorial domain.

The basis for the research presented in the work was a collected database on the technical state and damage of over 1000 buildings located in mining areas related to coal and copper mining.

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Surrogate-Based Structural Optimization of the Battery Enclosure of an Electric Vehicle

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As the demand for reducing carbon emissions and enhancing fossil fuel efficiency grows, electric vehicles (EVs) have emerged as a promising solution for the automotive industry. However, the limited capacity of current battery technology significantly restricts the driving range of battery-electric vehicles compared to internal combustion engine vehicles. One effective approach to extending the range of EVs is weight reduction [1]. In addition, evaluating the trade-offs associated with lightweight material substitution in EV components can lead to substantial reductions in both weight and cost [2-3]. Consequently, the adoption of composite materials as an alternative to conventional materials such as steel and aluminum has garnered increasing attention in recent studies.

This study conducts a surrogate-based structural optimization of an electric vehicle battery enclosure. Three material configurations are evaluated: fully carbon fiber-reinforced plastic (CFRP), fully glass fiber-reinforced plastic (GFRP), and hybrid fiber-reinforced plastic (HFRP). The optimization process considers design variables such as fiber orientation angles, ply thicknesses, and the carbon-to-glass fiber ratio. The objective function is defined as the structural weight for each material option. Constraints are imposed on structural performance criteria, including bending and torsional strength, vibration resistance, and crashworthiness.

Structural performance evaluations are conducted using ANSYS/LS-DYNA finite element software. The optimization process employs surrogate models, including conventional approaches such as polynomial response surface, Kriging, and radial basis functions, as well as machine learning algorithms like support vector regression and Gaussian processes. The surrogate models are constructed using MATLAB’s Statistics and Machine Learning Toolbox, while the optimization is carried out using MATLAB’s Global Optimization Toolbox.

This study was supported by the Scientific and Technological Research Council of Türkiye (TÜBİTAK) project no. 22AG024 under program no. 22AG001.

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Optimization of Lattice Structures Under Uncertainties Predicted by Neural Networks

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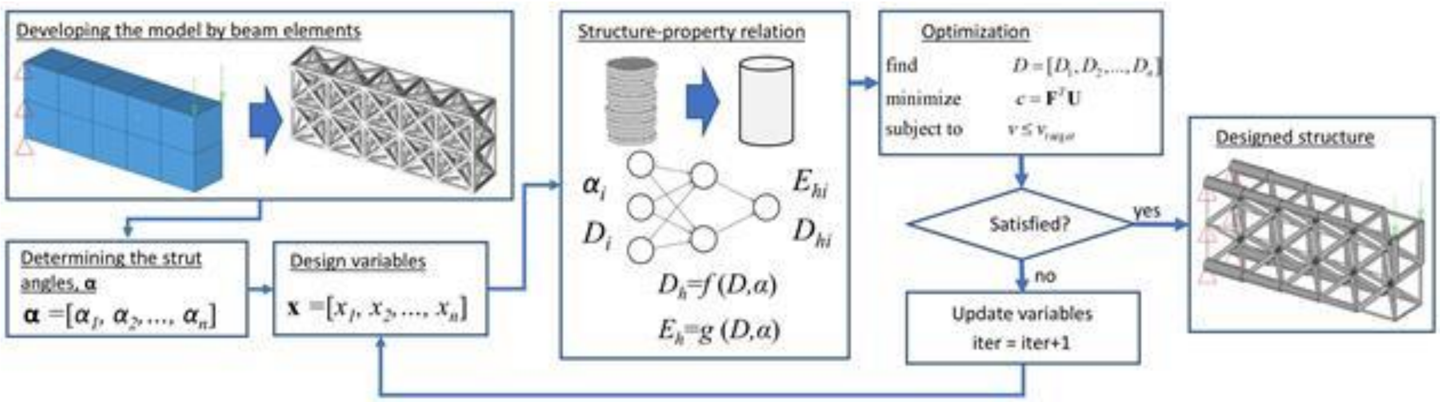
Introduction: The lightweight and high strength characteristics of lattice structures, coupled with their easily modellable topological features, are increasingly becoming preferred choices in engineering applications. Due to their complex geometries, additive manufacturing is preferred for the fabrication of strut-based lattice structures. These structures are primarily composed of strut elements. Considering the current capabilities of additive manufacturing, variations and uncertainties at the micro and millimeter levels often arise during layer-by-layer production of strut elements typically designed at the millimeter scale. These changes cause a difference in mechanical properties between the designed and manufactured structure. In this study, a two-step lattice optimization procedure is proposed as a design approach to account for uncertainties arising from the additive manufacturing of lattice structures, impacting their geometry and material properties.
Methods: Structure-property relationships were established using artificial neural networks between the parameters governing the modeling of strut elements, including diameter and angle variations, and the effective properties under uncertainties arising from the additive manufacturing by material extrusion. The artificial neural network models have been integrated into the lattice optimization process, which involves modelling with beam elements. Initially, an algorithm was created to convert a meshed model to lattice cells. Using the topological information obtained, a two-step optimization algorithm is initiated. The first step of the two-step optimization is the classical layout optimization where strut elements with diameters close to zero are removed from the topology. The second size optimization is performed to determine the optimized diameters of the strut elements in the topology with the specified minimum manufacturing constraint. Between the two optimization stages, a self-support structure algorithm has been developed to identify strut elements in the optimized topology requiring support. This algorithm adds supports by incorporating strut elements into the structure before topology optimization, enabling self-supporting structure fabrication. Additionally, within the scope of this study, a surface generation algorithm has been developed to create a manufacturable STL model representing the final optimized geometry.
Results: The proposed method’s effectiveness is shown through benchmark examples. Fabrication of the optimized designs was carried out using material extrusion technique, followed by testing to validate the efficacy of the proposed approach.
Conclusion: The results of the application examples showed that the optimized designs with predicted uncertainties by the trained neural networks give closer agreement with the experimental results.


Developing the model by beam elements
Structure-property relation
Optimization
find $D=[D_1, D_2, ..., D_n]$
minimize $c = \mathbf{F}^T\mathbf{U}$
subject to $v \le v_{target}$
Designed structure
α_i
D_i
E_{hi}
D_{hi}
$D_h = f(D, \alpha)$
$E_h = g(D, \alpha)$
Satisfied?
yes
no
Determining the strut angles, α
$\boldsymbol{\alpha} = [\alpha_1, \alpha_2, ..., \alpha_n]$
Design variables
$\mathbf{x} = [x_1, x_2, ..., x_n]$
Update variables
iter = iter+1

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Simulation-Based Design Optimization of Active-Control Rocket Canards in Subsonic Flight

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Rocket canards are small, vertical control surfaces located above a rocket's main rear fins, typically just below the nosecone, providing active-control maneuverability during flight. When an internal mechanism rotates the canards about their center relative to the rocket air frame, they achieve an angle of attack and produce a lifting force perpendicular to the airflow and tangential to the curvature of the air frame. This lifting force causes a moment relative to the rocket's center of gravity along both the roll and pitch axes, which can be used to stabilize the rocket mid-flight by providing corrective adjustments to the rocket's trajectory based on mid-flight avionics data. The larger the canards and the further the canards are placed above the center of gravity, the greater their control authority over the rocket's orientation and the greater their effectiveness in providing corrective adjustments. However, the addition of canard surfaces also inherently reduces the aerodynamic performance of the rocket and increases its coefficient of drag, both of which are also dependent on the size, shape and position of the canards relative to the rocket body. Thus, a trade-off occurs between the aerodynamic performance of the rocket and the effectiveness of the canards – smaller and lower canards have a greater aerodynamic performance and smaller corrective effectiveness while larger and higher canards have a smaller aerodynamic performance but greater corrective effectiveness. In this research, simulation-based design optimization methodology, which involves numerical simulation of rocket aerodynamic responses, meta-modeling techniques, and multi-objective optimization methodology, is used to obtain an optimum size, shape, and position of subsonic vertical-flight rocket canards for both aerodynamic performance and their active stability effectiveness.

Keywords: Design optimization, rocket canards, active stabilization, subsonic maneuverability.

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Reliability of Strength Test Results on Materials Using Statistical and Computational Methods

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Finite element analysis can be used to predict the strength of a material and its behavior under stress, but requires a comprehensive understanding of the material's properties, and its nonlinear behavior. In many cases, as per commercial software, the user does not know the exact programming code that is used for the finite element solution. The calculation of the uncertainty of the approximate solution to finite element problems is usually done through techniques such as sensitivity analysis and uncertainty analysis. These techniques allow estimating the impact of uncertainties in the input data (e.g., materials, geometry, loading) on the final system solution.
The ISO GUM Supplement known as JCGM 101:2008, Evaluation of measurement data — Supplement 1 to the "Guide to the expression of uncertainty in measurement" — Propagation of distributions using a Monte Carlo method, issued by the Joint Committee for Guides in Metrology, provides guidance for propagating the probability distributions assigned to the various incoming variables. A significant number of numerical simulations (Monte Carlo Method) are used to determine a probability distribution for the measured variable. The use of the Monte Carlo methodology in uncertainty estimation is based on the technique of propagating probability distributions rather than on error propagation which is described in the basic ISO GUM approach (JCGM 100:2008 - GUM 1995 with minor corrections - Evaluation of measurement data — Guide to the expression of uncertainty in measurement).
In this study, a simple example of finite elements application is described for estimating the point where the maximum principal stress in a cubic specimen indicates the point where the specimen fracture begins when an exact point force is applied at the center of its uppermost surface and the cubic specimen is evenly supported at its lowermost surface. The used value of the overall strength of the material is under assumption and its verification is not one of the objectives of this study.
For this assumed value of the material strength, the JCGM 101:2008 (Monte Carlo) method was applied based on (a) type B estimation of the input parameters (e.g. the value of the applied force, coordinates of the point where the force is applied, angle of the force in relation to the horizon, geometrical tolerances of the cube of the specimen, etc.) probability density distributions and (b) adequate number of the finite elements problem numerical solution runs for selected combinations of randomly distributed input parameter values in a way that their probability density distribution is not violated.

The result is not restricted to the probability density distribution of the strength value and the coordinates of the point where the finite elements model indicates the beginning of specimen fracture. The method analyzed in this study is presented in a way that it could be utilized in any finite element solution of a materials strength problem to produce a criterion of experimental results verification, based on the 95% estimated confidence interval for the strength result

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Stress Monitoring and FEA Simulation of the Structure of a Dual-Axis Tracking Photovoltaic System

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Dual-axis tracking photovoltaic systems track the movement of the sun along both horizontal and vertical axes, allowing photovoltaic modules to receive maximum solar irradiance throughout the day. This continuous tracking mechanism enables an increase in power generation of more than 20% compared to fixed solar panels.

Despite its advantages in power generation efficiency, the dual-axis tracking photovoltaic system has not been widely adopted in the market. The necessity of additional components such as actuators, motors, sensors, and controllers leads to a higher initial investment cost compared to fixed solar panels. Additionally, mechanical movement introduces maintenance costs. Structural stability is another concern, as a single supporting column holds multiple photovoltaic modules, raising apprehensions about potential collapse due to strong winds or typhoons. Therefore, research is required to implement structural health monitoring (SHM) for real-time assessment of the structural integrity and prediction of the system's lifespan.

A 16.1 kWp dual-axis tracking photovoltaic system was installed, and finite element analysis (FEA) was conducted to evaluate structural stress distribution. High-stress locations were identified, and strain gauges were strategically installed for real-time stress monitoring. The results indicated that the highest stress concentrations occurred at the edges of the horizontal metal tubes supporting the solar modules, whereas the central region experienced approximately a level of 30% von Mises stress compared to the edges. The system exhibited the lowest stress levels when the photovoltaic modules were in a horizontal position (90-degree tilt angle relative to the support column). However, as the sun's altitude decreased in the morning and afternoon, causing a reduction in the tilt angle between the support column and the photovoltaic modules, stress levels increased accordingly.

To enhance simulation accuracy, FEA results were calibrated against actual field-measured stress data, ensuring the simulation closely matched real-world conditions. Based on the refined simulation, the structural failure lifespan of the 16.1 kWp dual-axis tracking photovoltaic system was predicted with improved reliability.

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Degradation Processes of Large-Panel Building Thermal Modernization Due To Ineffective Room Ventilation

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Residential buildings made of reinforced concrete large-panel elements are characterized by low thermal insulation, despite the use of systemic insulation layers. Restrictive changes in standard requirements aimed at improving the thermal conditions of rooms in use have resulted over the years in the need to insulate external partitions, i.e. walls and roof coverings, and the replacement of leaky wooden joinery with windows made of plastics, e.g. PVC. An unexpected effect of thermal modernization works was the common phenomenon of the internal surface dampness of external walls. This phenomenon resulted in the rapid development of mold and fungi. Damp brown efflorescences were located especially in the corners of walls and in areas behind furniture. Excessive humidity levels in building materials and the growth of mould on their surfaces lead to gradual degradation and a decrease in the strength parameters of structural elements. During the authors' research aimed at explaining the causes of the described phenomena, attempts were made to verify the effectiveness of natural ventilation systems, commonly used in such buildings. As a result of measurements and numerical simulations, it was shown that thermal modernisation of the building effectively improves the tightness of the joinery, but at the same time increases the humidity of the internal air and negatively affects the so-called microclimate of the rooms, and may also lead to the occurrence of the "sick building" syndrome.

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Technical Condition Assessment and Failure Prevention in Municipal Buildings: A Case Study from Northeastern Poland

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The technical condition assessment of buildings is a complex and multifaceted process requiring systematic inspections to ensure safety, functionality, and sustainability. In response to this challenge, a collaborative research initiative, funded by the National Centre for Research and Development (NCBR) under the first INNOGLOBO Program call, has been undertaken by the University of Warmia and Mazury in Olsztyn in partnership with Universitat Politècnica de Catalunya in Barcelona. This project has led to the development of a functionality-oriented assessment methodology (FOAM) and its practical implementation in the form of an IT platform—Functional Assessment of Stocks Tool (FAST). The proposed methodology and tool aim to support decision-making processes in the management and maintenance of building stocks by providing a structured, data-driven approach to technical assessment.

This study presents an application of FOAM and FAST in managing municipal building stock in northeastern Poland, specifically in the town of Barczewo. The assessment covered eight municipal buildings under the administration of the Municipal Buildings Authority (Zakład Budynków Komunalnych). The long-term technical analysis of these structures enables the prevention of damage and deterioration, thereby optimizing resource allocation for maintenance and renovation. By employing FOAM, the research facilitates predictive maintenance strategies, ensuring that critical structural deficiencies are identified and addressed before they pose safety hazards to the buildings and their occupants.

The methodology integrates multiple assessment criteria, including structural integrity, material degradation, functional usability, and compliance with contemporary building regulations. FAST, as a digital platform, provides a systematic and user-friendly interface for storing, analyzing, and interpreting building condition data. This approach enhances the efficiency of decision-making by municipal authorities and property managers, allowing for proactive rather than reactive maintenance strategies.

The findings of this research highlight the effectiveness of the FOAM methodology in municipal building management. By leveraging digital tools and structured assessment frameworks, municipalities can improve their asset management practices, ensuring long-term building sustainability and cost-effective maintenance planning. The study also underscores the broader applicability of the methodology beyond the municipal sector, demonstrating its potential for adoption in other public and private building management contexts.

The presentation will discuss the detailed framework of FOAM, its integration within the FAST platform, and key insights from the case study. The results contribute to the ongoing discourse on the digitization of building assessments, predictive maintenance, and sustainable infrastructure management. The findings provide a model for other municipalities and building authorities seeking to enhance their approach to technical condition assessments through innovative methodologies and digital tools.

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A New Testing Procedure to Quantify and Assess Fatigue Properties of High-Performance Leaf Springs

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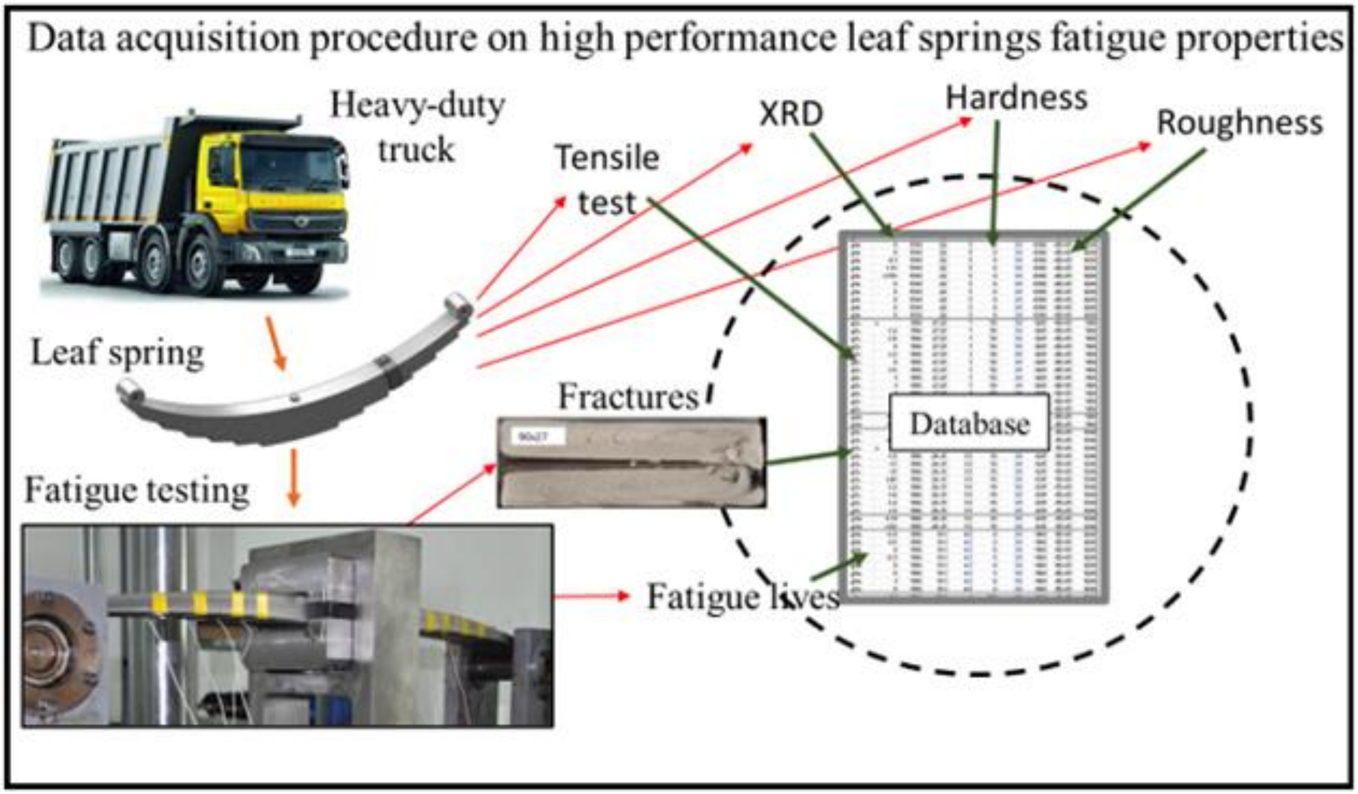
Introduction
This paper focuses on the study of the material and component fatigue parameters of high-performance leaf springs used in the suspension systems of heavy-duty commercial trucks. Currently, there is limited information on the fatigue performance, material characteristics and surface properties of leaf spring components, as manufacturers do not disclose this data and the accessible international literature is limited. Therefore, design and production engineers need to conduct extensive experimental testing throughout various phases of product development, consuming significant resources and time.

Methods
The procedure to get the leaf spring parameters consists of 5 steps, a) material characterization to determine the basic manufacturing and material properties, b) finite element analysis to identify the most stressed areas, c) fatigue testing of leaf springs together with stress and spring rate monitoring, d) material testing and fracture characterization after fracture and e) creation of database using only the most relevant results.

Results
The presented procedure gives a new perspective to the study of the leaf spring fatigue properties providing valuable data for the quantification of fatigue properties of high performance leaf springs and the creation of new theoretical models.

Conclusion
Well documented experimental procedures on a variety of testing samples and prototypes can provide valuable data to the scientific community. This data can be used to understand the advanced properties of the new leaf-spring production lines and set the basis for the development of new theoretical tools.


Data acquisition procedure on high performance leaf springs fatigue properties
Heavy-duty truck
Tensile test
XRD
Hardness
Roughness
Leaf spring
Fractures
Database
Fatigue testing
Fatigue lives

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Failure Analysis of Q345 Flame-Heated Pipe in a Natural Gas Station

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[1]Sichuan University, Chengdu, China, [2]China National Petroleum Corporation, Beijing, China

The research was conducted on failed Q345 flame-heated pipe used for purification of triethylene glycol aqueous solution, with the matrix materials destructively cracked and deformed after 3 years and 8 months of service. To find the cause of failure, macroscopic and microscopic examinations, chemical composition analysis, mechanical property tests, and simulation modeling was conducted. The results show that the presence of thick iron oxide and carbon deposits on both the inner and outer surfaces of the pipe, leading to reduced heat transfer efficiency and localized overheating. The yield strength of the pipe decreases due to the reduced thickness by corrosion. Besides, stress concentration was found at the damaged U-bend area from Ansys simulation. Above issues result in plastic deformation and cracking of the pipe near the weld heat-affected zone.

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Failure Analysis of Metal Components in 500 kV Substations in West of China: Case Study of GIS Valves and Main Transformer Bellows

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[1]*University Of Science And Technology Beijing, Beijing , China*

This study conducts a comprehensive and in - depth analysis of failure cases related to GIS valves and main transformer bellows in 500 kV substations in the western region of China. By systematically examining the materials, microstructure, crack morphology, and corrosion products of the failed components, the underlying failure mechanisms are uncovered.
The failure of the GIS valve is mainly manifested as brittle fracture, with cracks propagating along the austenite grain boundaries. Chloride ions were detected near the crack initiation site, indicating that environmental chloride corrosion is a crucial factor contributing to the failure. Material analysis reveals that the carbon and sulfur content in the valve exceeds the standard limits, resulting in sensitization and reduced toughness, which further promotes crack formation.
The failure of the main transformer bellows is characterized by a through - crack in the weld zone, originating from the heat - affected zone of the weld. The weld zone contains significant pore defects and residual stress, which trigger the initiation and propagation of fatigue cracks. Although the failure mechanisms vary in terms of materials and processes, both are affected by common factors, such as material defects, environmental factors, and stresses accumulated during long - term service.
Based on a comprehensive analysis of these two failure cases, this study puts forward recommendations for strengthening material control, optimizing the welding process, and enhancing environmental protection measures. These measures aim to extend the service life and improve the reliability of metal components in substations.

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Damage Intensity Index for Diagnosis and Prediction of the Technical Condition of Buildings

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[1]Agh Ust Krakow, Poland, Krakow, Poland

A building structure consists of many components. Each of them can be made using available technology and a wide range of materials with different strength parameters. This, in turn, can affect the range and intensity of damage that occurs during the life cycle of a building. From the point of view of building mechanics, the phenomenon of damage can be described as a process initiated when the permissible level of potential elastic deformation energy accumulated in a given structural element is exceeded. Damage is one of the factors considered when assessing the safety of a structure. Damage to load-bearing structural elements, which is usually accompanied by damage to secondary elements, is of great importance in this case. For this reason, a methodology for determining the damage intensity index was developed. This paper presents an original qualitative damage intensity index that is used to assess the technical condition of buildings and their components, but also to predict possible damage that may occur during use due to natural and/or anthropogenic factors (e.g. mining impacts). The idea of establishing a methodology for determining the damage intensity index resulted primarily from the lack of such a solution that would be applicable in scientific and technical studies for a large number of objects, taking into account their individual elements. This methodology was proposed in a series of publications by the authors. A damage intensity index was proposed for the building's structural and non-structural elements, with a total of 22 elements identified. These include 10 indicators for damage to load-bearing components, ranging from foundations, foundation walls and upper storey walls to ceilings, stairs and balconies/loggias, and finally the roof structure. The remaining 12 indicators concern damage to secondary elements, including damage to partition walls, cladding, floors, chimney walls, roofing, facades, woodwork, as well as external elements (building entrances, terraces, bands). For each of the elements, this indicator is determined on a 6-point scale. The partial least squares regression (PLSR) method, based on the results of the NIPALS (nonlinear partial least squares) algorithm, was used to determine the value of the generalised damage intensity index for the entire building. In the first stage of this method, the main components (from the space of input variables) are selected. In the second step, the dependencies between these components and the dependent variable are detected. Based on the damage indices of individual components, the application of this method made it possible to determine a generalised damage intensity index for entire buildings as a linear combination. In summary, the damage intensity index determined in this form is primarily used for the aggregated assessment of damage to individual buildings. It allows for the non-arbitrary consideration of the damage intensity index when determining the technical condition of buildings. In addition, it has been used many times in previous studies, e.g. in the construction of predictive models (for damage prognosis) based on machine learning (ML) methods.

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Numerical Analysis as a Method to Protect Underground Pipelines Under Dynamic Inputs

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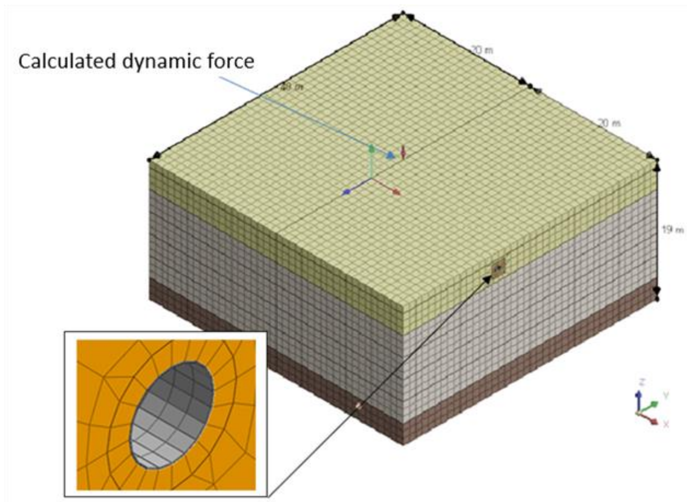
Measurements of mechanical vibrations of the medium are one of the methods to diagnose structures exposed to impacts that induce their dynamic response. An example of such impacts could be the driving of piles or sheet piles in close range of the structure. The problem occurs with regards to structures located entirely underground. In the case of free access to their interior (which applies, for example, to tanks or tunnels), it is possible to place the measurement sensors on the structure without excavating it and perform measurements under actual conditions. However, in the case of underground pipelines, setting the sensors requires excavating a section of the structure and therefore changing its operating conditions.
In a situation in which the pipeline is embedded in the ground for an extended period of time (on the order of 5 or more years), the two elements become linked in terms of displacement. The execution of an excavation disturbs this state, and this results in a change in the dynamic response and resulting stress increments in the pipeline structure. In some cases, the uncovering itself (without dynamic forcing) can result in dangerous stress changes in the pipeline jacket, including from the absence of soil pressure.
To avoid the problems highlighted above, the authors propose an analysis of the behavior of underground pipelines subjected to external dynamic forcing, which is based on FEM analysis calibrated with the results of measurements on the ground surface. Under appropriate assumptions, the analysis of the issue consists in modeling the system of pipeline - ground - inputs and investigating the dynamic response of the pipeline. It is essential to build an FEM model large enough to ignore the influence of boundary conditions - Fig. 1. In addition, it is necessary to determine the material parameters of the soil and structure as consistent with the real ones as possible.
An evident problem is the reliability of such a model - and here comes the essence of the proposed method. Simultaneously with the analysis of vibrations of the pipeline itself, the analysis of vibrations of specific points on the ground surface is carried out - and in these places vibration measurements are carried out – Fig. 2. On this basis, the model is calibrated each time, and only after obtaining a proper consistency of the measured vibrations with the calculated ones is the analysis of the pipeline itself carried out. The main results here are the determination of resonant (unacceptable) ranges and the calculation of the dynamic forces (in non-resonant ranges) that can be transmitted to the ground without the risk of exceeding the safe values of stresses in the elements of the pipeline structure.
The article discusses all model assumptions, and presents a computational example with a discussion of the results. The described analyses have already been successfully applied in practice, with implementations requiring the driving of piles near underground transmission infrastructure.


Calculated dynamic force
20 m
20 m
20 m
19 m

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Finite Element Analysis of Impact Behavior in Closed-Cell Aluminum Foams: A Comparative Study of Cell-Based and Continuum-Based Models

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Metal foams have attracted significant attention for applications in automotive, naval, aerospace, and biomedical industries due to their superior mechanical energy absorption, heat exchange and lightweight design. However, accurately predicting their mechanical response under impact loads remains challenging, often necessitating extensive experimental testing. Finite element method (FEM) models offer a promising alternative to reduce the reliance on such testing.
In this study, FEM models were developed to elucidate the mechanisms governing impact behavior, assess yield properties, and quantify energy absorption in closed-cell aluminum foams. The simulation results were validated against data from corresponding experimental uniaxial tests. Two distinct modeling approaches were employed. The first utilized a cell-based method, generating the initial foam geometry through the Voronoi tessellation algorithm. The generation of solid elements was optimized using the advanced pre-processor ANSA software package by setting appropriate mesh parameters and quality criteria to preserve the precise cell shapes. The second approach implemented an isotropic, strain-hardening, continuum-based model following the Deshpande-Fleck formulation. Finite element results were subsequently visualized and processed using the META post-processor.
The findings provide comprehensive insights into the macro- and micro-structural phenomena occurring during impact, thereby advancing the understanding of metal foam behavior under dynamic loading conditions.

E04

On the Development of a New Standard Related to Steel Health Monitoring

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[1]*National TU of Athens*

In this paper, the initiation of the process towards the development of a new standard related to the monitoring of residual stresses and stresses in magnetic steels by magnetic techniques is presented. The method is based on the monotonic correlation of magnetic properties and residual stresses in steels, proven for a vast variety of steel grades till now. The standardization process is based on inter-laboratory comparison tests using the same steel coupons, prepared by welding or by RF induction heating, by means of determining: (i) the residual stress by X-Ray diffraction in the Bragg-Brentano set-up, provided by the Slovak Academy of Sciences, the University of Seville and StressTech Inc., Finland, (ii) magnetic permeability measurements provided by the National TU of Athens (NTUA) and the Italian Metrological Institute (INRIM), (iii) magnetoacoustic emission measurements provided by the NTUA and the University of Gdansk, (iv) Barkhausen noise measurements provided by the University of Gdansk and Stresstech and finally, (v) field measurements on the surface of the steels provided by the NTUA and the Committee of Atomic and Alternative Energy sources (CEAA), France. All these seven (7) partners will run their corresponding Round Robin tests under the auspices of the corresponding Standardization Body. Initial results between partners demonstrate that all three described magnetic testing methods offer similar results, thus allowing for hopes of low uncertainties during these inter-comparison tests. However, there is the possibility of developing three or four different standards, based on magnetic permeability, magnetoacoustic emission, Barkhausen noise and magnetic field measurements. Furthermore, different standards will also follow due to the different fields of application of steels.

E06

On the Use of AMR Sensors for Stress Determination in Ships

Maria Tsironi[1], Gregorios Doumenis[2], Evangelos Hristoforou[1]
[1]National TU of Athens, [2]University of Ioannina

Three-dimensional anisotropic magnetoresistance (AMR) sensors have been used to determine the stress level at surfaces, where these AMR sensors are approached. The determination of the vertical magnetic field component dependence on the actual stress applied on the steel, illustrates a monotonic dependence of the field component on the locally applied stress, while in the other two components, the field component dependence is rather linear up to the Villari point of the steel under test. Therefore, AMR sensors appear to be attractive for the determination of stresses at the surfaces they are placed on. However, the motion of the ship changes the ambient field component under measurement in a non-predictable way. Therefore, the discrimination of the field component due to the applied stress from the field component due to the ambient field is not secure at all from this AMR measurement. The solution of this problem is the use of two AMR sensors, where one AMR sensor is placed closed to the steel under test and the second AMR sensor is placed in a distance, where the contribution of the stress field from the steel under test is negligible. For a low carbon steel, the distance threshold, after which the stress field doesn't contribute to the AMR response is around 30 mm. So, these two AMR sensors were set parallel each other at a distance of 30 mm, connected in series opposition in order to allow only for the stress field component to be present in their output. This system is constructed as a 30 mm X 30 mm X 30 mm cube, where inside the cube all required electronics are hosted.

E07

On a New Power Generator for Autonomous Stress Monitoring in Ships

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Autonomous sensor operation is useful in several engineering applications, with particular emphasis in maritime and shipping applications, especially in ship retrofitting with new technological products. For example, AMR sensors are able to detect stress history and monitor stress field in the area. They are set on during a retrofitting process, can have wireless operation, not only for detection reasons, but also for data transmission. This is particularly emphatic for the case of large ships, where such point stress detectors have to be installed in remote points. In these cases, the sequential transmission of data requires a power bank able to provide energy (mainly) for data transmission. For this reason, we have developed a magnetic power generator, comprised of a tube with two permanent magnets at the terminal points. A permanent magnet is moving inside the tube due to vibrations exerted in the ship by the machine, as well as due to the vibrations caused by external reasons, like sea waves. Discrete coils at different positions of the tube harvest power due to the motion of the permanent magnet. The structure has the standard size of an AAA battery and is able to provide power in the order of several mW, that are enough to provide data transmission every one minute. The experimental results have been compared with ANSYS-based finite element analysis, thus allowing for simulation of a large variety of similar structures, towards the optimization of permanent magnet and coil size. The power generator can also pass ATEX specifications due to its low power consumption and therefore it can be used in harsh environments.

E09

Stress Field and Possible Crack Generation Monitoring Using Magnetic Techniques

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[1]*National TU of Athens*

Low carbon steel dog-bone samples have been tested on an Instron stress-strain machine, with simultaneous measurement of the change of the three field components at the surface of the steel, using a three-dimensional anisotropic magnetoresistance (AMR) sensor. In the elastic stress-strain region, the response of the field component vertical to the steel surface was monotonically increasing, offering a response similar or identical to the magnetic stress calibration (MASC) curve of this steel grade. The other two components offered a monotonic change of the field up to the Villari point of the steel, after which the slope changed sign, till the yield point. After the elastic region and during the slip of layers at the yield point, the magnetic field components followed a flat and wiggled response, similar to the stress-strain response at the yield point. Entering the plastic deformation region, all three field components were increasing with respect to stress and strain, with a slope smaller, almost half, than the magnetic slope at the elastic region. All these results are absolutely useful for the determination of stress fields and particularly residual stresses in this steel grade. However, an additional observation due to the AMR sensor response may be also useful: at given stress-strain regions, AMR response in all field components offered large pulses, being present only during plastic deformation. These measurements have been repeated with new dog bone samples of the same steel grade, offering nearly the same response at nearly the same stress-strain points. This makes us believe that these pulses could correspond to large Barkhausen jumps, corresponding to a crack generation (large pulses) or anisotropy change (smaller pulses).

E13

Research on the Fatigue of Aluminium Wires Used for Overhead Power Lines

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This paper presents the findings of research conducted on the fatigue of aluminium wires that have been utilised for the purpose of overhead power lines. Aluminium Conductor Steel Reinforced (ACSR) conductors are a frequently employed material in the construction of overhead transmission lines. These conductors comprise a high-strength steel core that is encased by multiple layers of aluminium wires, which constitute the conductor's active electrical component. It is important to note that the long-term exposure of conductors to environmental factors such as sunlight, rime, and wind can result in damage and fracture. The predominant cause of damage to OHL conductors is wind influence, leading to vibration and, consequently, fracture of wires. In particular, the occurrence of fatigue cracking of the conductors is initiated by variable stress derived from von Karman vortices, initially affecting the outer layer of wires and subsequently the inner layers.

The dynamic component of tension, which is dependent on the static tension of the wire, its geometric construction and rigidity (the number and diameter of the wires, the coil angle), leads to fatigue destruction of the wires during overhead operation. This phenomenon leads to a progressive deterioration of the cable as a whole, characterised by a reduction in the electrically active cross-section, and, consequently, its mechanical properties. Over the past several years, the prevailing standard in the design of high-voltage overhead power lines has been to mandate a 50-year period of uninterrupted operation. This has led to an increased focus on the parameters required for materials utilised in the construction of such lines, with a particular emphasis on cables.

The objective of this research is to conduct an experimental evaluation of the impact of the strain hardening level of aluminium wires on their fatigue strength. The experimental findings have revealed that the power factor value for hardened wires is approximately twice as low as that of soft wires, thereby indicating a higher fatigue strength for the former. It is important to note that, depending on the stress level at which the test is conducted, the mechanism of origin of fatigue cracks is different. The paper presents the results of SEM observations of fatigue fracture. It is noteworthy that both cases exhibit typical fatigue cracks, characterised by a distinct fatigue damage zone in the hardened wire, with a smoothed, shell-shaped surface, front lines and the ad hoc damage zone occasionally visible. In contrast, when analysing the soft wire, the fatigue damage zone is reduced in surface area, and the temporary damage zone has evolved to exhibit a surface that is characteristic of flexible fractures.

Material Behavior Under Complex Conditions

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A Unified Viscoplasticity Model of CuCrZr Based on the Back Stress and Effective Stress Evolution Under LCF

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CuCrZr is a copper based precipitation hardening alloy that has the advantage of keeping its high strength and high thermal conductivity at high temperatures. Therefore, it is the main candidate for the divertor heat sink material in European DEMO fusion reactor. The divertor is expected to face extreme thermal and mechanical loading conditions leading to fatigue and creep-fatigue damage in the CuCrZr pipes. The knowledge of the cyclic mechanical response is essential for design optimization and accurate fatigue life prediction under these loading conditions. Similar to other FCC metallic alloys, CuCrZr experiences cyclic hardening during the first few cycles followed by cyclic softening for the rest of its lifetime.

A unified viscoplasticity model was developed to predict the LCF behaviour of CuCrZr at RT and 350 °C. The hysteresis loops were first partitioned based on the Cottrell method to study the back stress and effective stress evolution, both of which were observed to be strain range dependent. It was also observed that the back stress evolution replicates the hardening/softening behaviour of CuCrZr at both temperatures. Based on that, strain memory effect was included in the model by incorporating the effect of strain memory surface on both the isotropic and kinematic hardening variables. These modifications enabled the accurate modelling of the cyclic behaviour of CuCrZr for different strain ranges at both temperatures.

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High Cycle Fatigue Analysis of 2D Chiral Auxetic Structures

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This study investigates the high cycle fatigue (HCF) behaviour of two chiral auxetic structures subjected to cyclic loading. Chiral structures are known for their unique mechanical properties, such as good energy absorption, negative Poisson's ratio and high deformation capacity. Because of these properties, their use has slowly but steadily increased in different engineering applications. However, their fatigue performance under long-term cyclic loads remains underexplored. This research aims to provide insights into the fatigue behaviour of these novel geometries.

In the case of chiral structures, their struts or intercellular connections rotate around a common point, giving them an auxetic response; i.e., they expand when subjected to a tensile load. The two chiral auxetic structures (three-anti-chiral and tetra-anti-chiral), as shown in Figure 1, were analysed experimentally and computationally. Specimens were cut out of an aluminium plate AA 5083-H111 using abrasive water jet technology. They were tested in a high cycle fatigue regime on the high-frequency pulsator Zwick/Roel Vibrophore 100, considering the load ratio R = 0.1. The computational simulations have been performed in the framework of Ansys software, considering the stress-life approach when determining the fatigue life of analysed specimens.

The comparison between experimentally and computationally obtained S-N curves (i.e. the dependence between amplitude stress and the number of cycles to failure) showed a reasonable agreement. Based on this finding, it can be concluded that the proposed approach could be used further for geometric optimisations of other chiral structures concerning the fatigue behaviour under cyclic loading.

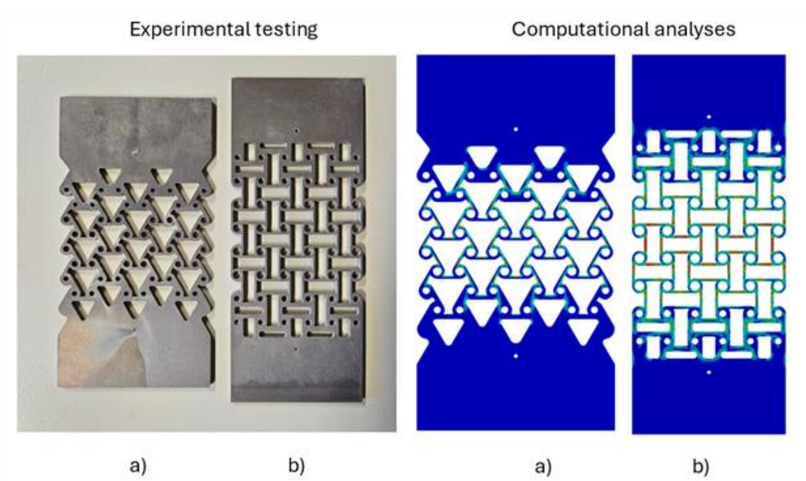

Figure 1: The geometries of the analysed chiral auxetic structures
a) Three-anti-chiral structure, b) Tetra-anti-chiral structure

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Laser Powder Bed Fusion: A Tool for Engineering Microstructures and Mechanical Behavior

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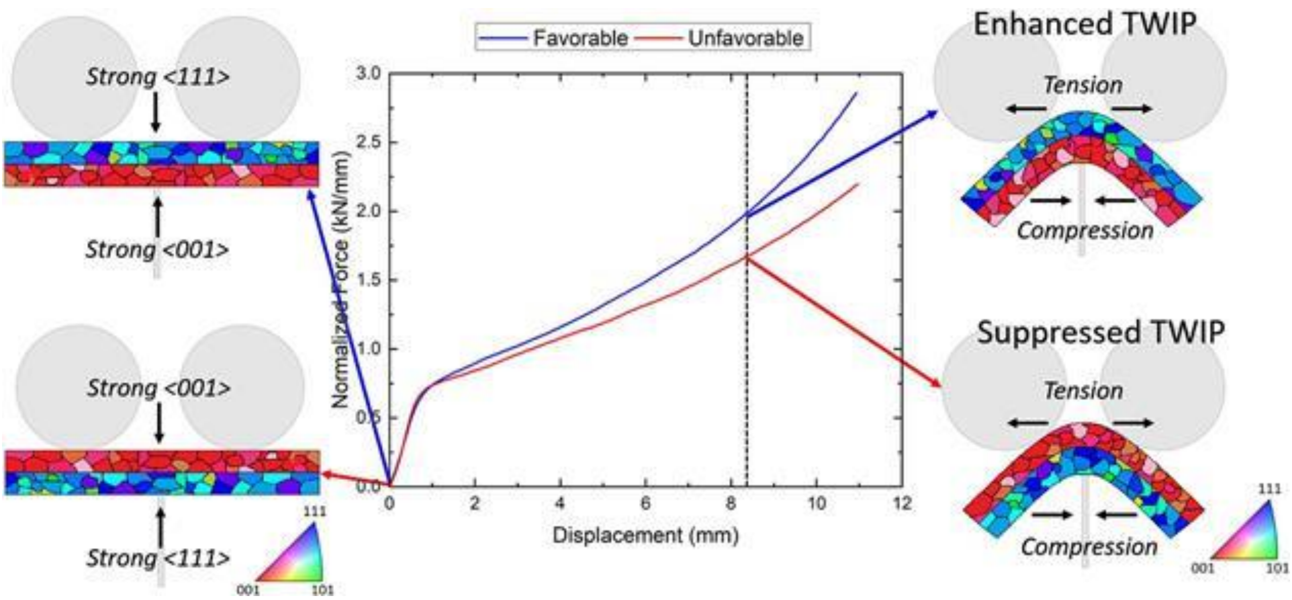
Laser Powder Bed Fusion (L-PBF) is a widely adopted metal additive manufacturing technique, offering not only geometric design freedom but also microstructural control. By fine-tuning process parameters, L-PBF enables precise manipulation of crystallographic textures, grain orientations and deformation mechanisms, allowing for site-specific tailoring of mechanical properties.

This work focuses on leveraging L-PBF to engineer austenitic stainless steels (304L and 316L) with tailored crystallographic textures which are optimized for specific loading conditions. Austenitic stainless steels exhibit Transformation-Induced Plasticity (TRIP) and Twinning-Induced Plasticity (TWIP), which can be enhanced or suppressed depending on crystallographic orientation. By optimizing L-PBF processing routes, we engineer microstructures that promote superior mechanical performance under complex stress states.

Characterization techniques, including in situ neutron diffraction and electron microscopy are employed to analyze the interplay between process parameters, microstructural evolution and mechanical response. The effectiveness of this approach is demonstrated through bending tests [1], where tailored microstructures achieve superior mechanical response compared to conventionally processed materials or unfavourably tailored materials (Figure. 1). The insights of this study pave the way for site-specific microstructural design, offering a new paradigm in the performance optimization of additively manufactured engineering components.

[1] C. Sofras, J. Čapek, X. Li, C.C. Roth, C Leinenbach, R.E. Logé, M. Strobl, E. Polatidis, Site-specifically tailored microstructures with enhanced strength and hardening through laser powder bed fusion, Materials & Design 237 (2023) 112539.


Strong <111>
Strong <001>
Strong <001>
Strong <111>
Favorable
Unfavorable
Normalized Force (kN/mm)
Displacement (mm)
Enhanced TWIP
Tension
Compression
Suppressed TWIP
Tension
Compression

E17

On the Developing Network of Adiabatic Shear Bands During High Strain-Rate Forging Process: A Parametric Study on the Effect of Specimen Aspect Ratio

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The present work investigates the developing network of adiabatic shear bands (ASB) during high strain-rate plane strain forging process of AISI 1045 steel orthogonal billets, aiming to capture the ASB trajectories and the propagating path in order to reveal the ASB network. A finite element (FE) numerical analysis is carried out in LS-DYNA software, developing doubly-coupled FE models by conjugating both structural-thermal (ST) and structural-damage (SD) couplings. The Modified Johnson-Cook (MJC) plasticity flow rule and damage law are implemented allowing for a thermo-viscoplastic approach for both material model and damage evolution, while further a temperature-dependent damage criterion is also adjusted introducing a critical temperature for material failure. The doubly-coupled analysis allows initially to capture the influence of both thermal and damage softening mechanisms which are the most dominant ones on ASB genesis and evolution, while further the numerical interaction between them due to the double coupling allows also to evaluate their impact level during their competition. Finally, a parametric study of specimen aspect ratio is conducted aiming to analyze its effect on the developing ASB network, focusing on the formation and the shape of the ASB patterns, as well as their size and developing characteristics like their width, spacing and intensity.

Acknowledgments:

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Experimental Investigation on the Formation of Adiabatic Shear Bands (ASB) During Dynamic Compression of AISI 1045 Steel at Different Strain Rates

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Current work investigates the formation of adiabatic shear bands (ASB) during high strain rate uniaxial compression of AISI 1045 cylindrical steel billets. Experimental dynamic compression tests are carried out utilizing a split Hopkinson pressure bar (SHPB) where different strain levels via interrupted tests, and strain rates of 1000-2000-4000 s^{-1} are examined. The post-experimental analysis delivers the stress – strain curve which is accompanied with several optical micrographs of the deformed microstructure at different strains, in order to capture the critical strain for ASB genesis. Optical microscopy is implemented in order to detect the formation of ASB and define their type and size. Further, the influence of strain rate is studied by analyzing its effect on the ASB genesis and evolution, focusing on detecting the critical strain, and the ASB type and size. Also, the adiabatic temperature rise inside ASB core is computed numerically aiming to quantify the magnitude of thermal softening mechanism and evaluate its influence on ASB genesis and critical strain. Finally, a strain – strain rate experimental map for AISI 1045 steel is designed for ASB formation, revealing the relative areas for stable and uniform plastic deformation, ASB formation and possible cracking.

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E19
In Situ CT - Advanced Failure Analysis in Tensile Shear Tests With Clinch Points

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Clinching is a well-established and cost-efficient joining method. It uses localized cold forming to create mechanical interlocks between sheet materials without the need for additional elements. To assess the structural integrity of such clinch points, destructive tests like tensile shear testing are commonly combined with imaging techniques such as microsectioning or computed tomography (CT). However, these methods can be affected by unloading-related phenomena such as springback and crack closure, which may alter the observable state of the joint. In this context, in situ CT offers a significant advantage: it enables the observation of the specimen under load, eliminating the influence of unloading effects. During in-situ investigations, the displacement is incrementally increased and interrupted at defined levels. While the specimen remains in its loaded state, a CT scan is performed. For comparison, ex-situ CT scans are performed after unloading the specimen and often repositioning it in a separate CT system. This preparation step may lead to crack closure or conceal other critical features. This work highlights the benefits of in-situ CT for detecting the initiation and progression of damage in clinched joints. Single-lap tensile shear specimens, made of two 2 mm thick aluminum sheets joined by clinch points, are tested. At selected displacement levels, both in-situ and ex-situ CT scans are conducted to capture the current deformation and fracture state. The specimen is then loaded further to the next displacement level, and the procedure is repeated. This approach allows a stepwise and detailed visualization of the evolving damage. The results show that cracks and necking initiate earlier than can be detected with ex-situ CT alone. These findings underline the value of in-situ CT for the calibration and validation of numerical failure models.

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The Challenging Role of Diffusion Coatings in Protecting Superalloys in Hydrogen-Rich Environments

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Recently, hydrogen has been proposed as an alternative fuel solution to reduce emissions and improve the sustainability of aviation. However, there are several challenges associated with the use of hydrogen and the degradation of materials in hydrogen-rich environments. In this study, the role of coatings in hydrogen-rich environments is investigated. Coatings often used on superalloys to improve their oxidation and corrosion resistance at elevated temperatures will be the first to be exposed to a hydrogen-rich atmosphere in such potential future scenarios. It is therefore important to understand their performance in different environments. For this purpose, a nickel-based superalloy was coated with a diffusion aluminide coating and was electrochemically charged with hydrogen. The coating was investigated in two different conditions. The first corresponds to the microstructure after the coating has received the required full heat treatment. The second condition is a combination of the full heat treatment process and an additional step of thermal exposure. This creates a thin oxide layer on the surface of the coating. After the thermal exposure, the surface of these samples was gently ground with a fine sandpaper to introduce some artificial damage to the oxide layer. After the heat treatment of the applied coating, three different microstructural layers are observed, an outer layer with equiaxed NiAl grains, a diffusion zone layer with inclusions, and an interdiffusion zone. After 48 hours of electrochemical hydrogen charging macroscopic alterations were observed only on the surface of the heat-treated coated sample. Scanning electron microscopy revealed that the macroscopic surface changes correspond to the spallation of the outer zone of the coating. Focused Ion Beam (FIB) cross-sectioning of areas where the outer layer was still present revealed the formation of macro voids between the outer and diffusion layers. Further cross-section investigations revealed the presence of cracks within the diffusion layer and at a depth of a few tens of microns from the surface. No cracks were found in the interdiffusion zone. In contrast, no spallation was observed in the case of the thermally exposed samples after 48 hours of electrochemical hydrogen charging. Only after 96 hours of chemical charging, surface blisters were observed at regions where the oxide layer was artificially damaged. Although the hydrogen environment investigated in this study does not correspond to that of hydrogen combustion, some initial observations on the performance of the coatings can be made, which will be presented and discussed.

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Adaptive Multiscale Material Modelling and Characterisation Suites for Assessing Interactions Between Hydrogen and Metallic Materials

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Deploying hydrogen technologies requires a tremendous effort to complete the infrastructure, requiring efficient material assessment suites and enabling industries to be more effective in developing and working with materials. Furthermore, since hydrogen is stored and transported in several forms, the material assessment suites must be flexible and capable of revealing hydrogen-material interactions in various conditions. In this work, we will present adaptive multiscale material modelling and characterisation suites for assessing interactions between hydrogen and advanced metallic materials and demonstrate their capabilities on hydrogen storage and transport components. Our ambition is to enable industries to be more efficient when developing and using new advanced materials, shorten the materials innovation cycle, seamlessly merge materials modelling and characterisation approaches along value chains, and create a robust material research ecosystem platform. The modelling and characterisation suites consist of 3 modules:
Physical realm: We will advance current experimental capabilities to reveal hydrogen-material interactions by compiling state-of-the-art characterisation methodologies across length scales, including (a) multiscale characterisation methods to study hydrogen microstructure interactions, (b) methods for studying macroscopic deformation and fracture properties, and (c) micromechanical and in-situ and ex-situ characterisation methods to study hydrogen effects.
Virtual world: We will propose a modularised multiscale and multiphysics material modelling platform for assessing hydrogen effects on metallic materials' behaviour. The modelling platform consists of 7 interdependent submodules: atomistic modelling toolset, hydrogen uptake models, hydrogen-induced phase transformation models, hydrogen transport models, continuum model of hydrogen effects on plasticity, hydrogen-aware fracture model, and macroscopic hydrogen-sensitive model. Besides advancing in modelling, the modularised concept will support the data exchange between models via an ontology-based data transformation script.
Data and knowledge management platform (DKMP): We will advance the standardised data management platform by integrating a materials ontology to understand hydrogen material interactions under actual conditions exposed to the hydrogen storage and transport components. Another benefit of having an ontology-based DKMP is its ability to facilitate data interoperability between disciplines.

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Analysis of the Delayed Cracking Mechanism of an Industrial Hot-Dip Galvanized DP1180GI Steel Coil

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Low-alloy high-strength dual-phase steel DP1180, due to its excellent mechanical properties and simple heat treatment process, has been widely used in the automotive manufacturing industry. However, as an inexpensive high-strength steel, its corrosion resistance has always been a factor limiting its long-term safe service. To solve this issue, researchers have applied a hot-dip galvanizing treatment to the surface of DP1180 steel sheets, coating the original steel with a layer of Zn to achieve corrosion resistance and aesthetic purposes, was named DP1180GI. Hot-dip galvanizing process mainly involves immersing the steel sheet in molten Zn to form Zn coating layer. This coating provides excellent corrosion resistance in the atmosphere, making hot-dip galvanizing a popular choice for manufacturing pipes, vehicle components, and more. The most common method for continuous hot-dip galvanizing of automotive plates is the Sendzimir method. However, due to the pre-treatment processes like heat treatment process in a protective atmosphere containing hydrogen before hot-dip galvanizing, steel sheets inevitably come into contact with a significant amount of hydrogen atoms. Once these hydrogen atoms penetrate the interior of the metal, accumulates at localized stress concentration points, it can lead to another issue that limits the safe service of high-strength steel, namely hydrogen embrittlement (HE) or hydrogen-induced delayed cracking (HIDC).
In practical industrial production, some automotive steel sheets, after undergoing hot-dip galvanizing treatment, were directly rolled into industrial coils and stored at room temperature. However, after being stored at room temperature for a while, noticeable delayed cracking might occurr near the innermost layers of the coils. Aiming at this phenomenon of delayed cracking, we analyzed the delayed cracking mechanism in the hot-dip galvanized steel coil DP1180GI steel plates subjected to bending deformation using methods such as the hydrogen microprinting test (HMT), thermal desorption spectroscopy (TDS), and finite element simulations. The analysis offers effective data references for enhancing industrial production processes. Ultimately, the key factor responsible for these incidents of delayed cracking was confirmed to be the redistribution of hydrogen atoms.

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Testing Gaseous Hydrogen Embrittlement in Steel Using Sub-Sized Fracture Toughness Specimens

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The transportation of hydrogen via both existing and newly constructed pipelines is emerging as a critical factor in the realization of a decarbonized energy landscape. A significant challenge in this domain is the degradation of the mechanical properties of pipeline steels due to hydrogen embrittlement (HE), which severely compromises the structural integrity and safety of the infrastructure. To address this issue, the present work introduces an innovative testing methodology that employs sub-sized specimens, machined from coupons extracted from operational pipelines, as a means of monitoring the progressive deterioration of material properties throughout service life.

The proposed approach is centered on the use of miniature fracture toughness specimens that are tested in a machine equipped with a small volume of gaseous hydrogen, employing the Edge Tracing (ET) technique to ensure precise test control. This technique is used to monitor the Load Line Opening Displacement (LLOD) and to measure the Opening Angle during testing. Through this method, it becomes possible to derive both the J–Δa and CTOD–Δa plots, which are essential for evaluating the fracture toughness of the material under various environmental conditions, specifically under air and in the presence of gaseous hydrogen (H2) at pressures of 30, 100, and 200 bar.

The experimental program utilized Mini Disk Shaped Compact Tensile (mDCT) specimens with a width (W) of 10 mm and a thickness (B) of 5 mm. These specimens were extracted from two different steel grades: an E355 modified steel grade supplied as a hot-rolled tube and an X52 grade steel recovered from a vintage pipeline. The load applied to the specimens was measured using a cell located inside the pressure chamber, ensuring that the data obtained were both accurate and reliable. The tests were performed at different stress intensity factor rates (approximately 0.85 and 50.8 MPa√m·min^{-1}) to closely examine how loading speed influences the fracture behavior of steels exposed to hydrogen.

The results of the investigation revealed distinct responses for the two materials in the presence of gaseous H2. For the E355 modified steel grade, there was a noticeable decrease in toughness at 100 bar H2, which further declined at 200 bar H2. In contrast, the X52 steel exhibited a uniform decrease in toughness at both 100 bar and 200 bar H2, while showing no significant loss of toughness at 30 bar H2. Interestingly, the E355 steel grade demonstrated an additional reduction in toughness when tested at a lower rate, a phenomenon that was not observed for the X52 steel under the same testing conditions.

SEM analyses were conducted on the fractured surfaces of the specimens to gain insights into the underlying mechanisms of hydrogen-induced damage. The SEM observations provided evidence of microstructural changes and fracture surface characteristics that correlate with the varying degrees of embrittlement observed in the two steel grades.

This research presents an initial evaluation of gaseous hydrogen embrittlement using mini toughness specimens across varied steel grades and testing conditions, offering insights into the complex interactions between material properties and hydrogen exposure.

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A Damage Model for the Simulation of Hydrogen Embrittlement in Metals: Mathematical and Computational Issues

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An isotropic, rate-dependent, elastic-plastic damage model with hydrogen effects is presented. The model can be used for the numerical simulation of failure in metallic materials due to hydrogen embrittlement. The effect of total hydrogen concentration (lattice and trapped) on the material flow stress as well as failure criteria for ductile and quasi-cleavage fracture are incorporated in the model. An algorithm for the numerical integration of the constitutive equations is developed and implemented in the general-purpose finite element program ABAQUS using a “thermomechanical analogy”. The mathematical character (elliptic versus hyperbolic) of the quasi-static incremental coupled mechanical-diffusion problem are studied. It is shown, both analytically and numerically, that the proposed viscoplastic model retains the elliptic properties of the governing equations and can provide mesh-independent numerical solutions in the post-bifurcation (softening) regime. The material parameters of the model are calibrated based on uniaxial tension experimental results for an X65 pipeline steel at both air and hydrogen environments. The predictions of numerical simulations agree well with available experimental data and provide accurate estimates for the location and type of failure (ductile vs quasi-cleavage) of the actual specimen in the presence of hydrogen.

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Numerical Analysis of Microstructural Characteristics on the Hydrogen Susceptibility of Pipeline Steels

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A secure energy supply is becoming increasingly important due to geopolitical instability and the push for zero emissions policies. In this context, hydrogen plays an important role as an alternative to fossil fuels. However, the safe transport of hydrogen-containing media remains a challenging task. The integrity of the material, determined by microstructural features such as grain morphology, impurity levels, phase fractions, and banded structures, is crucial for the hydrogen susceptibility of pipeline steels. Thus, advanced numerical approaches can be used to quantify the influence of different microstructural features on local hydrogen trapping behavior. This enables the optimization of microstructure design against hydrogen-induced damage. In this work, two X70-grade pipeline steels with ferritic-bainitic and ferritic-pearlitic microstructures were investigated. The corresponding microstructure models, generated as statistical representative volume elements (sRVEs), were built using the open-source software DRAGen. The required statistical input data were derived from EBSD measurements. To generate multiple statistically equivalent but geometrically different sRVEs from a single measurement, a Wasserstein Generative Adversarial Network (WGAN) was trained, by considering the relationships between microstructural properties. As a material model, a one-way coupled phenomenological crystal plasticity model with hydrogen diffusion was implemented in Abaqus/Standard using UMAT and UMATHT subroutines. The crystal plasticity model was iteratively calibrated based on a true stress-strain curve obtained from a quasi-static uniaxial tensile test at room temperature. The initial guesses for the different phases were derived from macro-indentation tests on multiple grains. To investigate the effect of non-metallic inclusions, sRVEs containing inclusions with varying aspect ratios and orientations were generated. By removing these inclusions, voids were introduced into the model. In addition to evaluating the effect of impurity levels, the impact of phase fraction and the number of pearlite bands on hydrogen diffusion was also analyzed numerically. The sRVEs were subjected to uniaxial tension, plane strain, shear and biaxial tension to evaluate the influence of stress state on hydrogen transport in conjunction with microstructural features. The results demonstrated the detrimental impact of non-metallic inclusions due to notch effects, which led to localized peaks in hydrostatic stress and plastic strain, resulting in higher local hydrogen concentrations.

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Design Optimization of CFRP Crashbox for High-Performance Automotive Applications

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Introduction and objectives

The present work explores the optimization of Carbon Fiber Reinforced Polymer (CFRP) energy absorbing structures, focusing on their application in advanced crashworthiness. CFRPs are highly regarded for their lightweight and excellent energy absorption properties, which make them ideal for enhancing vehicle safety, particularly in aerospace and automotive industries. The research aims to investigate, compare, and optimize the performance of conventional single-cell and multi-cell CFRP structures, analyzing the effects of tapering and different lamination sequences on energy absorption (EA), mean crushing force (MCF), and specific energy absorption (SEA).

Methods

An experimental campaign was conducted using drop tower tests on various CFRP automotive crash-boxes to assess their crushing behavior under impact. Two different laminate configurations were tested: constant thickness and tapered layups. Numerical simulations were carried out using Abaqus/Explicit to develop and calibrate a numerical model to be used for further design investigation. The FEM models, exploiting shell elements and a Hashin-based constitutive law, were calibrated to replicate the crushing behaviors observed in the tests.

Results

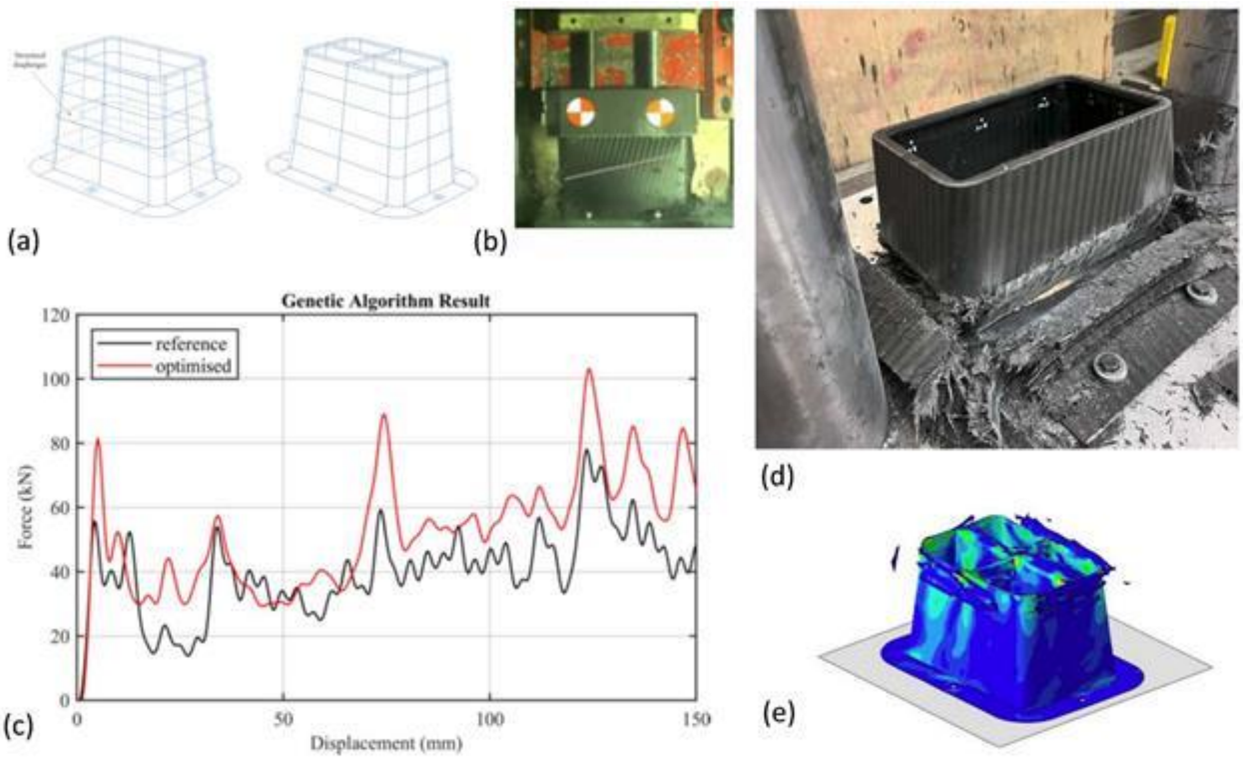
Experimental results highlighted challenges, such as unstable crushing initiation, catastrophic fracturing, and structural separations. Design modifications, including partial removal of upper surfaces, were introduced to enhance crushing stability. Tapered layups led to stress concentrations and an unstable crushing behavior. Numerical simulations successfully captured the macro-scale behavior of the crashboxes, demonstrating the effectiveness of the simplified modelling approach. Once validated, the model was used to explore geometry improvements, such as the introduction of longitudinal ribs and optimized laminate layups. These enhancements led to significant improvements in SEA and MCF, with the best configurations showing up to 49% higher SEA compared to their hollow counterparts.

Additionally, a Genetic Algorithm (GA) was employed to optimize the laminate sequences, enhancing the crashworthiness performance by improving energy absorption while maintaining structural integrity. The optimized laminate design, incorporating 45° fibers in key regions, demonstrated a notable 69.6% increase in energy absorption.

Conclusions

This study demonstrates a robust design optimization methodology for energy-absorbing composite structures, combining simplified but effective numerical methods, validated through experimental tests, with advanced optimization techniques.

Figure 1: (a) Geometries of single-cell and multi-cells crash boxes. (b) Drop tower impact testing. (c) Comparison between crush response of reference and optimized layups. (d) Morphology of crushed single-cell crash-box and (e) numerical morphology of crushed multi-cell crash-box.



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Calibration of a Non-Local Damage Model for CFRP Fabric Laminate Using Compact Compression and Compact Tension Tests

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Introduction

Fibre-reinforced polymers exhibit exceptional mechanical performance and energy dissipation capabilities, making them highly suitable for applications requiring high kinetic energy absorption, such as crash protection and impact resistance. Accurately simulating the crushing behaviour of these materials is complex, especially when using physically based models. A crucial aspect of such simulations involves the implementation of Non-local Damage Models (NDM), which require the full characterisation of the intralaminar properties of the composite material. The most widely used experimental methods for determining these properties are the Compact Compression (CC) and Compact Tension (CT) tests.

Methods

This study focuses on the calibration of intralaminar fracture energies and damage parameters for the Waas-Pineda damage model within the ESI-VPS commercial software for fabric-based laminates. The calibration process involves the numerical simulation of CC and CT tests, followed by direct comparison with experimental results to calibrate the damage parameters. Furthermore, numerical crashworthiness simulations were conducted to improve the calibrated model's accuracy. The results were again compared against experimental crash test data.

Results

Systematic parameter adjustment ensured an optimal correlation between numerical and experimental data, accurately representing the material's fracture behaviour. The validation process assesses the model's capability to capture key failure mechanisms and accurately predict the energy absorption characteristics of composite material components under dynamic loading conditions.

The comparison confirms the effectiveness of the Waas-Pineda model in reproducing the response of crashworthy composite structures, demonstrating its reliability in crash modelling applications.

Conclusion

This work highlights the importance of accurate parameter calibration in enhancing the predictive capability of damage models for composite materials. The findings contribute to the broader field of composite crashworthiness by providing a validated modelling framework that can improve the design and optimization of energy-absorbing composite structures in high-impact applications.

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Preliminary Evaluation of the Crashworthiness Properties of Sandwich Composite Panels With 3D Printed Cores

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Introduction

The crashworthiness of sandwich composite panels has gained significant attention in recent years due to their strength-to-weight ratio, energy absorption capacity, and structural efficiency in impact scenarios. Sandwich composite panels, consisting of lightweight core materials between stiff face sheets, are widely used in aerospace, automotive, and marine industries. A comprehensive analysis of previous research on energy absorption mechanisms, failure modes, and the influence of core materials on crash performance highlights the advantages of different core designs, including honeycomb, foam-filled, and 3D printed structures, in improving specific energy absorption (SEA).
This research aims to enhance understanding of the crash behaviour of these structures by conducting an experimental and numerical campaign.

Methods

The experimental campaign involves crash tests of sandwich panels with three different core configurations: aramid honeycomb, polymeric foam, and 3D printed structures. The external composite panels, manufactured using a carbon/epoxy prepregs, are produced separately. The core material is then positioned between these panels and bonding is achieved using an epoxy resin film, which ensures uniform adhesion. The entire assembly undergoes an additional autoclave curing cycle under controlled temperature and pressure conditions, ensuring the mechanical properties and structural integrity of the final component.
Quasi-static compression tests are conducted to assess the energy absorption capacity, failure mechanisms, and overall structural performance of each core type. The SEA parameter is utilised to compare the performance of different cores, eliminating the influence of specimen geometry on crashworthiness behaviour.
In addition, Finite element analysis (FEA), by means of ESI Visual Crash-PAM software, is performed and validated against experimental results. Crashworthiness simulations model the experimental setup by applying appropriate boundary conditions and implementing material properties and failure criteria. Different element types were tested to identify the optimal configuration, balancing the computational efficiency and results reliability.

Results

Experimental studies demonstrate that the selection of core material and geometrical configurations plays a crucial role in enhancing the crashworthiness of these panels. The influence of different core designs on the energy dissipation characteristics is explored. The 3D printed cores show interesting effects on the specific energy absorption of the sandwich panel with different contributions depending on the printed geometries. Furthermore, the study addresses the role of computational modelling in predicting crash behaviour and optimizing sandwich composite structures for enhanced crashworthiness. A predictive numerical analysis campaign is a valuable tool for decreasing the experimental trial and error processes, especially for new 3D printed architectures. The development of dedicated models could be a step forward in the assessment of the crashworthiness of sandwich composite structures.

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Fiber Metal Laminates for Battery Boxes: A Compromise Between Strength and Rigidity

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FENICE (Upscaling, KAVA9, EIT RawMaterials, www.fenice-composites.eu, 2022–2025) is an EU-funded project (€2.5M) targeting TRL 7. It addresses fire resistance in battery enclosures to improve the safety of lithium-based battery modules, with a focus on developing sustainable composite materials for automotive mass production.
The project aims to optimize the trade-off between mechanical performances (strength, stiffness, and resonance frequency), fire resistance, and sustainability. The first resonance frequency of a component is primarily influenced by mass and stiffness (elastic modulus). In the case of Fiber Metal Laminate (FML) battery enclosures, achieving sufficient rigidity while minimizing weight is essential to meet OEM specifications. To avoid resonance-induced noise from engine and road vibrations, the first natural frequency must exceed 30 Hz. FENICE partners are investigating monolithic and sandwich-structured FMLs with various layups reinforced by glass or basalt fibers. Materials are being assessed for mechanical and thermal behavior, fire resistance, mass reduction, and vibration damping, with the objective of identifying optimal solutions for industrialization. Sustainable resins considered in this study were recyclable Elium® (from Arkema), Crossfire hybrid PET-Epoxy hybrid resins (www.crossfire-srl.com), and biobased Polyfurfuryl Alcohol (PFA), associated to glass and basalt fabrics. In sandwich structures, considered core materials were recycled PET (150 g/dm³, 10 mm) and cork (120-180 g/dm³, 10 mm)
Methods
Sandwich based on cork were prepared by infusion (with Elium resin and aluminium sheets with tiny holes, EP 2759399B1) followed by post curing (at 90 °C). Monolithic and Sandwich composite panels based on PFA and Crossfire resin were produced at 180 °C and associated to recycled PET (which supports processing in warm press). All tests were performed applying relevant international standards (e.g. ASTM D-7249). Fire resistance was evaluated using cone calorimetry (ISO 5560-1). Flexural strength (UNI-EN ISO 14125) was measured before and after 10 minutes of thermal exposure at 700 °C and after Neutral Salt Spray (NSS) aging tests.
Results
Sandwich structures showed enhanced stiffness relative to monoliths, positively influencing resonance behavior and load capacity. Crossfire samples show a slightly lower flexural module compared to the PFA and Elium ones, but much higher flexural strength and superior fire resistance. Crossfire resin (Italian patent no.

102024000013807) exhibits thermoplastic behaviour at elevated temperatures, enabling recyclability via chemical depolymerization or mechanical remolding, without separation of the R-PET core from skins.

Conclusions

FMLs with sandwich architecture are promising candidates for battery enclosures, offering high stiffness-to-weight ratios and enhanced vibration and fire performance, thereby satisfying key automotive design requirements. Thermoplastic PET cores tends to melt down upon exposure to fire, but this takes time (more that 10 minutes) thanks to thermoinsulating characteristics of glass-reinforced and aluminium composite skins. Sandwich structures with rPET cores showed significantly higher stiffness than corresponding monolithic structures. At low deformations, the introduction of the RPET core resulted in at least a 12-fold increase in stiffness properties compared to monolithic structures, ensuring a first resonance frequency over 30Hz for the battery case structure. Another advantage of optimised FMLs is that exposure to corrosive environments (simulated using NSS) does not lead to compromised mechanical performances.

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High-Stability Passive Film for Enhancing Corrosion Resistance in Aluminum Cast Alloy

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Corrosion resistance of aluminum alloy is markedly affected by alloy composition. The alloy composition, especially copper, can effectively strengthen mechanical properties but seriously damage corrosion resistance due to impairing stability of passive film on the surface of AlSiCuMg aluminum cast alloy. Herein, a novel design strategy of passive film has been proposed for effectively enhancing the corrosion resistance in Al-9%Si-4%Cu-0.25%Mg alloy. The highly-stable passive film with nanocrystalline structure and stable nanocrystalline boundary is constructed by Zn and Zr co-microalloying in the alloy. This co-microalloying strategy increases the passive film thickness, significantly decreases its defect density by 79.5 %, enhances the passive film by promoting formation of γ-Al_2O_3 nanocrystalline structure and enhancing the stability of nanocrystalline boundaries. This study provides a theoretical idea of stability enhancement of passive film for designing corrosion resistant AlSiCuMg aluminum cast alloy.

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Study on Improving Corrosion Resistance of 6000-Series Alloys With High Cu Content

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In general, adding Cu element to Al-Mg-Si alloys will accelerate the precipitation kinetics of strengthened phases and significantly improve the strength. However, when the Cu content is higher than the critical value of 0.1wt.%, the alloy's intergranular corrosion (IGC) sensitivity will be greatly increased. It also proves that there is a contradictory relationship between strength and corrosion resistance. It is necessary to balance between the two. In this study, the microstructure of 6000-series alloys with high Cu content are regulated by online quenching, microalloying and prestressing. High Cu content 6000-series alloys achieve synergistic improvement in strength and corrosion resistance. The tensile strength is more than 430 MPa, the yield strength is more than 400 MPa, and the elongation was no less than 13.6%. High performance 6000-series alloys with IGC grade 2 (corrosion depth ≤ 100 μm). This study will provide a new idea for the preparation of high-performance 6000-series alloys and contribute to the development and upgrading of high-quality corrosion-resistant aluminum alloys.

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Microstructure-Properties Control and Hydrogen Embrittlement of High Strength Precipitation-Hardened Martensitic Stainless Steel

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High strength precipitation-hardened martensitic stainless steel has been widely used in aerospace and nuclear power engineering as a key structural component and fastener due to the excellent mechanical properties and corrosion resistance. With the development of technology and the improvement of service requirements, the manufacturing of precipitation-hardened martensitic stainless steel with higher strength and better elongation is one of the main research directions of advanced high strength steel in the future. However, the higher the strength of material, the higher hydrogen embrittlement (HE) susceptibility. HE limits the development and safe service of the high-strength steel. In this research, the microstructure, mechanical properties and corresponding HE susceptibility of PH13-8Mo steel subjected to conventional heat treatment condition were analyzed. The mechanical properties and HE resistance of PH13-8Mo steel were further modulated. A novel high strength and elongation precipitation-hardened martensitic stainless steel was designed by adding 2.5wt % Cu on the basis of PH13-8Mo steel, and its main strengthening and toughening mechanism were investigated. Furthermore, the HE mechanism of this novel precipitation-hardened martensitic stainless steel was analyzed, and its HE resistance was optimized.

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Corrosion Fatigue Behavior of 304L and 316L Stainless Steels in MEA-Based Solutions

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The use of amine-based solutions in CO2 capture processes has gained significant attention the last few years, as it is considered one of the most effective technologies for carbon capture. Among these, monoethanolamine (MEA) stands out as a preferred absorbent mainly due to its high mass transfer efficiency, fast absorption rate and low cost. In these capture units, the amine fluid circulates through pipes, moving from the absorber to the regenerator and finally to the heat exchanger, before returning to the absorber, in a continuous loop. Corrosion fatigue in such units arises from the combined effects of mechanical stress and the corrosive solution.

This study is focused on the investigation of the corrosion fatigue behavior of 304L and 316L stainless steels when exposed to MEA-based amine solutions, containing SOx and NOx pollutants, under both CO2-loaded and unloaded conditions. S-N curves were extracted from bending experiments in C-ring specimens, with stress ratio R=0. Fatigue tests were also performed in corrosion-free environments. Scanning electron microscopy analysis was used to better understand the failure mechanism and the contribution of corrosion to the final failure.

Results revealed that all corrosive solutions significantly contributed to the reduction of fatigue life in both stainless steels. Notably, the MEA loaded solution containing SOx/NOx pollutants, which exhibited the higher corrosion rate, resulted in the lowest corrosion fatigue life. Additionally, SS 316L demonstrated superior fatigue life compared to SS 304L, while SS 304L showed multiple crack initiation sites. SEM analysis indicated that the fracture surfaces remained similar, regardless of the amine solution used, with the fracture type changing along the crack propagation direction.

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Effect of Tantalum Low-Alloying on the Corrosion and Wear Performance of a Biomedical Co-28Cr-6Mo Alloy Fabricated by Vacuum Arc Melting

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This study focuses on the development of Co-28Cr-6Mo-xTa alloys via Vacuum Arc Melting (VAM). The objectives of this work are: a) to assess the suitability of VAM for fabricating Co-28Cr-6Mo-xTa in terms of microstructure homogeneity and surface degradation properties, and b) to evaluate the corrosion and wear resistance of Co-28Cr-6Mo-xTa alloys.
VAM is an effective way of fabricating in terms of cost and ease of manufacture and can result in very fine microstructures of minimal porosity and high corrosion and wear resistance.
Regarding the experimental methodology, each specimen was turned over and remelted five times in the VAM furnace to assure chemical homogeneity. The microstructure was evaluated by X-Ray Diffraction, Optical Microscopy and Scanning Electron Microscopy (SEM/EDX). Corrosion resistance testing was conducted by cyclic potentiodynamic polarization in simulated body fluid (SBF) at 37°C and pH=7.4±0.1. The dry sliding wear behavior was evaluated by a ball-on-disk tribometer.
The Co-28Cr-6Mo-xTa specimens had a dendritic microstructure with a segregation of Mo and Ta into the interdendrites. The specimens exhibited high resistance to uniform corrosion (corrosion current densities of the order of 10-4 mA/cm2), non-susceptibility to localized corrosion and true passivity (passive currents << 0.1 mA/cm2) in SBF at 37°C. Ta addition reduced the corrosion rate of the Co-28Cr-6Mo alloy. As the addition of Ta was increasing, lower wear rates were also attained (order of 10-6 mm3/(N m)). The effect of Ta on the surface degradation properties of Co-28Cr-6Mo alloys was compared to the effect of Nb.

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Corrosion Fatigue Performance of Aluminum Alloys for Transportation: A Case Study on 6061-T6 vs. 6082-T6

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Corrosion fatigue, which is well known as the combined action of cyclic mechanical loading and corrosive environments, poses significant challenges to the integrity and service life of structural components, es-pecially in critical applications in transportation and aerospace. Investigating and understanding the fac-tors which influence corrosion fatigue mechanisms is essential for developing effective mitigation strate-gies. In this context, this comparative study presents the results on microstructural analysis and corrosion fatigue experiments of widely used heat treated aluminum alloys 6061-T6 and 6082-T6 with focus on their different copper content.

The microstructural analyses of the extruded 6061-T6 and 6082-T6 aluminum alloys were performed us-ing optical microscopy, scanning electron microscopy with energy dispersive X-ray spectroscopy. The fully reversed cantilever beam fatigue experiments were conducted at 0.2 Hz in two environmental conditions: ambient air and salt spraying (3.5 wt% sodium chloride).

Both extruded alloys exhibit the characteristics of double-size grains, which consist of relatively large size and fine grain bands distributed along the extrusion direction. The presence of Fe-containing course in-termetallic particles with Cu (AlFeSiCu), and Mn (AlFeSiMn) distributed along extrusion direction were found in alloy 6061-T6 and alloy 6082-T6, respectively. Sporadic secondary phase MgSi was found without obvious longitudinal distribution in the aluminum matrix.

The fatigue life of both alloys was decreased by over 30 times in corrosive environment. Also, the corro-sion fatigue response of 6082-T6 alloy characterized a wider scatter in S-N curve data. Microscopic analy-sis indicate that localized corrosion contributed to the early stages of fatigue crack development with pit-ting corrosion serving as a precursor to crack initiation. The formation and distribution of these pits were influenced by the presence of intermetallic particles, which act as active sites for efficient cathodes to support anodic attack. To investigate the synergistic interactions between corrosion reactions and cyclic mechanical loading that accelerate fatigue crack propagation, the cracks paths were compared. Despite the difference in copper content, that might affect the susceptibility of the alloys to intergranular corro-sion and anodic dissolution of grain boundaries, both alloys exhibited a tendency of transgranular crack propagation. In the current case 3.5 wt% sodium chloride solution mainly affected the crack initiation stage.

The role of testing conditions, particularly the presence of chloride ions, has also been studied. Fatigue experiments were conducted in 0.5, 2.0 and 3.5 wt% sodium chloride solutions under constant cyclic loading

with specimens made of 6061-T6 alloy. It was found that the alloy experienced random pitting corrosion in all selected environments resulting in slightly different fatigue lives. In addition, increasing the testing frequency from 0.2 Hz to 10 Hz led to prolongation of fatigue life.

Results obtained show a significant effect of the 3.5 wt% sodium chloride solution on the fatigue life for both alloys. The crucial role of secondary phase intermetallic particles was a key result providing a better understanding of the corrosion fatigue behavior of 6XXX aluminum alloys. These findings can also im-prove material selection for operation in specified conditions.

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Effect of Artificial Ageing on Mechanical Properties of Recycled Polypropylene Hollow Chamber Sheets

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A wide range of packaging materials, such as polyolefin, polyester, polyamide, polyacrylate, polyvinyl, epoxy polymers, etc., can be used to safely transfer and archive documents, photographs, and collections from archaeological, library, or museum holdings. Since loan activities of museum objects to promote access are increased, storage containers made from polypropylene (PP), a common thermoplastic polymer, fulfill the requirements for effective, safe, and affordable materials with enhanced properties in addition to good mechanical stability and long lifetime, and full accounting for end-of-life aspects especially when the conditions may cause biological or deterioration due to environmental factors [1,2]. The use of PP in the form of hollow chamber sheets is of great interest, since boxes made from this material are stable, durable in time, offer a balanced combination of hardness and flexibility, and can protect cultural heritage objects from damage ensuring their long-life conservation. Several types of recycled PP are suggested, as alternative materials to replace conventional PP from fossil resources, improving sustainability and environmental protection [2]. This study aims to assess specific packaging materials for cultural heritage objects by comparing the mechanical properties of different types of recycled polypropylene hollow chamber sheets (rPPhcs) with a conventional one (cPPhcs) derived from petroleum refining. The research is carried out within the European programme HORIZON-CL2-2021-HERITAGE-01: GREENART (GREen ENdeavor in Art ResToration), which highlights the protection and conservation of the cultural heritage through a multidisciplinary approach by proposing new solutions based on green and sustainable materials [2]. Within this framework, the present work aims to provide comprehensive experimental data on the mechanical properties, after artificial ageing, of different packaging materials made from polypropylene, from recycled materials in order to replace conventional ones. Artificial ageing of the examined specimens was performed using an accelerated weathering chamber. Investigation of mechanical response was carried out by creep testing and hardness measurements of both the conventional (cPPhcs) and recycled (rPPhcs) materials, before and after ageing. Specimens' morphology was examined through non-destructive spectral imaging in visible and near infrared radiation (VIS) and ultraviolet-induced visible luminescence (UVL), as well as microscopy techniques, such as

Dino Lite handheld digital microscopy to capture close-up views of selected areas in various spectral regions (visible, UVL, and near-infra-red). The results showed that the condition and mechanical performance of the specimens are affected from the ageing process.

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Assessing the Ageing Effect of Green Organic Coatings Under Development on Bronze Alloy Substrate

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The metal cultural heritage artefacts are susceptible to degradation due to corrosion reactions with their environment. Consequently, preventive conservation which encompasses methods and actions to avoid, minimize or delay such degradation without altering the materials or structures of the items, as defined by the Conservation Committee of the International Council of Museums (ICOM-CC) [1] is crucial. A primary method for protecting metal artefacts against corrosion and degradation is to apply protective coatings [2]. This research investigates the protective efficiency of a series of green organic coatings on a bronze RG7 alloy substrate. These coatings are being developed within the framework of the GREENART Project (GREen ENdeavor in Art ResToration, HORIZON Europe, 2022–2025), which aims to research and develop green and sustainable systems for the curative and preventive conservation of works of art, serving as substitutes for conventional ones, already used in this field. Therefore, the present work focuses in comparing these green coatings with conventional organic coatings currently used in art restoration and conservation, such as Incralac and beeswax. To achieve this, an experimental approach was designed based on configurative artificial ageing experiments in a sealed and environment-controlled ageing chamber. Samples were aged at 40 Degrees Celsius and 65% Relative Humidity (RH) for 2, 4, or 8 weeks, conditions considered mild for metal artworks. The assessment of the protective coatings was carried out using a wide range of interdisciplinary techniques. Specifically, in addition to documenting the mock-ups through visible reflectance (VIS) and ultraviolet-induced visible luminescence (UVL) imaging, they were examined macroscopically using visible, ultraviolet and infrared illumination via digital microscopy (DINO). Furthermore, the optical properties of the coatings were monitored using glossimetry and colorimetry and their respective thicknesses were statistically measured by Thickness Coating Analysis. Finally, Scanning Electron Microscopy coupled with Energy Dispersive Spectroscopy was used to monitor the presence of corrosion. The outcome endeavours to determine the corrosion and degradation resistance contribution, and efficiency of green organic coatings in comparison to conventional and traditional ones, on bronze mock-ups, simulating their potential implementation for the conservation and protection of bronze statues.

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Anisotropic Thermomechanical Fatigue in a Nickel-Base Single Crystal Superalloy: Effects of Strain Rate, Rafting Microstructure and Thermal-Mechanical-Oxidation Damage Mechanisms

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Nickel-base single-crystal superalloys (NBSX) are widely used as turbine blade material in advanced commercial aero-engines. The material undergoes complex fatigue loading paths like creep-fatigue and thermomechanical fatigue (TMF) during service. Strain rate sensitivity, material anisotropy and rafting microstructure will influence the mechanical responses under TMF loadings. Accurate modeling of high-temperature fatigue performance is of essential importance for the safe service of commercial aero-engines. In the present work, the anisotropic isothermal fatigue and TMF behaviors are studied in a NBSX. Fatigue tests are conducted along different crystal orientations with a wide strain rate range and life reduction over 90% is observed along lower strain rates and rafted alloys. The rate-dependent deformation is modeled using crystal plasticity constitutive theory, decomposing the total slip rate into plasticity and creep components. The proposed constitutive model successfully describes cyclic deformation behaviors, capturing the effects of strain rate, material anisotropy and rafting microstructure.
Fractography analysis reveals additional creep damage mechanism during isothermal fatigue with evidence of creep damage on the crack surface and distinct creep facets. Lower strain rates enhance the influence of creep on fatigue crack propagation. In-phase (IP) and out-of-phase (OP) TMF tests conducted in distinct crystal orientations revealed thermal-mechanical-oxidation interplay in crack initiation modes and damage mechanisms. Creep damage nucleated from internal casting pores in IP-TMF and propagated by mode I. The creep facets were controlled by the activated slip systems. Fatigue damage was orientation dependent and developed by slipping along different crystallographic planes. Oxidation-assisted cracking in OP-TMF tests was non-crystallographic for all three crystal orientations. Multi-layer structure of the oxide layers near the crack tip revealed successive growth of oxide and the crack grew within the oxidized material.
Life assessment is realized through two distinct damage models. Linear damage summation model accounts for anisotropic fatigue and creep damage along crystallographic slip systems and is validated by multiple tests. Effect of rafting microstructure is introduced by tensorial microstructural parameters. Nonlinear damage accumulation model enables stepwise damage increment and characterized the damage evolution process. Fatigue lives under various loading paths are well modeled with most data points fall within the three-time scatter band. These findings provide valuable insights and modeling tools for understanding and predicting the fatigue performance of NBSX under complex loading conditions.

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The Role of Heat Treatment on Fatigue and Fatigue Corrosion Behavior of Cast and Chip-Based Hot Extruded AA6060

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The increasing demand for sustainable manufacturing raises the interest in alternative methods of secondary aluminium production. The high cost, the high carbon footprint, and the emerging material loss are among the disadvantages that present the conventional (melting and casting) method. As a result, the exploitation of aluminium chip wastes through cold compaction, hot extrusion, and porthole die pressing, consolidates remarkable characteristics for its mechanical properties. However, there are few studies on the solid-state recycling for aluminium alloy relating to the behaviour of fatigue and fatigue corrosion.

In this study, machined chips of 6060 aluminium alloy were recycled by a novel solid-state recycling method. The resulting extruded specimens underwent a homogenization heat treatment during hot extrusion and subsequently a natural or artificial aging. The fatigue and fatigue corrosion performance of the above material have been consequently investigated.

The analysis of test results and fracture mode were derived by detailed optical and scanning electron microscopy (SEM) observation after fatigue testing. The results were discussed in comparison to the conventionally produced material (cast-based) under the same extrusion and heat treatment conditions. The fatigue corrosion behaviour of all the specimens was investigated under 3.5% wt. NaCl solution and the fatigue parameters were set to R= 0 and f= 25Hz.

The findings highlighted the critical role of robust bonding either under fatigue or corrosion fatigue stresses. Given that the quality of chip bonding in the as-received material is not adequate in most chip-based samples, the fatigue life appeared shorter in comparison to cast-based samples. The corrosion fatigue tests concluded in the same result but at proportionally lower level. In addition, fractography analysis revealed multiple cracks that appeared inside the recycled specimens resulting in different crack propagation mechanisms compared to conventionally produced specimens.

With further optimization of chip bonding and process parameters, solid-state recycling methods such as these hold significant potential for reducing the environmental impact of secondary aluminum production.

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Theory of Intermediate Twinning and Spontaneous Polarization in Ferroelectric Potassium Sodium Niobate

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Potassium sodium niobate is considered a prominent material system as a substitute for lead-containing ferroelectric materials. It exhibits first-order phase transformations and ferroelectricity with potential applications ranging from energy conversion to innovative cooling technologies, thereby addressing important societal challenges. However, a major obstacle in the application of potassium sodium niobate is its multi-scale heterogeneity and the lack of understanding of its phase transition pathway and microstructure. This can be seen from the findings of Pop-Ghe et al. (Ceram Int 47(14):20579–20585, 2021, https:// doi. org/ 10. 1016/j.ceram int. 2021. 04.067) which also reveal the occurrence of a phenomenon they term intermediate twinning during the phase transition. Here, we show that intermediate twinning is a consequence of energy minimization. We develop a geometrically nonlinear electroelastic energy function for potassium sodium niobate, including the cubic-tetragonal-orthorhombic transformations and ferroelectricity. The construction of the minimizers is based on compatibility conditions which ensure continuous deformations and pole-free interfaces. These minimizers agree with the experimental observations, including laminates between tetragonal variants under the cubic to tetragonal transformation, crossing twins under the tetragonal to orthorhombic transformation, intermediate twinning and spontaneous polarization. This shows how the full nonlinear electroelastic model provides a powerful tool in understanding, exploring, and tailoring the electromechanical properties of complex ferroelectric ceramics.

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Low Hysteresis and High Performance in Pyroelectric Energy Conversion Using Phase-Transforming Barium Strontium Titanate

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The growing demand for sustainable energy solutions has intensified interest in harvesting low-grade waste heat, existing as temperature fluctuations in both industrial processes and everyday environments. Pyroelectric energy conversion, which exploits the temperature-dependent polarization of ferroelectric materials, offers a particularly effective approach for converting heat to electricity directly.
First-order phase transformations in ferroelectric materials can significantly enhance the figure of merit (FOM) of energy conversion by inducing an abrupt change in polarization during phase transformation. However, the accompanying symmetry-breaking structural transitions often lead to microstructural incompatibility, which degrades cyclic functional stability and diminishes energy harvesting performance over thermodynamics cycles.
In this work, we present a material development strategy for optimizing the FOM in pyroelectric energy conversion by tuning the phase transformation compatibility of crystal structure in barium titanate material system with Sr doping. As the Sr composition increases, we observe a transition in phase transformation behavior from first-order to second-order-like, accompanied by changes in thermal, electrical, and ferroelectric properties. Through crystal structural analysis, we calculated the compatibility conditions for the $(Ba,Sr)TiO_3$ material system and identified the optimal compositions associated with the lowest thermal hysteresis in phase transformations. Our findings demonstrate that these compatible compositions yield the highest FOM, leading to enhanced pyroelectric energy conversion performance.
Overall, our study proposes an alternative approach to material design through phase diagram and crystal structure analysis, which is particularly suitable for selecting materials to develop pyroelectric energy-conversion devices.

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Supercompatibility and Stress-Free Interfaces in Shape Memory Alloys

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Introduction

Functional fatigue and transformation hysteresis pose a major challenge in the design of shape memory alloys for numerous applications. These effects are attributed to the plasticity induced by the motion of highly stressed interfaces during the repetitive phase transformation cycles. It has been shown in the past that the alloys satisfying the cofactor conditions have excellent reversibility characteristics and low hysteresis. It is also known that satisfying the cofactor conditions results in the elimination of transition layer at the phase interface by formation of triple junctions between Type I/II twins and austenite. This mechanism allows for efficient transformation of one phase into the other without incurring any energy penalty due to elastic stresses. Consequently, the reversibility of the transformation and the functional life of the material are enhanced. Taking inspiration from the cofactor conditions, we investigate whether it is possible to eliminate the transition layers in the case of compound twins as well. The simultaneous elimination of transition layer for Type I/II as well as compound twins could maximize the modes of formation of stress-free interfaces between the phases. This may enhance the reversibility beyond that predicted by the cofactor conditions. We also investigate whether the enhanced compatibility can unlock any new microstructures which may provide easy pathways for the phase transformation to proceed.

Methodology

The microstructural features in shape memory alloys are successfully explained by the geometrically non-linear theory of martensite. According to this theory, the microstructure observed in materials is a consequence of the material trying to minimize its elastic energy. The energy landscape of the material is assumed to be convex (single well) at higher temperatures, which changes to a non-convex (multi-well) as the material cools below the transformation temperature. The well(s) in each case correspond to the deformation gradient(s) that make up the microstructure. The deformation gradients in any two neighbouring regions always differ by a rank 1 matrix. All the deformation parameters are reduced to functions of lattice parameters alone. All the compatibility conditions can be thought as constraints on the lattice parameters. The objective is to identify the appropriate set of compatibility conditions that eliminate the transition layer between austenite and Type I/II as well as compound twins.

Results

We propose a new set of compatibility conditions which can eliminate the transition layer in Type I/II twins as well as compound twins simultaneously. The solution strategy can also be extended to cover the case of elimination of transition layers in non-conventional twins as well. This covers the analysis for all generic twins. We also showcase some theoretically predicted microstructures, which may enhance the reversibility of the material.

Conclusion

Inspired by the commutation properties of the stretch tensors of martensitic variants, we propose a new set of compatibility conditions capable of simultaneously eliminating the transition layer in Type I/II twins and compound twins. The new compatibility conditions may serve as guidelines for alloy discovery.

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Phase Change Materials for Elastocaloric Cooling

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Elastocaloric cooling is a solid-state refrigeration technology based on shape-memory alloys undergoing martensitic phase transformations in a thermodynamic cycle. This requires materials with high enthalpy of transformation combined with high structural integrity. The latter can be achieved by obeying the cofactor conditions, which mathematically define compatibility relationships between the austenite and martensite phases where the transformation is super-reversible. We have in the present work investigated quaternary TiNiCuZr compounds in the search for materials with excellent elastocaloric properties. A combinatorial thin-film deposition approach was used, based on magnetron sputtering employing a target with the composition $Ti_{44.5}Ni_{40.5}Cu_{10}Zr_5$. With a non-rotating substrate, this gave films with a graded composition, ideal for high-throughput experiments. Several different characterization and testing techniques were employed to assess the properties of these films. The film compositions were assed with energy-dispersive X-ray spectroscopy (EDS) in a scanning electron microscope (SEM). The measured compositions varied throughout the films, with elemental concentrations varying by 2–4 at% from those of the sputtering target. Transient grating spectroscopy (TGS) was used to characterize the elastic and thermal properties of a wide range of compositions. This provided elastic constants as a function of composition, which gave a clear indication of areas with the austenite and martensite crystal structures present at room temperature. Combined with theoretical studies of the same compositions, specific areas of the films were then identified as promising for elastocaloric applications, with the compatibility criteria being close to satisfied. Those areas were selected for further testing. Differential scanning calorimetry (DSC) was used to assess the phase transformation of different compositions, and martensitic phase transformations were observed for six compositions. The final austenitic (martensitic) transformation temperature A_f (M_f) varied between 283.1–322.7 K (236.0–283.0 K) when the compositions varied between $Ti_{46.0}Ni_{38.5}Cu_{8.9}Zr_{6.6}$ – $Ti_{45.6}Ni_{41.6}Cu_{7.5}Zr_{5.3}$. The transformation was confirmed with temperature-dependent X-ray diffraction showing a cubic B2 phase at high temperature (austenite) and a lower-symmetric phase at low temperature (martensite). Microscopic tensile testing was performed on selected compositions, but the mechanical properties of the thin films were not adequate for such testing. Nevertheless, the broad range of techniques exploited in this study led to a detailed view of the interplay between composition, microstructure, thermal, and mechanical properties of TiNi-based quaternary alloys.

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Size and Orientation Effects on Martensitic Phase Transformation in Cu-Zn-Al Micropillars

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Objective

Martensitic phase transformations in Cu-Zn-Al alloys give rise to functional behaviors such as superelasticity and the shape memory effect, making them attractive for various applications. While the bulk behavior of these alloys is well-characterized, their response under small-scale mechanical loading is complex and remains an area of ongoing research. This study explores the effects of pillar size and crystallographic orientation on stress-induced martensitic transformation in Cu-Zn-Al single crystals using nanomechanical compression testing.

Methods
Two compositions of β-phase Cu-Zn-Al single crystals were selected for nanomechanical studies. Samples were cut and prepared with surface orientations corresponding to the (001), (011), and (111) planes of the austenitic phase, as confirmed by electron backscatter diffraction (EBSD). Micropillars with diameters ranging from 0.8 to 3 µm were fabricated using focused ion beam (FIB) milling. Mechanical compression tests were performed at room temperature using a nanoindenter to induce martensitic transformation in the pillars.

Results
Micropillar compression experiments revealed a clear size effect on the martensitic phase transformation. Smaller pillars showed diminished or incomplete transformation compared to larger ones. In addition, crystal orientation significantly influenced the nature and extent of the transformation, with certain orientations exhibiting more substantial transformation strains during compression. For some orientations, no transformation was observed, indicating a strong dependence on crystallographic alignment. These observations highlight how geometric confinement and orientation affect transformation behavior at small scales.

Conclusion
This study demonstrates that both geometric confinement and crystallographic orientation significantly influence stress-induced martensitic transformation in Cu-Zn-Al alloys at the microscale. These results offer valuable insight into martensitic transformation mechanisms in confined volumes, relevant for small-scale material design or fine-grained microstructures.

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Mechanical Characterization of Recovered Fibers and Fiber/Matrix Interface After Water/Ethanol-Based Solvolysis of CFRPs

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In recent years, there has been a growing global interest in recycling carbon fiber-reinforced plastics (CFRPs). However, the thermosetting matrix of CFRPs presents significant challenges in the recycling process. A promising approach is chemical recycling using subcritical and supercritical fluids, which can break resin bonds and enable controlled degradation. This method facilitates the recovery of carbon fibers with minimal damage, making them suitable for reuse.

This study introduces a novel solvolysis approach using environmentally friendly water/ethanol mixtures in different volume ratios (25/75 vol.%, 50/50 vol.%, 75/25 vol.%, and 100/0 vol.%) as solvents. Experiments were conducted at 320°C, 350°C, and 380°C with varying reaction times. The primary focus is on the mechanical properties of recycled carbon fibers (rCFs) and how factors such as temperature, solvent type, and reaction time influence the efficiency of thermosetting resin removal. Additionally, the effect of solvent type on resin removal efficiency is examined. The rCFs were analyzed using Scanning Electron Microscopy (SEM) to assess surface morphology, identify potential resin residues, and measure fiber diameters. After SEM analysis, mechanical characterization of rCFs and rCF/matrix interface was conducted by means of single-fiber tension and fiber pull-out tests, respectively.

The decomposition efficiency of the epoxy resin in CFRPs, measured by mass, ranged from 35-70% at 320°C and increased to 75-95% at higher temperatures. The results from the tension tests indicate that under certain experimental parameters where the fibers are almost clean, their tensile strength and Young's modulus are comparable to those of virgin fibers. However, in cases where significant resin remains on the fibers, mechanical degradation is observed, with strength reductions reaching up to 40%. From the microbond tests, the interfacial shear strength (IFSS) of the rCFs was measured. Under optimal conditions, the degradation was limited to 15% compared to virgin fibers. However, some experiments showed much more severe degradation, with significantly higher IFSS reductions. The results demonstrate that promising conditions exist for the recycling of CFRPs, with mechanical properties that underline their potential for reuse.

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Residual Fatigue Life and Strength Estimation of a Thermoplastic Mono-Stiffener Panel via FRF Analysis: A Numerical Exploratory Study

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This study numerically investigates the applicability of random vibration signals for detecting fatigue damage and estimating the residual fatigue life and strength of a composite panel. The panel consists of a skin reinforced by a welded omega-profile stiffener, both made of PAEK/T700 thermoplastic material. The numerical investigation is conducted using two models applied in an alternating manner: a progressive fracture model (PFM) and a random vibration model. The PFM comprises two modules: a static module and a fatigue module. The fatigue module is used to generate different fatigue states (FS) of the panel, while the static module predicts the residual compressive strength of the panel for each FS. The fatigue module of the PFM is validated using data from compression-compression (C-C) fatigue tests conducted on the panel with a stress ratio of 0.1. Following fracture analysis, the random vibration model is employed to perform Frequency Response Function (FRF) analyses for both the healthy panel and its various FSs. The numerical results indicate that the FS of the panel can be accurately estimated through the FRF amplitude curves. Furthermore, a correlation has been established between the residual force, failed area, normalized frequency ratios, and damage metrics. These findings underscore the potential of random vibration-based approaches for fatigue damage assessment in composite structures, particularly in aerospace applications

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Mechanical Performance of Inorganic Polymer-Based Fiber Reinforced Composites Under Static and Cyclic Loading Conditions

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The demand for advanced structural materials in the electric vehicle (EV) sector has significantly increased, particularly for battery enclosures, where safety and sustainability are key concerns. The need for fire-resistant materials that also minimize reliance on critical raw materials has driven extensive research into innovative solutions that align with circular economy principles.

To address these challenges, the "FENICE - Fire rEsistant eNvironmental frIendly CompositEs" project has developed a new class of fiber-reinforced composites designed to maintain structural integri-ty both under normal operating conditions and after exposure to extreme temperatures. These materials integrate continuous or chopped carbon fibers within an inorganic polymer matrix, a water-based system obtained from aluminosilicate clays and amorphous silica. The matrix is chemically activated at room temperature using alkaline solutions of potassium silicates and hy-droxides, leveraging the geopolymerization process. Additionally, the incorporation of refractory ceramic micropowders enhances thermal stability and mechanical performance.

Thanks to their optimized rheology, these composites are well-suited for vacuum infiltration and lamination techniques, widely used in traditional fiber-reinforced polymer (FRP) manufacturing. A simple post-curing process at 180-220°C significantly improves heat resistance, enabling the material to withstand temperatures above 650°C while achieving full fire resistance.

Despite their promising properties—such as low-temperature processing, thermal stability, and oxidation resistance—these inorganic composites may suffer from usuitable mechanical re-sistance under specific working conditions or undergo degradation when subjected to prolonged cyclic loading. This characteristic could limit their use in applications where sustained mechani-cal stress is a concern. Indeed, ensuring that these composites can withstand prolonged mechan-ical loads is essential for their long-term reliability in the automotive sectors, where special atten-tion has to be paid to the effects of acceleration and deceleration forces acting on battery enclo-sures.

To address this issue, a series of tensile and bending tests have been conducted on carbon fiber-reinforced specimens to evaluate their mechanical behavior, also exploring conditions of cyclic loading. The results provide critical insights into the real-world performance of these materials, helping to define safe operational conditions.

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Performance Comparison of Isogrid Rib-Stiffened and Conventional Helicopter Fuselage Panels Under Discrete Source Damage and Complex Loading Conditions

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This study examines the effects of damage caused by circular holes and n-sided star-shaped discrete sources—focusing on the shape, size, and location of such damage—on the performance of lower helicopter fuselage panels made from Aluminum-2024-T3. The research compares conventional stiffened panels with isogrid rib-stiffened panels, exploring how various loading conditions, including combined in-plane compression and shear, affect the panels. Finite element methods are used to assess how different types of damage influence the panels' strength, stiffness, structural stability, and frequency response.

Key findings demonstrate that isogrid rib-stiffened panels consistently outperform conventional panels across several performance metrics. Critical load cases were identified, with load case 5 being the most severe. The results show that isogrid panels offer superior damage resistance, particularly against n-sided star-shaped damage at the panel tips. These panels experience reduced displacements, enhanced flexural stiffness, and maintain lower and more uniform von Mises stress, effectively managing localized stresses and minimizing damage effects.

Frequency response analysis reveals that isogrid panels exhibit significantly higher natural frequencies in modes 2 and 3, indicating increased stiffness and load-bearing capacity. While circular hole damage has little effect on natural frequencies, n-sided star-shaped damage notably lowers frequencies, especially in conventional panels. Conventional panels suffer a substantial decrease in mode 1 frequencies, whereas isogrid panels demonstrate greater frequency stability under similar conditions. Furthermore, isogrid panels display higher buckling load factors, reflecting their superior performance under buckling conditions. Despite the presence of damage, isogrid panels retain higher buckling load factors compared to conventional panels, indicating better structural integrity. Conventional panels with n-sided star-shaped damage show significantly negative buckling load factors, while isogrid panels maintain positive values, showcasing their greater resilience.

Overall, this study highlights the superior performance of isogrid rib-stiffened panels in managing damage, preserving structural integrity, and resisting buckling. While these panels have a slight weight increase of 16.7%, they offer valuable insights into optimizing design and improving the robustness of helicopter fuselage structures under complex loading conditions.

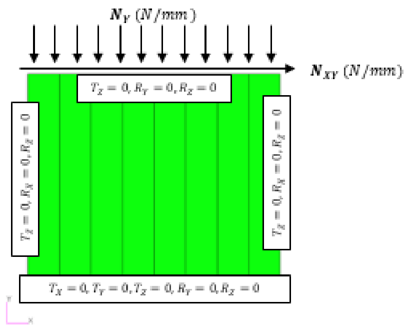

Fig. 1. Loading and boundary conditions for the design of both panels under combined compression and shear.

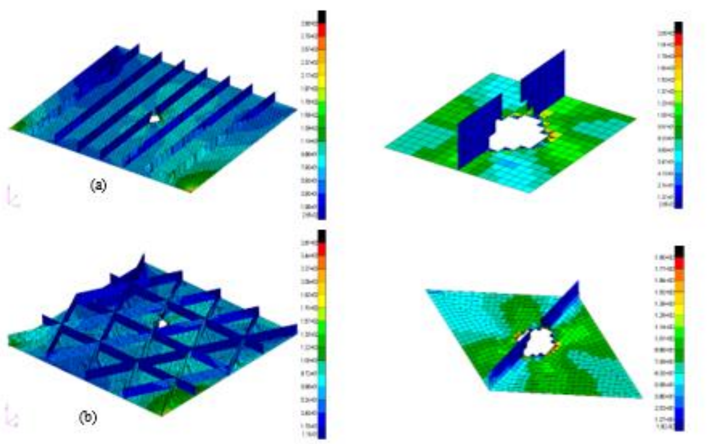

Fig. 2. Comparison of localized von Mises stress (MPa) on panels with n-sided star damage located at the skin and stiffener of (a) conventional stiffened panel and (b) isogrid rib-stiffened panel.

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Parametric Investigation of Adhesively Bonded Joints in Alternative Power Systems Integration Into an Aircraft Fuselage

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The main driving factor for the improvement of aerospace structures is the increase of their strength to weight ratio. Polymeric composite materials possess specific properties that rival or even surpass metal alloys. Their inherent anisotropy, low out-of-plane performance and complex mechanical behaviour are some of the major hurdles that need to be overcome in order to become acceptable replacements. Mechanical fastening provides reliable joining while also sustaining a high level of strength. However, such a perforative method, often lead to irreversible and not easily identifiable damage to fibrous composite materials, which can lead to intralaminar and interlaminar damage progression during the service life of the composite components. On the other hand, bonded and welded joints are capable of carrying the applied loads, while also distributing them on the joint area smoothly without causing significant damage to the material. The most commonly adopted method is adhesive bonding, which allows for lower structural weight compared to mechanical fastening, lower fabrication cost, higher flexibility and better damage tolerance due to even load distribution.

Although some investigation of the implementation of alternative power sources for the propulsion of aeronautical structures, such as Liquid Hydrogen (LH_2)has been performed, very little work has been conducted on the possible structural integration of the necessary components and sub-systems, namely Liquid Hydrogen (LH_2) tanks, batteries and fuel cells, to these structures. Special consideration should be placed in order to account for the increased risk regarding the use of highly flammable and combustible hydrogen and solid state batteries in the case of penetration and puncture.

In this study, a top-to-bottom building-block integration approach is developed by determining the optimal joining concept utilizing an automated parametric approach and key performance indeces such as weight, stress distribution and effective utilization of the adhesives properties and strength. A concentrated support concept and a distributed support concept are examined. The selected concepts from the parametric investigation are examined more thoroughly in order to assess the different damage modes including: disbonding of adherends, inter-ply delamination, intra-ply crack development and fiber breakage. Static,

fatigue and impact loading conditions can be examined by incorporating commercially available as well as custom algorithms into finite element models. The initial stages of the investigation are performed in a Finite Element simulation environment, in which the ability to perform an automated parametric analysis will be leveraged, utilizing built-in capabilities as well as algorithms in Python, before a more in depth analysis of the failure modes under static, fatigue and impact loading conditions is performed.

Keywords**:** Composites, Adhesive Bonding, Damage Tolerance, Structural Analysis, Finite Element Analysis, Parametric Investigation, Numerical Modelling, Hydrogen Powered Aircraft.

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Multi-Physics Finite Element Model of Cryogenic Hydrogen Tanks Focusing on Joining and Integration Concepts

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During the last decades, climate change has become a prominent issue, with a efforts spend in finding alternative solutions. Transportation is one of the main causes of emissions polluting the environment. Hence, fossil fuels need to be replaced with more environmentally friendly ones. Hydrogen is one of the most promising, as it produces no CO_2 and CO emissions, when it is used in fuel cells. When combusted in thermal engines, low particle and NO_x emissions may be expected, that can be further minimized through optimized combustion techniques.

As an aviation fuel, hydrogen has been attractive since the second half of the 20th century, with the successful testing of the experimental airliner Tupolev Tu-155 in 1988 being one of the pioneer milestones towards the adoption of hydrogen as a viable aviation fuel. Although several projects demonstrated the feasibility of liquid hydrogen (LH_2) in aircraft, overcoming conflicting requirements like low heat losses, high strength and low weight LH_2 tanks with low cost have kept the Technology Readiness Level low. An additional reason for hydrogen's attractiveness is its heating value of 120 MJ/kg, while conventional fuels, like Jet A-1, have a value of approximately 42 MJ/kg, which means hydrogen has about 2.8 times more energy per mass unit. On the contrary, the gaseous hydrogen (GH_2-ambient temperature) has a density around 0.09 kg/m^3, with the maximum practical density of 70.8 kg/m^3 being achieved in liquid form (LH_2) at -253 ^oC, while liquid hydrocarbons have a density around 820 kg/m^3. Therefore, hydrogen requires a much larger storage volume even when stored under cryogenic conditions, which makes its adoption in aviation challenging. As LH_2 is the most viable option for aviation, well insulated double-walled tanks are required.

In this direction, the present work focuses on the development of a parametric multiphysics finite element model of cryogenic hydrogen tanks, with the aim of investigating and optimizing the connection between the inner to the outer tank walls. The tanks are designed for application on a regional aircraft with an energy content equivalent to the average amount of kerosene for the category. The connection concepts presented and investigated in the present work were developed with the aim to provide stiffness by adequately constraining the inner storage vessel while allowing thermal contraction/expansion, and also minimizing heat transfer and thermal stresses. The developed model comprises a thermal module that conducts heat transfer analysis under specific temperature boundary conditions and calculates the heat flux towards the inner vessel, and a structural module, that performs stress/displacement analysis using the thermal analysis results as inputs in combination with other mechanical loads. The simulation results are used as inputs for the optimization process of the inner tank supports, leading to an optimal concept from a structural and thermal point of view.

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Strain Rate Dependent Fracture Behavior of AW5754 Aluminum Alloy: A Multiaxial Loading Study

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Aluminum alloy AW5754 is extensively used in the automotive industry due to its numerous advantages, including body weight reduction, good corrosion resistance, weldability, and ease of processing and forming. The vehicle components produced from this alloy are often subjected to multiaxial loading at varying strain rates and amplitudes. Therefore, it is essential to accurately analyze the material's fracture behavior under such loading conditions to predict its mechanical response. However, the tensile test results of the standard specimens, even when conducted at different strain rates, may not adequately capture the overall fracture behavior of the material under multiaxial loading conditions. To accurately determine and model the fracture initiation behavior of the material under varying stress states, it is essential to test different specimen types that represent a range of stress conditions. The measurement should then be used to develop appropriate mathematical models that capture the material's fracture in these stress states.
This study investigates the effect of strain rate on the predicted fracture behavior of AW5754 aluminum alloy under multiaxial loading conditions. The primary objective is to derive the triaxiality locus, a diagram illustrating the relationship between the equivalent plastic strain to fracture and the stress triaxiality factor. Various experiments involving different sample geometries under various strain rate axial loadings are conducted to obtain the necessary data for the analysis.
Uniaxial tensile tests are performed on eight specimen types, each with different notch geometries, to determine different stress states in the samples. Accurate deformation measurements are obtained using extensometers positioned at critical points. These tests are repeated for three different strain rates, including quasi-static loading conditions. Using the data collected from these experiments, finite element (FE) models are parametrized and executed to calculate the equivalent plastic strain and stress triaxiality factor. The simulation results are compared with experimental measurements to validate the accuracy of the models. Subsequently, the simulation outcomes are used to generate a stress triaxiality locus through a curve-fitting process.
An exponential curve correction function is employed to appropriately model the relationship between the equivalent plastic strain to fracture and the material's stress state. By determining the triaxiality factors and integrating both experimental and numerical techniques, this study offers valuable data and insights to accurately predict fracture stress and evaluate the stress state of structures made of AW5754 alloy under varying loading speed.

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In Situ Characterization of Strain-Induced Phase Transformations in L-PBF Multitextured Metastable Stainless Steel Using Advanced Neutron Imaging

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Introduction

The ability to control microstructure in laser powder bed fusion (L-PBF) by locally adjusting processing parameters enables the fabrication of complex components with tailored properties. By leveraging L-PBF's microstructure control, it becomes possible to engineer local phase transformations, enabling site-specific mechanical behavior and superior component performance. In particular, the capability to manipulate the crystallographic texture is of great importance for metastable austenitic stainless steels, as twinning-induced plasticity (TWIP) and transformation-induced plasticity (TRIP) effects are strongly dependent on the crystallographic texture along the loading direction [1–5]. In this way, L-PBF can be used to tailor microstructures in austenitic steels to enhance or suppress phase transformations as needed, opening the possibility of building complex components with locally different material properties.

Methods

The complexity of L-PBF-built samples requires advanced spatially resolved non-destructive characterization techniques to analyze the microstructure evolution and crystalline phase distributions in the bulk. In this respect, neutron imaging techniques hold great advantages. Here we investigate the transformation behavior of L-PBF-manufactured multitextured metastable stainless-steel specimens under uniaxial tension employing advanced neutron imaging techniques. Using polarization contrast neutron imaging (PNI) [6] , we quantify the in situ formation of α'-martensite and assess the correlation between local crystallographic texture and the TRIP effect [7]. Additionally, diffraction contrast neutron imaging, i.e Bragg edge imaging (BEI) [8], is employed to map phase distribution and texture evolution during deformation in complex geometries.

Results

We successfully quantified the α'-martensite volume fraction evolution under in situ uniaxial tension in additively manufactured multitextured specimens employing polarization contrast neutron imaging. We follow the texture evolution in the core and shell by analyzing the changes in height of the Bragg edges using Bragg edge neutron imaging.

Conclusions

The results demonstrate a direct correlation between the crystallographic texture and the TRIP effect when disentangling the PNI and BEI signals from different regions in the sample. It is demonstrated that laser powder bed fusion additive manufacturing enables the creation of site-specifically tailored texture which enables the control of the strain hardening with regard to specific predetermined regions while neutron imaging techniques are valuable tools for advanced materials characterization.

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Research on the Preparation of Stress-Free Standard Samples for Short-Wavelength Characteristic X-Ray Diffraction

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High-end metal components in advanced equipment may experience cracking and other issues during service due to uneven distribution of residual stress. Therefore, accurately measuring the residual stress distribution within these components is crucial. Our team has independently developed a short-wavelength characteristic X-ray diffraction (SWXRD) device, which utilizes a compact light source to enable non-destructive testing of residual stress inside crystalline material components in a laboratory setting. However, due to the lack of high-quality stress-free standard samples and their preparation methods, the testing accuracy is not high.
This study employed methods such as tensile treatment, heat treatment, cryogenic treatment, and high-energy acoustic beam reduction to prepare internal stress-free standard samples for aluminum alloy diffraction. The texture, grain size, and orientation of the samples before and after treatment were characterized using SWXRD, XRD, EBSD and other equipment.
The results indicate that the high-energy acoustic beam treatment yielded the best results, with the treated samples exhibiting the least residual stress, within ±10 MPa. The diffraction intensity and texture remained largely unchanged compared to before treatment, and the diffraction peaks showed no significant broadening. After annealing, the residual stress in the samples was within ±15 MPa, with a 10% increase in diffraction intensity and no significant change in diffraction peak width. Other preparation methods showed poorer reduction in residual stress, with significant changes in diffraction intensity and severe broadening of diffraction peaks.

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Texture Evolution in Transforming and Twinning Materials: A Comparison of Neutron Diffraction and MTEX-Based Simulations

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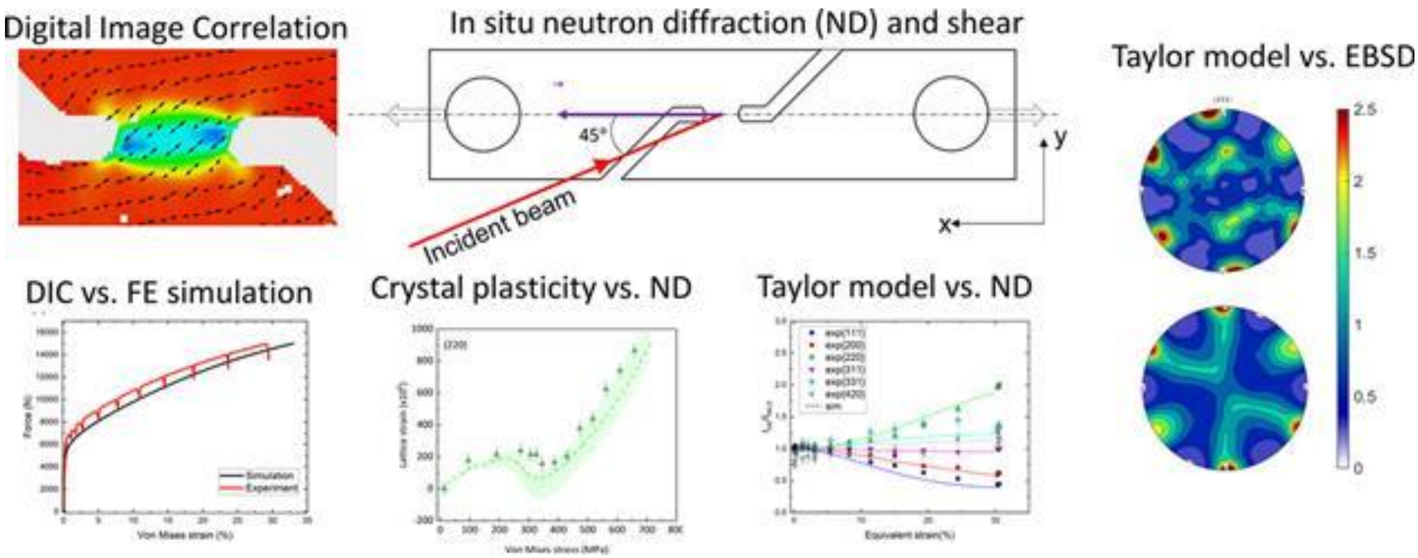
Understanding texture evolution during mechanical deformation is essential for materials undergoing phase transformations and twinning, as these processes significantly influence their mechanical properties. This work presents a combined experimental and modeling approach to capture and predict texture evolution under mechanical loading. We utilize in-situ neutron diffraction (ND) measurements to track lattice strain and crystallographic orientation changes during deformation and compare these results with simulations performed using the MTEX toolbox.

A key innovation of this study is the incorporation of transformation-induced plasticity (TRIP) and twinning-induced plasticity (TWIP) effects into the texture simulations, allowing for a more comprehensive representation of the microstructural changes. We examine three material systems—high-manganese steel, 304 austenitic stainless steel, and 316 austenitic stainless steel—each exhibiting distinct deformation mechanisms. The neutron diffraction experiments provide direct insights into the evolution of phase fractions, internal stresses, and preferred orientations during loading, while the MTEX-based modeling enables a detailed reconstruction of the underlying crystallographic transformations.

Our results demonstrate the synergy between experimental diffraction data and advanced texture simulations, highlighting the ability to capture complex deformation pathways, including twinning and phase transformation. This integrated approach enhances our understanding of the mechanical response and microstructural evolution of materials under service conditions, offering a robust framework for predicting the performance of advanced engineering alloys.


Digital Image Correlation
In situ neutron diffraction (ND) and shear
45°
Incident beam
y
x
Taylor model vs. EBSD
DIC vs. FE simulation
Simulation
Experiment
Von Mises strain (%)
Crystal plasticity vs. ND
(220)
Von Mises stress (MPa)
Taylor model vs. ND
Equivalent strain(%)

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Phase Formation and Texture Evolution of 316L-CuCrZr Multi-Material Structures

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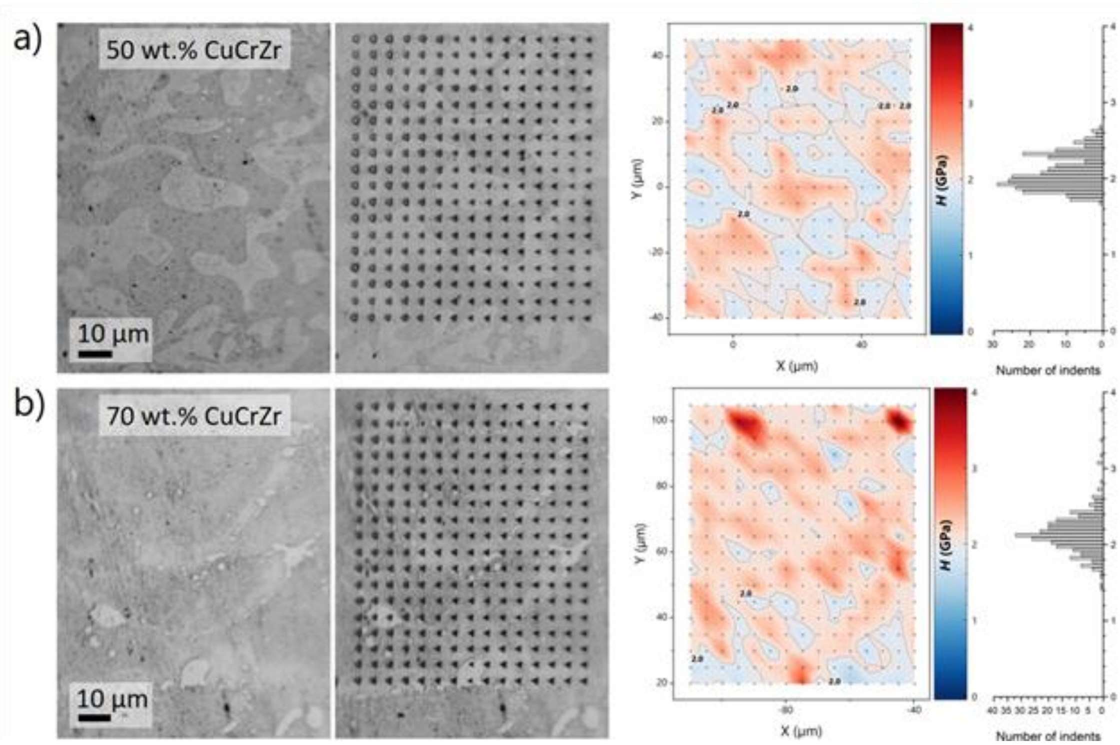
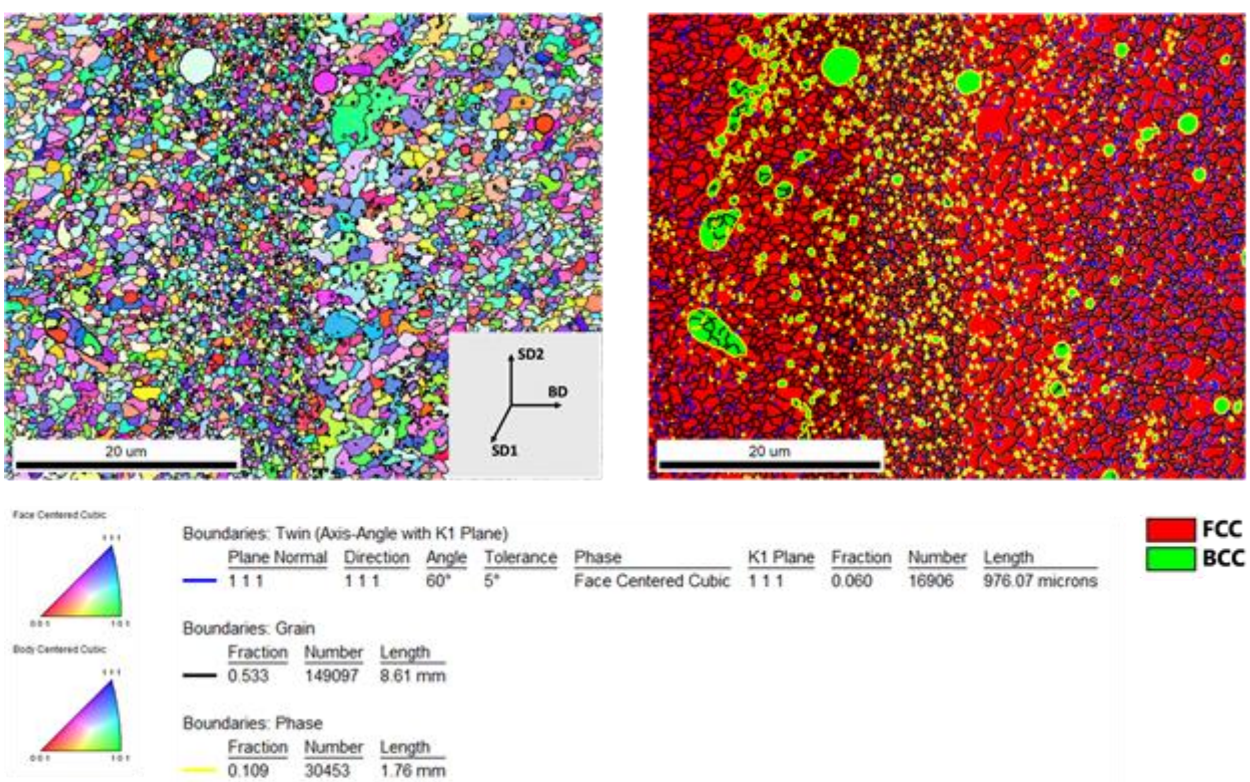
316L-CuCrZr Laser Powder Bed Fusion multi-material structures have attracted research interest due to their promising material combination, however they pose significant issues related to cracking phenomena and hence poor structural integrity. In this study, we propose a compositional modification approach to mitigate cracking by introducing carefully selected premixture layers between 316L and CuCrZr, designed to promote ferrite formation that resists cracking. To characterize such chemically graded materials, advanced characterization methods are required. The presence of ferrite in these multi-material structures is confirmed using Polarization Contrast Neutron Analysis (PNI), while its temporal evolution is investigated via in-situ annealing Synchrotron X-ray diffraction. Neutron Bragg Edge Imaging reveals that the phase transformation from austenite to ferrite correlates with significant texture evolution and a concurrent reduction in the Coefficient of Thermal Expansion, as revealed by in-situ annealing neutron diffraction. The melt pool morphology for different premixture compositions is examined using in-situ radiographic analysis, complemented by in-situ acoustic emission monitoring. Additionally, high-speed imaging enables the estimation of temperature distribution and the solidification behavior of the various compositional steps in the multi-material structures. Post-mortem microstructure characterization, employing EBSD, TKD and STEM-EDS analysis provides a valuable tool to elucidate the mechanism of ferrite formation, while the overall mechanical behavior of the structure is evaluated using nano-indentation mapping.


a)
50 wt.% CuCrZr
10 µm
b)
70 wt.% CuCrZr
10 µm
Y (µm)
X (µm)
H (GPa)
Number of indents


20 um
SD2
BD
SD1
20 um
Face Centered Cubic
Body Centered Cubic
Boundaries: Twin (Axis-Angle with K1 Plane)
Plane Normal Direction Angle Tolerance Phase K1 Plane Fraction Number Length
1 1 1 1 1 1 60° 5° Face Centered Cubic 1 1 1 0.060 16906 976.07 microns
Boundaries: Grain
Fraction Number Length
0.533 149097 8.61 mm
Boundaries: Phase
Fraction Number Length
0.109 30453 1.76 mm
FCC
BCC

201

Enhancing the Mechanical Behavior of L-PBFed Austenitic Steels by Tailoring Crystallographic Texture for Biaxial and Shear Deformation

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Austenitic stainless steels are widely used in engineering applications due to their excellent mechanical properties and corrosion resistance, driven by the Transformation Induced Plasticity (TRIP) and Twinning Induced Plasticity (TWIP) effects. Apart from the profound advantage of producing complex geometries, laser-powder bed fusion (L-PBF) provides the possibility of manipulating microstructures and crystallographic textures. Specifically, it has been found that shallow melt pools promote the formation of <100> crystallographic texture along the building direction (BD), while deeper melt pools promote the formation of <110> crystallographic texture along the BD [1]. Further advancements have demonstrated that with appropriate process parameters and controlled laser scanning strategies, crystallographic texture can also be tailored along in-plane directions [2]. By leveraging the texture-manipulation capabilities of L-PBF alongside the strong orientation dependence of TRIP and TWIP effects, it is possible to achieve L-PBFed components with equal or even superior mechanical properties compared to their wrought counterparts [3].
This study explores the deformation behavior of 304L stainless steel fabricated via L-PBF, focusing on the relationship between crystallographic orientation and mechanical response under complex loading conditions. First, the required microstructures were identified using Finite Element Modeling. By fine-tuning the process parameters, tailored crystallographic textures were achieved, and their effects on TRIP and TWIP mechanisms were evaluated under equibiaxial and shear deformation conditions. Extensive electron backscatter diffraction (EBSD) analyses were used to monitor the microstructural evolution during deformation, revealing that the TRIP and TWIP effects were strongly dependent on the predicted grain orientations.
The results demonstrate that L-PBF can be effectively leveraged for tailoring microstructures and enhancing the strain-hardening capacity of austenitic stainless steels under complex stress states that occur during service. This study underscores the crucial role of microstructural tailoring in L-PBF materials and paves the way for the development of high-performance components for applications requiring enhanced strength, ductility and energy dissipation.

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Analysis of the Causes of Defects in Lead Tap Joints for Electric Vehicles

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In this study, an analysis of the causes of detects in lead tap joints for electric vehicles was performed. The material used is a C1100 (Equivalent ASTM C11000) copper and laser welding process was applied. In order to scrutinize the cause of joint defects, chemical positions, microstructures and the mechanical properties of the used material were examined including non-destructive testing (micro X-ray CT). In addition, thermodynamic calculation was carried out by ThermoCalc software in order to investigate the influence of oxygen in the material. The cause of the defects of lead tap joints is deduced from the test results. Non-destructive CT analysis results showed that sound joints had almost no pores, while defective joints had many coarse pores. It is thought that the formation of these pores was due to gas pores existing on the surface of the material, and that the gas pores, which were subjected to high pressure due to rolling, caused coarse pores during welding process. Thermodynamic simulation analysis results for the material show that gas pores may be formed during material manufacturing (solidification) when the oxygen content is locally high. In conclusion, it is determined that the high pressured pores existing on the surface of the material formed large pores during welding, causing defects in the joints.

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Mechanical Properties and Failure Risk of Cement Mortars Containing Cement Kiln Dust and Gas Treatment Residues From Municipal Solid Waste Incineration

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The article presents the mechanical properties of cement mortars modified with a mixture of waste materials derived from the thermal treatment of municipal solid waste and cement production processes. The study utilized solid waste from flue gas treatment in municipal solid waste incineration plants, classified under the code 19 01 07* (MSWI-SW), as well as cement kiln dust (CKD) collected from the dust removal process of rotary kilns during cement production, classified under the code 10 13 80.
The hazardous waste material (19 01 07*) was used as a partial replacement for natural aggregate, while the inert waste (10 13 80) was applied as a cement substitute in amounts ranging from 0% to 20% of the binder mass. The flexural and compressive strengths of the composites were determined after 7 and 28 days of curing, as well as after frost resistance testing involving 25 freeze–thaw cycles. Statistical analysis of the experimental results enabled the development of high-quality predictive models describing the influence of these waste additives on the mechanical performance of the cement-based composites. Additionally, the effect of the chemical composition of the introduced waste materials on crack initiation and propagation, as well as on the behavior of mortars under aggressive environmental conditions (chloride and sulfate exposure), was investigated. The study also includes scanning electron microscopy (SEM) analysis of fracture surfaces, identifying crack initiation sites and propagation paths, as well as elemental mapping of the fracture zone using energy-dispersive spectroscopy (EDS).

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On the Development of an Advanced Fatigue Testing Machine for 3-Point Bending of Polymer Matrix Composites

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Introduction

This work reports on the conversion of a crank press into a smart fatigue testing machine, for 3-point bending of polymer matrix composite specimens, monitoring the load and loading cycles and automatically detecting visual signs of damage (delamination / layer detachment).

Smart testing machine design and implementation

An eccentric press with an maximum stroke of 150 mm was converted into a smart fatigue testing machine (Fig.1(a)). The stroke frequency is adjusted by an inverter. The stroke counter uses a Hall sensor and a 1st order filter to circumvent noise. A special jig base supports the specimens undergoing three-point bending (Fig.1(b-c)). It is mounted on the table via four 500 N load cells feeding an HX711 ADC converter. A DFK MKU130-10x22 camera was placed below the circular opening of the base to record photographs of the lower part of the specimen (Fig.1(d)) at suitable process interruptions commanded through a relay by an Arduino microcontroller, especially after a drop in the initial load is recorded, indicating the onset of failure. The image undergoes background clipping in real-time and is fed to a trained neural network to check for damage, (Fig.1(e)). The process is controlled by a custom made GUI on PC where also the neural network runs. All coding was done in Python.

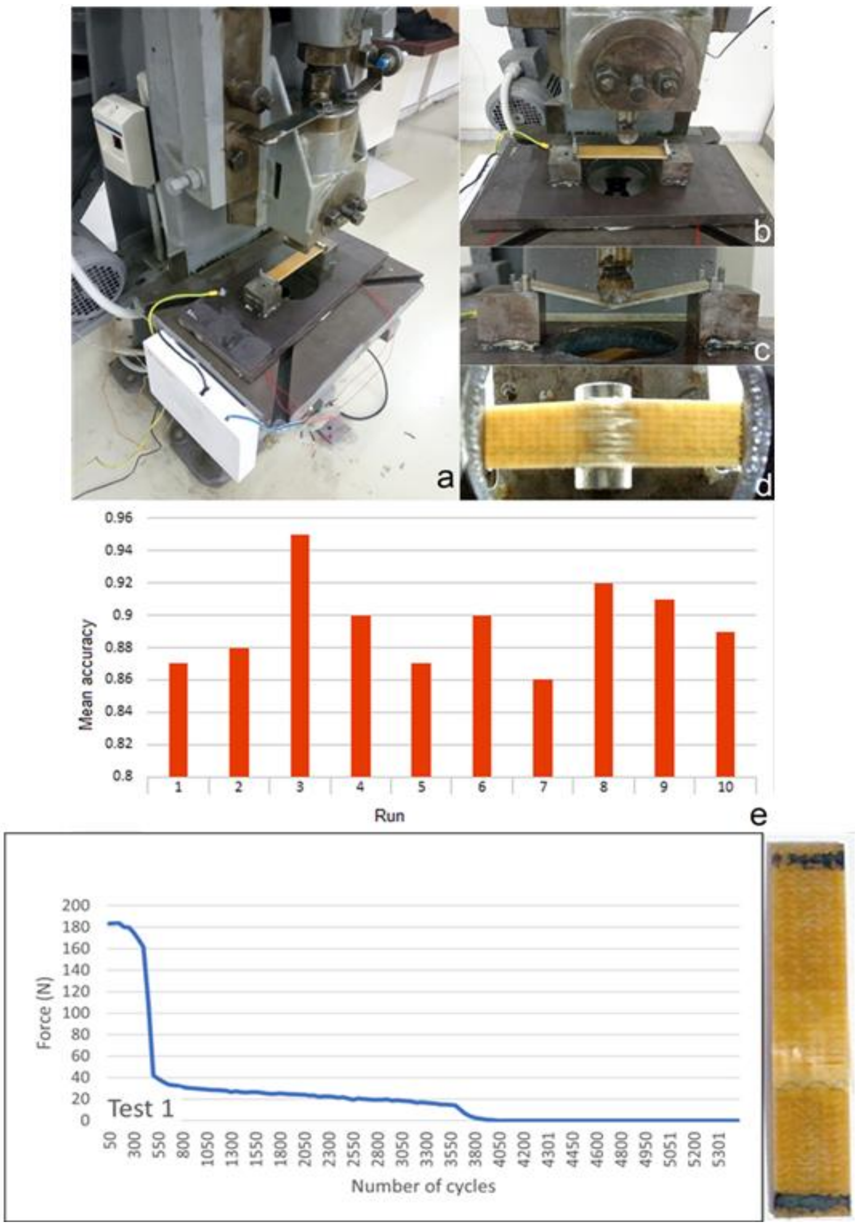
For the detection of damage, typically manifested as different coloured region in the specimen's bottom surface, pre-trained ResNet-50 network was used In a tensorflowTM environment, with a learning rate of 0.0001 and early stopping to improve the results, a ReLU activation function, a dropout rate of 30% and a sigmoid activation function at the output since binary classification is sought. Initially, black and white photographs (at reduced resolution of 200 X 200 pixels) of 65 healthy and 65 damaged specimens were gathered. From each subset, 5 photographs were used for testing while the rest for training. Augmentation to 540 photographs in each subset was achieved by varying brightness and contrast of the original ones. By randomly changing selection of the testing and training photographs ten different data sets were obtained, accuracy being promising but needing improvement (Fig.1(e).

Preliminary results

An indicative fatigue test is presented for a 130 X 23 X 3 mm specimen consisting of 4-layers of FibermaxTM G320X E-glass 45 -45 90 biaxial weave fabric. The specimen was made by hand layup and is certain to have internal flaws expected to lead to its failure. It was tested at 32 mm maximum displacement. The initial load of 180 N is dramatically reduced at 550 cycles to 40 N, slowly dropping to 18 N in the course of another 3000 cycles approximately, then being zeroed, see Fig. 2.

Conclusion

The machine is operator friendly and adequately controlled using low-cost equipment. It can use video instead of photos to avoid testing process interruptions. Moreover, the neural network's accuracy for failure detection will benefit from increased resolution of photos and can also be extended to classify the extent of specimen damage.



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Hydrogen-Induced Plasticity in Titanium: In Situ Electron Microscopy and Nanoindentation Testing

Ms. Xiaohan Dai[1,2], Dr. María Jazmin Duarte Correa[1], Prof. Degang Xie[2], Prof. Gerhard Dehm[1]
[1]Max Planck Institute For Sustainable Materials, Düsseldorf, Germany, [2]Xi'an Jiaotong University, Xi'an, China

Introduction

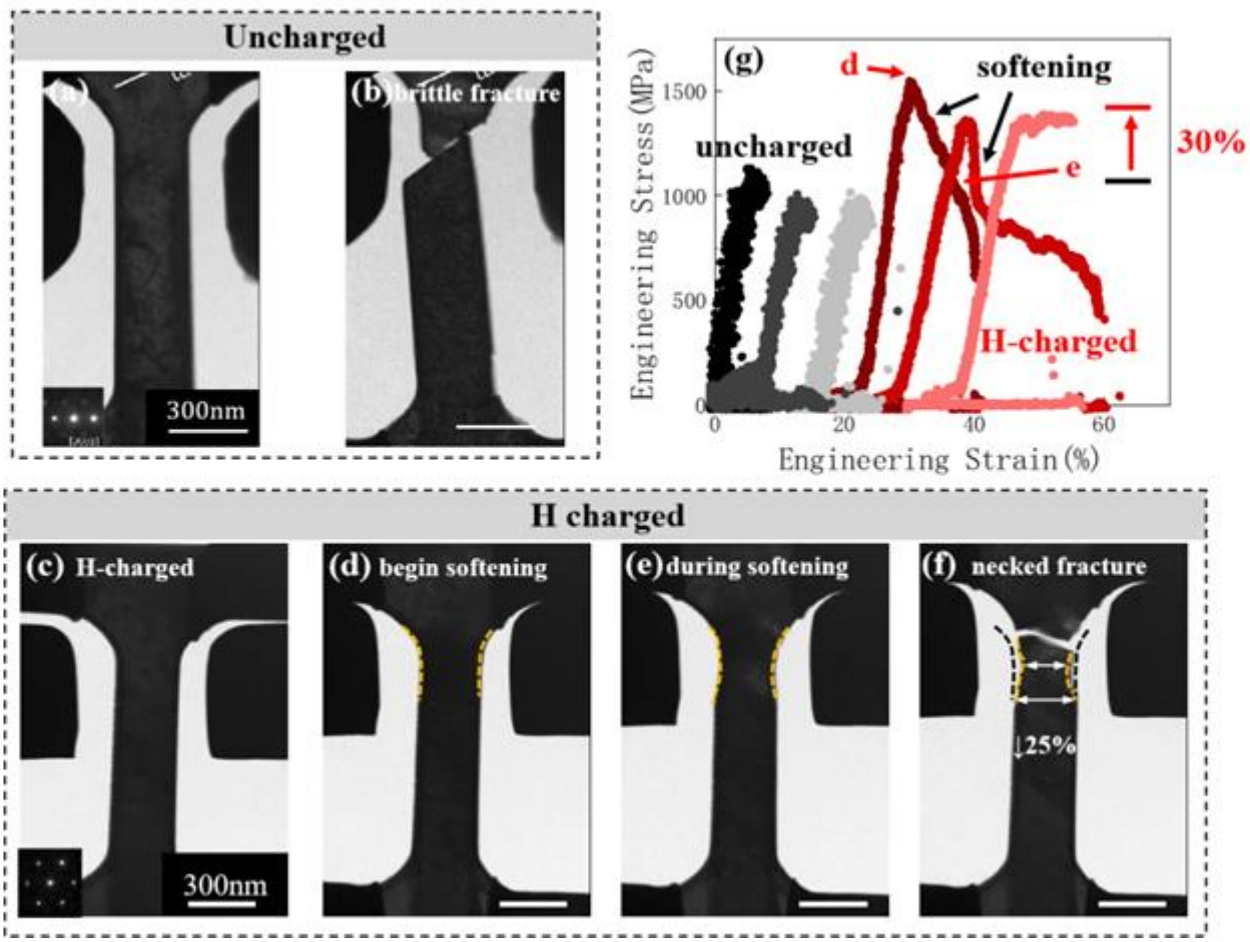
Titanium alloys are valued for their low density, high strength, and corrosion resistance, but poor room-temperature formability limits their applications. Hydrogen enhances plasticity during high-temperature processing, but its room-temperature effects remain controversial. Both hydrogen embrittlement and hydrogen-enhanced plasticity are reported, yet research focuses on embrittlement due to its detrimental impact. The mechanisms behind hydrogen's dual role are poorly understood, hindered by the lack of real-time microstructural observations. This knowledge gap impedes a comprehensive understanding. Here, we use advanced in situ techniques to address this limitation and reveal new insights into hydrogen's role in titanium alloy deformation.

Methods and Results

This study employed in situ Environmental Transmission Electron Microscopy (ETEM) and backside hydrogen-charging nanoindentation to investigate hydrogen's effect on the mechanical behavior of titanium. In ETEM, nano-sized single-crystal titanium samples were charged with hydrogen at 2 Pa for 30 minutes, resulting in localized surface softening due to limited hydrogen diffusion.
Moreover, high-temperature and high-pressure gas-phase hydrogen charging achieved 0.12 wt.% hydrogen with uniform distribution, leading to a 22.7% increase in strength, enhanced plasticity, and a transition from brittle to ductile fracture with 25% necking. Smooth stress–strain curves indicated uniform plastic deformation. All tested regions were free of hydrides, confirming that the effects arose solely from soluble hydrogen.

Conclusion

In conclusion, hydrogen improves both strength and plasticity of single-crystal titanium at room temperature, challenging traditional hydrogen embrittlement theory. These findings provide new insights for optimizing titanium materials in structural applications.


Uncharged
(a)
(b) brittle fracture
300nm
(g)
d
softening
uncharged
e
30%
H-charged
Engineering Stress (MPa)
1500
1000
500
0
20
40
60
Engineering Strain (%)
H charged
(c) H-charged
(d) begin softening
(e) during softening
(f) necked fracture
↓25%
300nm

E08

New Steel Stress Coupons Based on Induction Heating and Consequent Quenching

[1]Eleni Aivazoglou[1] , Spyros Angelopoulos[1], Evangelos Hristoforou[1], **Gregorios Doumenis**[1]
[1]National TU of Athens

During the last two decades, our group has developed a methodology to provide the dependence of magnetic properties on residual stresses from a single steel coupon, i.e. from a steel parallelepiped, cut in two pieces and welded autogenously. Provided that the two steel parts are maintained in a non-changing position, the cooling-down process in the heat affected zones and the fusion zone after welding, results in a stress profile from minus yield point up to plus yield point of the steel under test. Although we succeeded to determine the so called Magnetic Stress Calibration (MASC) curves with this method, it has been proven difficult to make this technology repeatable and transferable. This issue has been resolved by using a new methodology, according to which the steel coupon is locally heated by induction heating process. A straight, water cooled, 6mm diameter copper tube is set on top of the steel coupon, transmitting 30 A current at a frequency of 30 kHz. This way, the eddy currents at the vicinity of the copper tube offer a temperature that decreases from the middle heating point towards the two ends of the coupon, due to the relatively low thermal conductivity of (magnetic) steels. Monitoring the maximum temperature Tmax of the steel coupon by an IR camera, after Tmax reaches one third of its melting point, the steel coupon is inserted in room temperature water or oil, dependent on the steel grade, maintaining its geometrical shape by two ceramic plates forcing it to do so. Thus, the temperature gradient is transformed to stress gradient, allowing for repeatable generation of residual stresses in this heat affected zone of the steel coupon.

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Cavitation Effects on Fullerene Enhanced Lubricants on Piston Ring Tribology

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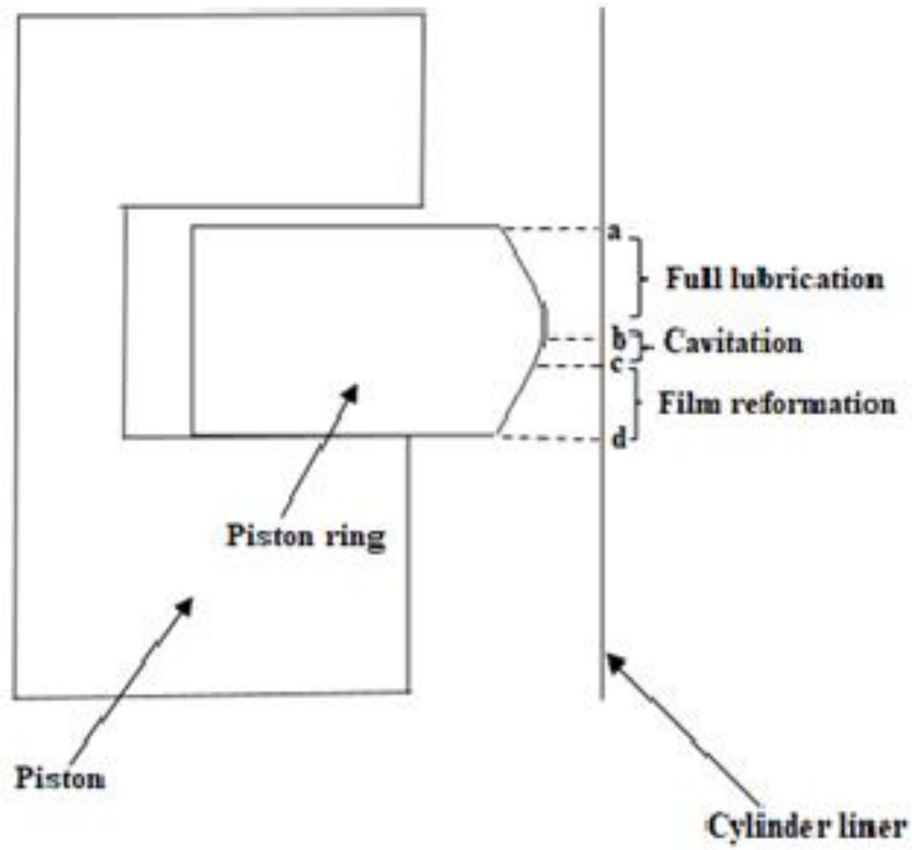
Cavitation in engines lubrication is a critical phenomenon affecting either the performance or longevity of internal combustion engines. This study investigates the influence of fullerene additives on the lubricant's cavitation behaviour under varying engine operating conditions. The analysis considers three different rotating speeds regimes such as, 1500 rpm at 50% throttle, 1500 rpm at 100% throttle, and 2000 rpm at 100% throttle. A comprehensive numerical model is developed, integrating heat transfer phenomena between the piston ring and the cylinder, along with the Greenwood-Tripp's model toconsider the surface interactions. The research aims to compare the effects of fullerene-enhanced against conventional lubricants, focusing on cavitation effect, thermal distribution, and overall tribological performance. A significant aspect of this study involves evaluating the temperature distribution across the lubricated area, thereby highlighting the role of fullerene additives in heat dissipation and, consequently, in reducing cavitation wear.The Greenwood-Tripp model is employed to assess asperity contact and its influence on lubricant film stability under different operating conditions. Furthermore, the developed numerical model incorporates coupled thermal and tribological interactions to predict the behaviour of the lubricating film under varying engine loads. By simulating the heat transfer phenomena between the piston ring and cylinder, the model is adequate to provide a deep understanding of temperature gradients and their effects on cavitation formation. Additionally, the model integrates surface roughness parameters, allowing an in-depth analysis of asperity deformations and their contributions to lubricant film stability. Comparative analysis of simulation results indicates that fullerene-enhanced lubricants exhibit superior thermal management properties, leading to a reduction in localized overheating and cavitation-induced damage. The model predicts that under high-load conditions, with the lubricant to maintains a more uniform thermal profile and to reduces asperity interactions. Thereby, film integrity is improved and then the wear resistance is increased. These findings suggest that fullerene additives could play a crucial role in optimizing lubricant formations, for high-performance engine applications. This studyalso, provides a comprehensive framework for evaluating cavitation behaviour in lubricated contacts, by integrating thermal, tribological and fluid dynamic considerations.
The insights that gained from this work pave the way for further experimental validation and the refinement of predictive models.

Keywords: cavitation, fullerene, piston ring, lubricant.


a
b
c
d
Full lubrication
Cavitation
Film reformation
Piston ring
Piston
Cylinder liner

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3D Modelling, Analysis and Construction of an Exhaust System in a Formula Student Car

Dr. Antonios Lontos[1], Dr. Andreas Gregoriou[1]
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This paper presents a newly designed stainless-steel exhaust system for Frederick University's Formula Student car. The design process and step-by-step details of the exhaust header, secondary exhaust pipe, and muffler manufacturing are thoroughly outlined. Special attention was given to fitment, considering the engine's placement within a steel tube chassis. The exhaust system emphasizes equal-length runners and primary exhaust pipes, which optimize engine performance.

The performance and fuel consumption of spark-ignition engines are closely linked to exhaust system design, particularly exhaust flow and back pressure, both of which significantly affect gas exit efficiency. Back pressure, the difference between atmospheric and exhaust pressure, plays a crucial role in the movement of combustion gases. Research indicates that higher back pressure leads to increased fuel consumption. Efficient engine operation depends on maximizing cylinder filling with the air-fuel mixture, which directly impacts power output and torque. Exhaust design also influences mixture homogeneity, affecting both performance and emissions. This study aims to minimize back pressure within the manifold, as lower back pressure improves efficiency.

The exhaust gas velocity magnitude at different engine speeds reveals variations in flow characteristics, particularly in the joint region of the exhaust ducts before the outlet, where a velocity drop is noticeable at lower rpms. A potential concern is choked flow in the ducts, which could increase back pressure and hinder performance. However, the design successfully prevents a sharp pressure rise, reducing the negative effects of back pressure. Vortex formation occurs due to gas impact in the narrowing cross-section, influencing flow behavior. A Venturi effect is also observed near the exhaust manifold outlet, which could impact back pressure and volumetric efficiency at high rpms. Naturally aspirated engines typically suffer from reduced volumetric efficiency at high speeds.

After verifying the simulation results, the manifold was built and installed. The vehicle demonstrated excellent acceleration and smooth power output. The construction utilized 35mm stainless steel tubes, shaped using cold-working operations.

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Machine-Learning-Assisted Sustainable Design Approach on the Case of a Multi-Material Automotive Component

Prof. Angelos Filippatos[1], Mr. Christos Giotopoulos[1], Dr. Harry Psihoyos[1], Dr. Anastasios Zavos[1], Mr. Athanasios Kyriazis[1]

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Sustainability-driven design of critical mechanical components requires a challenging trade-off between multiple, contradicting and inter-disciplinary requirements, originating from the ongoing industrial and societal sustainability goals [1]. Further complexity to the design phase is introduced through the vast material portfolio, metallic, composite and multi-material combinations. Even if a designer provides a mechanically stable concept, he must further comply with environmental regulations, while ensuring market competitiveness and manufacturing feasibility. However, achieving these goals with standard design procedures is quite challenging, as each design variant must meet multiple, conflicting criteria.
To address this challenge, we apply machine learning (ML) algorithms as design-assistance tools to the design process, to identify design solutions. Based on a numerical dataset of design configurations, ML-models are trained to guide the designer to identify interesting design configurations, which meet functional requirements and sustainability criteria. Specifically, we investigate our approach on the example of an A-pillar from the automotive industry. The A-pillar is a critical structural automotive component that requires high load-bearing capacity to withstand extreme loads, such as rollover collisions, while maintaining minimal weight to improve vehicle's fuel efficiency [2].

We study a reference hybrid pillar made of metallic and composite sheets infused with thermoplastic cellular ribs [3]. Nonlinear Finite Element (FE) analyses are conducted for various designs, geometric configurations and materials. The results are post-processed to a numerical dataset used to assess functional and sustainability requirements, i.e. mechanical performance, environmental impact, and cost metrics. ML-regression models are trained to predict optimal design configurations according to the sustainability criteria [4].

Besides ML-typical scoring indexes, we add a validation step by back-feeding a FE model with the identified parameters to assess the deviation between ML-predicted and FE-simulated designs. First results show promising, as our approach could provide valuable decision-making support, allowing engineers to efficiently and accurately identify optimal configurations.

Keywords: Automotive engineering, A-pillar, Machine Learning, Sustainable Design.

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Simulation and Analysis of the Chill-down Process for the Design of a Handling and Distribution Cryogenic Subsystem

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The increasing global demand for cryogenic applications in fields such as aerospace, energy, and maritime has driven significant advancements in the study and simulation of cryogenic processes. These processes involve the handling, transport, and storage of cryogenic fluids, which require precise thermal and flow control to ensure efficiency and safety. This paper presents a comprehensive simulation model developed in MATLAB Simulink, capable of representing a cryogenic handling and distribution subsystem—from the initial intake of liquid and gaseous cryogens in a laboratory setup, through their transfer via insulated pipelines, and ultimately to their intake into an experimental test rig.

The proposed procedure follows a three-step cooling strategy designed to achieve controlled temperature transitions while minimizing thermal stresses and pressure fluctuations. The process begins with the purging of the subsystem using gaseous nitrogen (GN_2) to remove contaminants and prevent ice formation. Liquid nitrogen (LN_2) is then introduced to further lower the temperature to its boiling point (77K), followed by liquid helium (LHe) to reach the final target of 20K. Throughout each cooling stage, the model calculates cryogen consumption, process duration, and periodic thermal measurements to ensure safe and efficient operation.

By providing insights into the dynamic behavior of cryogenic flow, heat transfer, and boil-off rates, this study enables more effective resource allocation and process optimization. The results contribute to improved planning and management of cryogen usage, reducing waste while enhancing operational efficiency. Finally, the modular design of the Simscape model allows for seamless adaptation across a wide range of cryogenic applications, accommodating varying target temperatures, pressures, and system requirements. This flexibility makes it a powerful tool for optimizing cryogenic processes, facilitating future advancements, and enhancing the efficiency of diverse cryogenic systems.

Keywords: Chill-down process, Simscape modelling, Evaluation of handling and distribution subsystems, Modular pipeline design, Boil-off minimization, Cryogenic design.

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Towards the Design of a Cryostat for Large Scale Testing

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The increasing demand across the maritime sector to achieve net-zero emissions by 2050, in line with EU regulations, has paved the way for alternative fuels such as liquid hydrogen (LH_2). To facilitate this transition, specialized insulation equipment must be developed and tested to store LH_2 successfully under cryogenic conditions. Up to now, a variety of cryostats have been developed, focusing mainly on testing small-scale specimens, typically up to a few centimeters. However, membrane-type tanks consist of numerous insulation blocks made of multiple materials, with a total thickness of up to one meter. To date, these components have been tested separately due to the challenges associated with testing such large components as a whole.

To address this challenge, this paper presents a design approach of a cryostat intended for large-scale testing. Beginning with defining specific technical requirements and applications. The design process is then outlined, starting with an analysis of the design problem, which includes determining the design requirements, technical specifications, and constraints. The conceptual design phase follows, where the functions of the cryostat are identified, alternative designs are formulated and synthesized, and a screening and scoring process is applied. This is followed by the configuration design phase, which focuses on component structuring and the analysis of design configurations. The design development phase covers various aspects, including assembly and manufacturing considerations. Finally, a representative model for the optimal solution is presented, highlighting the most critical information that needs to be addressed, along with a comprehensive economic analysis of the potential cost of the cryostat.

This paper contributes to advancements in the cryogenic sector by offering a systematic approach for designing large-scale cryostats. This approach could serve as a representative design methodology for a variety of applications, including maritime and aviation.

Keywords: Cryostat Design, Product Development, Engineering Design, Large-Scale Testing, Cryogenic Conditions, Liquid Hydrogen.

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Promoting Sustainability in Aviation Engineering Through an Interactive Educational Platform

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Sustainability in aviation is increasingly becoming a focal point as the industry strives to reduce its environmental impact and implement eco-efficient technologies. Addressing the growing demand for sustainability, it is crucial to inspire and equip the next generation of engineers with the necessary skills to develop innovative, sustainable aviation solutions. The 3DSustainAvio project, funded by La Fondation Dassault Systèmes, responds to this need by developing an interactive digital platform aimed at raising awareness about sustainability in aviation. This initiative is a collaborative effort between the Mechanical Engineering Department (MEAD) and the Computer Engineering Department (CEID) at the University of Patras. The primary goal of the project is to engage high school and first-year bachelor students in STEM fields, particularly in aviation engineering, while emphasizing the importance of sustainability in the industry. By providing an interactive, immersive learning experience, the platform encourages students to explore sustainability-focused aviation engineering and to consider it as a viable career path. Additionally, the project is designed to promote diversity in the sector by reaching out to underrepresented groups and motivating them to pursue engineering careers in aviation, thereby fostering a more inclusive workforce in the industry.
The project's methodology leverages cutting-edge technology, including Unity for developing the 3D environment, enabling rich interactivity and dynamic visualizations. To enhance the experience further, MetaQuest VR is integrated into the platform, allowing students to engage with virtual aircraft models and evaluate their sustainability. The platform is designed around a holistic sustainability framework that encompasses environmental, technical, economic, and social dimensions. This approach ensures that students gain a comprehensive understanding of the various challenges and considerations involved in sustainable aviation design, including the impact of their decisions on the broader community and the environment.
The platform also offers students the opportunity to explore alternative aircraft models, each representing different sustainability solutions. By interacting with these models, students can assess factors such as fuel efficiency, emissions, recyclability, and other critical sustainability indicators. The holistic approach encourages students to consider the interconnected nature of aviation technologies and sustainability, offering them a deeper understanding of the broader implications of their engineering decisions.
The pilot phase of the 3DSustainAvio project has been successfully completed, with highly positive feedback from both high school and university students. Participants praised the immersive and interactive nature of the platform, as it helped them better understand the complex sustainability challenges facing the aviation

industry. The hands-on experience also allowed students to explore the real-world implications of sustainability practices in aviation.

Looking ahead, the project will continue to refine the platform based on user feedback and extend its reach to additional regions of Greece and Cyprus. By leveraging the extensive educational and scientific networks of the University of Patras, the project aims to inspire students to explore and engage with sustainable aviation practices.

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Thermomechanical and Sustainability Assessment of LNG and LH2 Membrane Tank Designs

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As the maritime sector moves toward cleaner energy sources, identification of effective insulation for Liquefied Natural Gas (LNG) and Liquid Hydrogen (LH2) carriers takes on greater importance. These systems must handle structural loads, manage heat transfer at cryogenic temperatures, while also meeting sustainability benchmarks. The purpose of this abstract through advancing to a previously established conceptual framework for sustainability assessment of multi-material membrane tanks, is to provide a detailed trade-off between different membrane tank designs integrating advanced thermomechanical simulations.

Central focus of this work is the thermomechanical simulation of different panel designs where mechanical loads and cryogenic temperature gradients affect both structural integrity and thermal performance. These different designs are produced based in the available literature and design solutions identified through previous sustainability assessment. By detailed simulations, the results of changes in layer thickness, material choices, or overall configuration can alter stress distribution, deformation, and boil-off rates. Our findings show not only how trade-off studies are essential but also that detailed thermomechanical performance have to be taken into account when examining the feasibility of design solutions.

By merging thermomechanical modelling with sustainability metrics, it becomes possible to engineer cryogenic insulation solutions that meet strict structural and thermal demands while remaining economically and environmentally viable. This integrated methodology is especially useful to the maritime sector, where there is increasing pressure to cut emissions and improve fuel storage efficiency. Our findings highlight a direct route to more robust, resource-efficient LNG and LH2 storage systems, showing how early-stage consideration of sustainability and thermomechanical response can shape innovative and responsible design strategies.

Keywords: Trade-off, Thermomechanical simulation, Liquid Hydrogen, Sustainability, Membrane Tank, Multi-Material Design.

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Towards a Decisions Support System for the Selection of SAFs in the Maritime Sector: Metrics and Application to NH3 Fuel System

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The decarbonization of the maritime industry is a central priority for the International Maritime Organization (IMO). The IMO's efforts to align with the Sustainable Development Goals (SDGs) are reflected in the implementation of various regulations and design metrics, such as the Energy Efficiency Design Index (EEDI) and Carbon Intensity Indicator (CII), which encourage the adoption of alternative technologies to reduce carbon emissions.

As part of this broader framework, the current work focuses on developing a decision support system to assess the sustainability of alternative marine fuels, such as ammonia (NH3) to facilitate the decision-making process for their integration into the maritime sector. The proposed Holistic Sustainability Assessment (HSA) framework consists of five key pillars: Performance, Cost, Environmental Impact, Social Impact, and Circularity. These pillars often present conflicting objectives. To address this, the framework employs the Analytical Hierarchy Process (AHP) methodology to identify stakeholder priorities, such as those of the design engineer, ship-owner, and public opinion, while incorporating multiple Multi-Criteria Decision-Making (MCDM) methods to calculate a Sustainability Index for the specific use case.
The present work focuses on identifying the HAS metrics for each pillar and quantifying them using real-life data from alternative fuel systems. After defining the relevant metrics for each pillar, a 31,000 deadweight tonnage (DWT) Heavy Lift Vessel using NH_3 as its primary fuel source was used to demonstrate the applicability of the proposed framework, comparing it with a conventional vessel using a traditional fuel source.

In conclusion, this study aims to provide a comprehensive and data-driven approach to evaluating the sustainability of alternative marine fuels, with a particular focus on NH3 and also offer a decision-support tool for stakeholders in the maritime industry. The findings will provide valuable insights into the feasibility and

impact of transitioning to ammonia as a marine fuel and could be expanded to include other alternative fuels or different types of systems.

Keywords: Maritime Industry, Alternative Fuel Technologies, Holistic Sustainability Assessment, NH3 Bunkering System, Framework Proposal

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3D-Printed Ceramic Solutions for Passive Cooling and CO_2 Absorption: Investigating Material and Fabrication Parameters in LDM for New Eco-Sustainable Design Paradigms

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This study investigates the materials and fabrication selection criteria for 3D-printed aluminosilicate components aimed for passive cooling and CO_2 absorption in indoor conditions, considering their environmental impact across their production stage. The dual-function components are fabricated using Liquid Deposition Modelling (LDM), an Additive Manufacturing (AM) technology based on customised slurry-based feedstock materials. To assess the environmental implications of the production process, the study employs the Life Cycle Assessment (LCA) methodology, a standardised framework used to quantify potential environmental impacts across the product's life cycle.
The study outlines a systematic approach to materials and fabrication processes selection, focusing on the functional properties required, the importance of locally sourced materials, and the constraints imposed by the fabrication techniques. The fabrication methodology was analysed for material/energy efficiency and waste generation. Post-processing stages were evaluated to identify opportunities for energy savings, particularly by exploring Low-Temperature Firing (LTF).
The selected criteria proved efficient in enhancing shaping control and minimising shrinkage variability, with a recorded weight loss of 3.04% via LTF. Additionally, the LCA findings confirmed energy and emissions savings, which reduced the overall energy resource demands of the production process, as well as the climate change impact by 30%.
This study reinforces the importance of integrating environmental considerations into the design of 3D-printed building elements, by prioritising locally sourced materials and adopting energy-efficient fabrication techniques. The incorporation of LCA insights ensures that these components are designed with a clear understanding of their environmental footprint, paving the way for more informed and sustainable manufacturing practices.

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Leveraging AI for Structural Health Monitoring: Ultrasonic Guided Waves in Predicting Delamination Damage in Aircraft Composites

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The incorporation of composite materials in the aviation industry has significantly improved strength-to-weight ratios, enhancing overall aircraft performance. However, these materials are prone to barely visible damage, such as delamination. Structural Health Monitoring (SHM) is essential for ensuring safety, reliability, and longevity. SHM systems use sensors such as fiber optics, piezoelectric transducers, and acoustic emission detectors to continuously monitor structural integrity in real-time. This approach helps detect failures, reducing maintenance costs and improving operational efficiency. The integration of SHM in modern aviation not only enhances structural resilience but also supports the transition towards more efficient and sustainable aircraft maintenance paradigms.
This study explores an advanced AI-driven approach to predicting structural damage in aircraft laminates. The method focuses on identifying and localizing delamination damage growth in composite structures, thereby improving the assessment of aircraft health and operational usage. By utilizing ultrasonic guided wave (UGW) inspection simulations combined with experimental measurements using piezoelectric transducers, extensive datasets are efficiently generated and analyzed.
Building on this foundation, the study integrates numeric-experimental validation and noise modeling techniques to enhance the reliability of structural health monitoring. In addition to UGW inspection simulations, a dedicated experimental campaign of composite plates delamination with attached piezoelectric transducers has been developed. By comparing simulated and experimental signals, discrepancies introduced by real-world noise factors, such as material inhomogeneity, sensor placement or thickness irregularities, are examined. To address these variations, deep learning techniques are employed to model and mitigate noise, refining the predictive accuracy of the deep neural network (DNN). Incorporating deep learning methods to encapsulate noise from experimental data and introducing it into simulations enables the creation of more realistic and robust machine learning models. This approach bridges the gap between simulations and real-world applications in aerospace structural health monitoring.

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An Update on the Direct Quenching and Partitioning Route for the Realization of Tough, Ultrahigh Strength Steels

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Direct quenching and partitioning (DQ&P) route has come a long way, since the first experiments were successfully conducted using 0.2C (high) Si and/or Al steels. The specific objective was to develop a steel with yield strength ≥ 1100 MPa, combined with good tensile ductility and adequate low temperature toughness. Right from establishing appropriate composition and process designs through comprehensive physical simulation, emphasis was principally placed on ensuring a cost-effective processing route amenable for subsequent industrial hot strip production. Whilst the martensitic matrix has the potential to provide the required strength, a small fraction of retained austenite finely divided between the martensitic laths imparts improved work hardening characteristics and uniform elongation without loss of impact toughness. Ausforming in no-recrystallization regime resulted in extensive refining and randomization of the martensite packets/laths besides fine division of interlath austenite, thus resulting in an all-round improvement of mechanical properties, including low temperature toughness and uniform elongation. Fractographic studies of tensile-tested DQ&P specimens revealed quasi-cleavage mode of fracture with the intermittent presence of shallow dimples corroborating the TRIP-induced improved tensile elongation. On the other hand, the constrained nature of austenite-to-martensite transformation required higher energy to drive the crack forward resulting in appreciable improvement in fracture toughness. Significant progress has since been made to extend the processing route to medium carbon steels but required significant changes in processing route to realize desirable microstructures and properties. The key research strategy encompasses studying structural refinement approaches, phase transformation characteristics, accompanying microstructural and fracture mechanisms using advanced metallography as well as analytical techniques.

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Smart System Design and Process Control Enabled Green Manufacturing of PM Parts Through Binder-Free FAST Sintering

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The growing demands for functional ceramic and metallic materials and their composites in energy harvesting applications necessitates the development of sustainable and efficient manufacturing processes. An innovative approach is adopted for powder metallurgy (PM) manufacturing through the integration of smart system design and artificial intelligence-driven process control in a binder-free Field Assisted Sintering Technology (FAST) system. The patented system design, developed at the University of Strathclyde, demonstrates significant advantages in energy efficiency, material utilisation, and process optimisation, compared to conventional sintering methods and systems.

The smart system design incorporates advanced tooling and localised heating strategies, enabling precise temperature control and optimal energy distribution during the sintering process. The powder preparation and processing are conducted in a controlled inert atmosphere, significantly reducing contamination and oxidation risks while ensuring superior product quality. This protective environment, combined with precise process control, minimises the waste of valuable raw materials and enables the production of high-performance thermoelectric and piezoelectric components for energy harvesting applications. The innovative approach not only minimises energy consumption but also significantly reduces processing time.

The system features comprehensive real-time process monitoring capabilities that provide immediate feedback and detailed data logging of processing conditions. This monitoring system ensures accurate digital documentation of each sintering cycle, creating valuable datasets that can be utilised for artificial intelligence analysis and process optimisation. By combining these detailed process records with AI-driven analysis, the system enables informed parameter selection for new materials, reducing the number of experimental trials required. This data-driven approach not only enhances process efficiency but also provides valuable insights for the development of improved powder compositions, advancing the field of functional materials research.

This smart manufacturing approach represents a significant step towards sustainable powder metallurgy processing, demonstrating how the integration of intelligent system design, process control, and artificial intelligence, can create a more efficient and environmentally conscious manufacturing pathway for processing energy harvesting materials, directly contributing to green technology development.

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A Neuro-Symbolic AI Approach for the Modeling and Optimization of Sustainable Production Systems

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In this paper an AI approach using Neuro-Symbolic methods is presented, which can support the modeling of production systems, considering and combining factors for sustainability and green production. The design, modeling and optimization of production systems at factory, job-shop and machine-center levels are mainly achieved by using methods from Production Management, Operations Research (OR), Statistics (e.g. for Processes Control and Quality Control - SPC), Manufacturing Processes theory (e.g. for machining, forming, etc.), Control theory, Energy usage optimization, etc. These methods aim towards a more efficient production, improved products' quality, shorter delivery times and cost reduction. Additionally, many enterprises have to consider sustainability rules and restrictions, and often need to apply human experts' knowledge for the design of greener production and products.

The application of the above methods in a combined manner, utilizing also the use of large production and products' data sets, including Life Cycle Assessment (LCA) data, require the support of new data-driven and symbolic AI methods for data processing, models' creation and human experts' knowledge representation and processing, including processing for reasoning. Especially the data-driven AI approach, using Artificial Neural Networks (ANNs) methods, is useful for the creation of models, when well-defined mathematical or physics-based models are not available or are not adequate enough. The ANNs can be trained using historical and/or experimental data from processes or systems and can create models representing the process or the system under consideration. Furthermore, the use of Symbolic AI methods, and more specifically the use of Knowledge Engineering (KE) methods, can further support productions' system design, by utilizing, combining and processing human experts' knowledge with AI data-driven modeling methods.

Lastly, since sustainability in production systems requires the use of Total Quality Control techniques, Knowledge Engineering methods can be critical to the minimization of production errors, the reduction of trial and error scheme so that societal goals in addition to jobs and growth could be better achieved.

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Elastic-Plastic Constitutive Modeling Based on Equilibrium-Informed Neural Network With Full-Field Data

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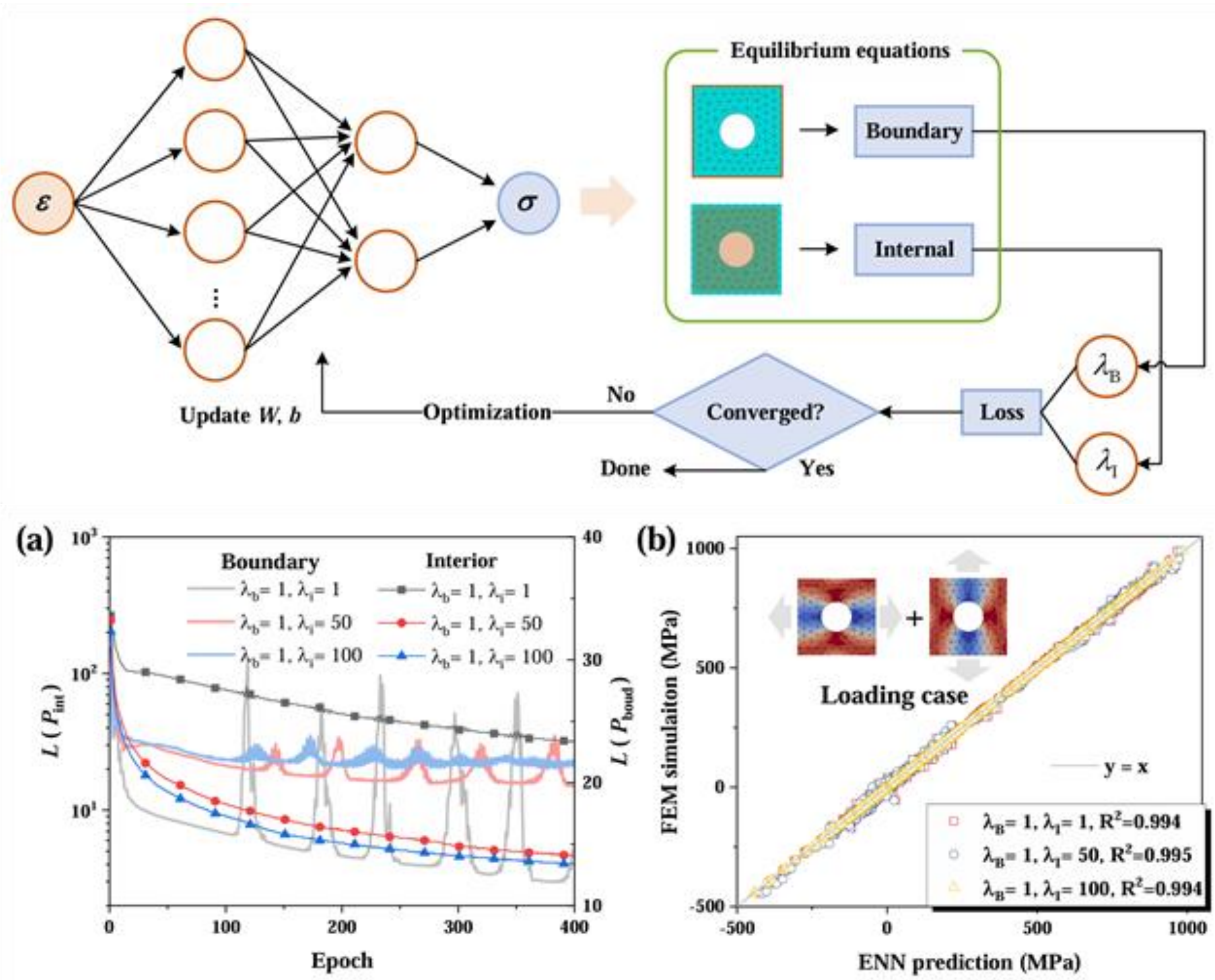
Artificial intelligence (AI), as a potential alternative to conventional phenomenological constitutive models, is expected to gradually become a transformative approach to constitutive modeling. Numerous AI-based material modeling methods have already emerged at the numerical experiment level. However, numerical models are still constrained by the original elastoplastic mechanical frameworks and assumptions, and largely serve to accelerate computation. The present work focuses on constructing a data-driven elastoplastic constitutive model from the perspective of material testing. It employs an intelligent constitutive modeling method based on full-field strain and the equilibrium of external forces, using limited structural-level material mechanical tests to establish neural network-based constitutive models. A pretraining-based method is proposed to provide an initial solution for elastoplastic constitutive behavior, and then the target material behaviors are learned based on equilibrium-informed neural network (ENN). The applicability of the method for materials with different hardening behaviors is validated, and the stability under measurement noise interference is also assessed. Furthermore, from an experimental perspective, the present work explores the impact of structural geometry, mesh configuration, and loading conditions on the construction of data-driven elastoplastic constitutive models, providing corresponding suggestions and guidance. The construction of data-driven material constitutive is expected to enhance the understanding of material constitutive behavior, with both broad applicability and practical value.


ε
σ
Equilibrium equations
Boundary
Internal
λB
λI
Loss
Converged?
No
Yes
Optimization
Update W, b
Done
(a)
Boundary
Interior
λb= 1, λi= 1
λb= 1, λi= 50
λb= 1, λi= 100
L (Pint)
L (Pboud)
Epoch
(b)
Loading case
y = x
λB= 1, λI= 1, R²=0.994
λB= 1, λI= 50, R²=0.995
λB= 1, λI= 100, R²=0.994
FEM simulaiton (MPa)
ENN prediction (MPa)

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Safety Through the Prism of Industry 4.0: Augmentation of Past Approaches

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Risk assessment comprises the hazard identification, assessment of related risks and evaluation of current and recommended control systems, to ensure people's safety in the workplace and minimise any harmful effects on human health. There are several process hazard analysis (PHA) methods depending on process development status (i.e., conceptual stage, under development, operational unit or system), the criteria and scope of the assessment (e.g., human safety-oriented assessment, analysis of process failures, etc.), as well as the scoring systems and the different parameters and factors, such as likelihood of failure, detectability, effectiveness or controls or any other risk control measure [1].

Process hazard analysis techniques such as failure mode and effect analysis (FMEA) summarise the identified failure modes, the likelihood of events, consequences resulting in physical and human health hazards and exposure to airborne pollutants, and controls providing a risk priority number (RPN) to prioritise mitigating action. At the same time, new systems and technologies of Industry 4.0 are gaining increasing attention as risk and safety management tools [2]. The use of artificial intelligence (AI) and machine learning (ML) tools, and cloud computing offer real-time monitoring and analysis of preventing actions, as they are able to exploit non-linear correlations between the targeted stressors and other environmental or process parameters. Industry 4.0 offers a novel approach by conjugating the use of AI/ML analytics for risk assessment of innovative processes and the production of advanced materials. Especially within the framework of advanced materials, such as high-entropy alloys (HEA) which are gaining increasing attention due to their significant mechanical, thermal, and physical properties, the manufacturing protocols are not standardised or established or are currently on a low TRL level.

Therefore, the study explores the steps for the development of augmented PHA methodologies where the previous risk assessments of various processes can be used as training instances for the AI/ML models. The resulting algorithms can subsequently support the selection of additional controls and designing the manufacturing process at early or conceptual stages taking into account the safety dimensions mitigating the associated risks. This methodology can benefit both the safety practitioners and the manufacturers, providing a cost-effective and in-depth analysis of potential risks and use of appropriate hazard controls ensuring a safe-by-design approach.

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From Deep Learning to Generative AI in Materials Science: A Review of Current Applications, Challenges, and Future Perspectives

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Deep learning has emerged as a transformative tool in materials science, enabling the analysis, prediction, and optimization of material properties across various classes, including steels, light alloys, polymers, bio-based materials, composites, and ceramics. The integration of Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), Transformers, and Physics-Informed Neural Networks (PINNs) has revolutionized materials research, offering novel approaches for defect detection, microstructural analysis, property prediction, and failure modeling.

Building upon these advancements, Generative AI is expanding the frontiers of materials design and simulation. Techniques such as Generative Adversarial Networks (GANs), Variational Autoencoders (VAEs), and Diffusion Models are being employed to generate synthetic microstructures, design novel material compositions, and simulate degradation and failure modes before physical testing. Steels and light alloys benefit from AI-assisted crack simulation and fatigue life prediction. Polymers and bio-based materials leverage generative models to create new polymer architectures and assess sustainability. Composites see advancements through AI-driven fiber orientation optimization and damage reconstruction. Ceramics, due to their complex multiphase structures and brittle nature, utilize deep learning for grain boundary analysis and fracture prediction, while Generative AI enhances sintering simulations and synthetic dataset generation.
By synthesizing key results across different methodologies, this review serves as a checkpoint for researchers and engineers navigating the rapidly evolving intersection of AI and materials science. The discussion provides guidance on selecting suitable models, dataset requirements, and computational challenges, helping to bridge the gap between AI-driven computational advancements and experimental materials research. Future perspectives highlight the potential of hybrid AI models, combining physics-based simulations and deep learning techniques, to accelerate material discovery and optimization.

Keywords: Deep Learning, Generative AI, Materials Science, Steels, Polymers, Composites, Ceramics, Machine Learning, Defect Detection, Microstructural Analysis, Model Selection

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Post-Corrosion-Repair Thickness Measurements Using Lamb Wave Technology: An Aviation MRO Case Study

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In the aviation industry, all commercial aircraft are required to undergo thorough routine examinations of their structural components and systems consistently throughout their lifespan to ensure quality, safety, and reliability. Out of the several MRO tasks that must be performed on the aircraft during a check, the prevention, detection, and control of corrosion is one of the most crucial. By employing inspection routines and tasks it aims at monitoring corrosion in all the structural areas of the aircraft, including the wings and fuselage. If an anomaly is detected during routine inspections, corrosion needs to be removed in order to prevent further deterioration of the structure and ensure the structural integrity of the aircraft. The corrosion repair process involves blending all identified corroded spots; leaving it untreated can make the aircraft unairworthy in just a few years. After repair, thickness measurements need to be carried out. If the remaining thickness does not satisfy regulatory requirements the aircraft is deemed not fit-to-fly and needs additional repairs. Currently, the remaining thickness measurement routine is performed manually through a time-intensive process that requires an inspector taking pulse-echo ultrasonic point measurements over the region of interest. These point measurements are then combined into a contour map of the inspected area. Such a process comes with a set of limitations including repeatability and positioning accuracy issues, the time it takes to collect the raw data and visualize them, and the potential cost of outsourcing the inspection to third parties. This study presents a novel approach to determining the remaining thickness after corrosion-removal treatment by employing a non-contact, Lamb-wave-based method. Previous work with the system highlighted its capability in post-corrosion repair inspection. In the current iteration, the scanner system aims to be an integrated mobile workstation that includes the inspection, data-acquisition, post-processing and report-generation systems offering the potential to automated, faster and effectively more advanced corrosion-detection practices in aviation MRO.

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Standrard Specimen Geometries Lead to Inconsistent Structural Adhesives' Quasi-Static and Fatigue Properties

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This work questions the recommendation regarding the use of standard specimen geometries, (Type I, Type II, and Type IV), for estimating the tensile quasi-static and fatigue properties of structural epoxy adhesives. The work presents results from an experimental program investigating the performance of structural epoxy adhesives indicating a significant effect of the specimen geometry, especially when referring to fatigue loading. Simple finite element models are also developed to facilitate the comparison of the stress distribution along the three specimen geometries. The fatigue experimental results allowed the derivation of probabilistic S-N curves, showing higher fatigue sensitivity of Type I specimens compared to Type II and IV. Furthermore, probability distribution function (PDF) curves of the equivalent static strength estimated by using Sendeckyj's wear-out model attributed lower mean strength and higher variance for Type I specimens validating the fatigue data.

The structural adhesive used was a Sikadur-330, a thixotropic bi-component epoxy adhesive by SIKA Schweiz AG. The base material has a bisphenol-A-based epoxy component (white colored) whereas the hardener material consists of aliphatic amines (grey colored). This adhesive is primarily used in civil engineering applications including bonding fiber-reinforced polymeric composite strips to strengthen the existing concrete or steel structures.

Uniaxial quasi-static and fatigue experiments were performed using an MTS Acumen® electrodynamic testing machine equipped with a load cell of 3 kN, having ± 1% of applied force accuracy and 0.5 µm resolution digital displacement recorder. A built-in software, MTS TestSuiteTM multipurpose, was used to design and control the experiments. All the experiments were conducted under controlled ambient conditions of 23 ± 2°C and relative humidity of 40 ± 10%. A typical experimental set-up of static and fatigue experiments is shown in Figure 1.

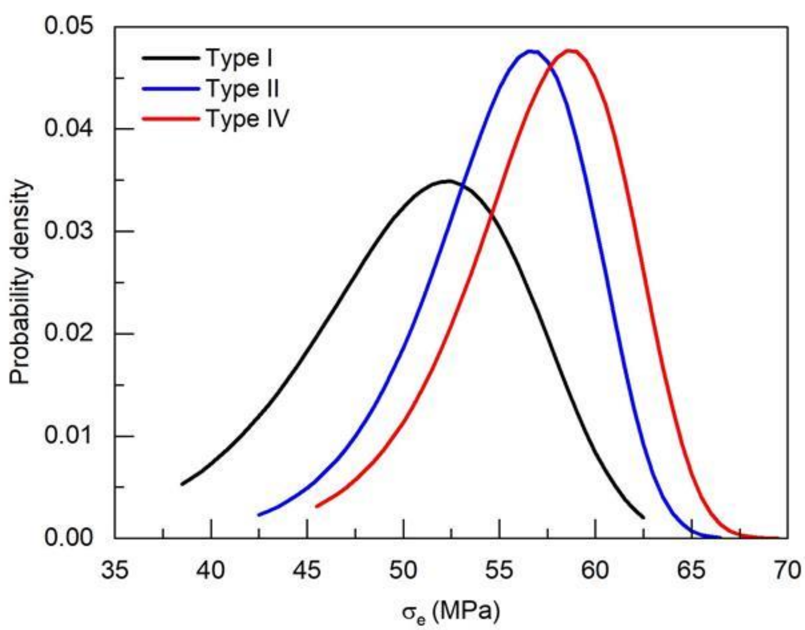
Results showed a significant effect of the specimen geometry, especially on the fatigue properties.

The fatigue data of Type I, Type II, and Type IV specimens were statistically analysed based on Sendeckyj's wear-out fatigue model that allows the use of quasi-static tensile strengths and residual strengths from fatigue run-out specimens in statistical analysis. The wear-out model is based on the stress-life-equal-rank-approach (SLERA) assuming that if a specimen exhibiting greater fatigue strength should also demonstrate superior strength under quasi-static loads. Consequently, it correlates with an equivalent quasi-static strength, with the applied maximum cyclic stresses, the residual stress of any runout specimen, and the number of cycles to failure.

The probability distributive function (PDF) of the equivalent static strength estimated by the model for Type I, Type II, and Type IV adhesive specimens is presented in Fig. 2. showing a clear difference between Type II and Type IV mean value and that of Type I specimens. In addition, the variance of Type I specimens is approximately 31% higher than both Type II and Type IV specimens.

In the analysis, quasi-static experiments were conducted at low strain rates under displacement control and at higher strain rates, similar to those in fatigue loading, under force control modes. The experimental results question the validity of the standard recommendations for fatigue investigations

(a) (b)



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Integration of a Cobot Platform With an Advanced NDT Sensor System: A Sensitivity Case Study Using Direct Velocity Mapping

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Today, the aviation sector is facing changes not only technological in nature but also socio-economic. With an expected labour shortage in the near future, the Maintenance, Repair and Overhaul (MRO) industry is required to evolve and develop more robust and intelligent practices, like predictive maintenance, by adopting emerging technologies such as artificial intelligence and digital twins. To develop predictive maintenance models necessary for the advancement of MRO protocols, automated non-destructive testing (NDT) systems are a fundamental requirement. Such systems make it possible to obtain repeatable measurements that are mutually comparable and can include a wide range of sensors, all while reducing the labour-intensive and time-consuming tasks normally associated with these processes. However, in the highly regulated field of aviation, validation and qualification of new technology is necessary. In a previous work of the authors, an NDT ultrasonic micro-electromechanical systems (MEMS)/laser array scanner was proposed as a new alternative for surface or near-surface defect detection and thickness measurements in aircraft structures. In this study, the scanner was attached to a cobot and a sensitivity study was performed in order to determine the accuracy of the system as a whole. The tests were performed on three different specimens: i) a small (rectangular) flat aluminium plate, ii) a larger (square) aluminium plate with continuously increasing thickness in one direction, and iii) a flat glass plate with constant thickness. For the small aluminium plate, which fits within the scanning region of the system, results were comparable to those taken from conventional ultrasonic scans. However, a distinct step was observed on the thickness maps of the second plate, as well as artifacts and thickness deviations, as the cobot arm extends from its initial position. This is attributed to positioning differences between the two performed measurement sweeps of the end-effector being stitched together – required since the area of the plate is larger than the default scanning width of the scanner. Likewise, positioning deviations were found when scanning the glass plate. When investigating the underlying causes, the horizontal distance between the cobot end-effector and the system's control box (and the payload difference between the software input and the actual load the cobot has to carry) were found to influence the measurements. To compensate for these effects, possible solutions include incorporating an intermediate step swath in the trajectory, lowering the weight of the sensor array, and/or accounting for the deviation effect in the wavefield data analysis to obtain a thickness map without artefacts. Applying these improvements would strengthen the feasibility of the integration of the cobot platform with advanced NDT sensor systems.

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Guided Wave-Based Damage Detection Using Integrated PZT Sensors in Composite Plates

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Introduction

Ultrasonic guided wave method is successfully used for structural health monitoring (SHM) of aircraft structures utilizing PZT sensors for guided wave generation and detection. To increase the mechanical durability of the sensors in operational conditions this paper demonstrates the feasibility of the integration of PZTs into the G/PMMA composite plate and evaluates the possibility of impact damage detection using generated guided waves.

Methods

Two types of PZT sensors were embedded into different layers during the manufacturing process. Twelve layers of glass fabric with PMMA matrix were used to form the plates. Generally, radial mode disc sensors were used for Lamb wave generation and thickness-shear square-shaped sensors were used for both Lamb and shear wave generation. First, the wave propagation was analysed considering the sensor type and sensor placement within the layup. The main objective was to propose the optimal sensor network with embedded sensors for successful impact damage detection. RAPID algorithm was utilized for damage localization and visualization.

Results

It is generally stated that Lamb wave A0 mode is sensitive for impact damage. Based on initial measurements it was found that for disc sensors the optimal placement for A0 mode generation and detection was between the 11th and 12th layer, whereas for shear sensors the suitable placement was in the midplane. Detection capability of both sensor types was compared considering impact damages in different locations within the plates.

Conclusion

Detection and localization of multiple impact damages was successful for both sensor types. The possibilities and limitations of embedded shear sensors in comparison with the radial ones were revealed.

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Digital Twins in Aviation MRO Research: Connecting Inspection and Repair Processes to Diagnostics, Prognostics, and Data-Driven Decision Support Systems

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Driven by a need to address anticipated qualified worker shortages in aviation MRO, coupled with the need to increase efficiency and maintain a high safety standard, research on novel inspection methodologies, novel repair methodologies, and data-driven decision support systems is both diverse and active. Often called Digital Twins, there are many frameworks to describe the process and structure of data acquisition, handling, interpretation, and exploitation in an industrial context. The definition of Digital Twin has evolved over time, emphasizing connections and their directions between physical entities and digital entities of processes, systems, components, or designs. Their application in aviation maintenance often focuses process digitization and data exploitation to reduce waste, decrease workload, increase efficiency, and improve reliability. When fully implemented, they enable a better and holistic understanding and description of aviation vehicles, components, and their status over time.

Existing conceptual frameworks for aviation link the physical processes (e.g., inspections and repairs), and the data-related processes (e.g., acquisition, storage, analysis, diagnostics and prognostics) leading to decision-support systems for future maintenance. However, research projects and system evaluations often address these elements in isolation, neglecting their interconnections. This approach leads to inefficiencies and lost benefits, considering the complete potential of an ecosystem of interconnected physical and digital methods.

During novel technology development, the technical aspects often take a pivotal role, while human behavior complexities, integrations into existing ecosystems, and implications for regulatory frameworks are not directly considered. Other aspects that regularly remain out of scope are longer-term safety, cascading system failures, and human-automation interaction implications. However, taking these aspects into account early and deliberately is crucial to increase the technology readiness level of novel methodologies and systems in the Aviation MRO domain. Without it, developed tools will remain “technological islands”. These islands work well in isolation and in laboratory conditions but fail to meet expectations in actual operation due to challenges in equivalency, user acceptance, and human factor implications.

This paper presents a framework for Digital Twins specifically tailored to aviation MRO characteristics and needs. It presents definitions and examples of connections of the elements of digital twin processes (physical entities, digital entities, and data) while considering human factors, automation, and regulation. By connecting the elements of the complete maintenance process with these framing factors, both the potential improvements and possible complications can be identified and evaluated early in the design process.

The framework is illustrated through applied research projects in collaboration with MRO providers and national knowledge institutions in the Netherlands, linked to studies at Amsterdam University of Applied Sciences: fluorescent penetrant inspection of engine blades, ultrasonic inspections of aircraft structures, automated multi-sensor inspection of components, and data-driven investigations of component maintenance. Together, these examples span the complete range of the described Digital Twin architecture, showcasing its connecting potential and highlighting synergies. This description presents the starting point for the discussion of regulatory and automation-related implications of innovative systems, closing the gap between existing processes and the envisioned application of novel digital automated tools and methods to address the industry challenges.

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Data-Based Estimation of Materials Behavior and Parameters in Design and Failure Analysis of Engineering Components

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Knowledge of material behavior and related properties and parameters is essential in the process of designing new engineering components, evaluating and improving existing ones, but also in subsequent analyses of those that failed in service when root causes need to be determined to avoid and prevent future failures. Regardless of the task being performed, available material information is rarely sufficient. This problem is especially pronounced in failure analyses. In many cases, no original information/documentation is available and very limited material information can be gathered from failed components because extraction of material specimens needed for more detailed testing often requires extensive effort or it is not possible altogether. Critical, load-bearing components are increasingly being produced with functionally graded materials with varying properties throughout the component, which presents additional challenge in experimental determination of needed material parameters. For these reasons, methods enabling estimation of advanced monotonic as well as cyclic and fatigue materials parameters from basic monotonic material properties continue to receive attention and new ones are developed. The fact that they enable reasonably accurate determination of material parameters and behavior from relatively limited, but easily obtainable material data (chemical composition, microstructure, hardness) makes them particularly interesting also for the purpose of failure analysis. Recent developments of conventional estimation methods and those based on artificial neural networks and other machine-learning based approaches are discussed in this paper as well as the possibilities of their application in the framework of failure analyses of engineering components.

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Probabilistic Algorithm for Waviness Defect Early Detection During High-Precision Bearing Manufacturing

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The grinding process of bearing components is a critical step in their manufacturing, as it directly impacts the functional properties of raceways and other critical surfaces. One important failure arising during the grinding process is waviness in the machined surface. This geometrical error cause vibrations in operation with the consequent impact in power losses, noise and fatigue.

The present work proposes an in-line detection system of waviness defects in bearing raceways. The system uses accelerometers installed near the part in the grinding machine and runs a detection algorithm in a calculation unit in its control board. Results are sent via Ethernet to the central quality control of the line. The embedded algorithm uses the frequency content of the measured signal for predicting the surface quality of the final part.

The prediction of the surface quality is done by learning a non-parametric model describing the transmission between the surface geometry and the measured vibration content. In order to obtain this model, a calibration process is conducted for each bearing reference, ensuring the model accounts for the specific geometric and operational characteristics of the parts. By analyzing the correlation between accelerometer signals and harmonics, the algorithm predicts the probability of waviness occurrence.

The proposed system has been implemented in a high-precision bearing production line, validating its effectiveness across multiple parts of the same reference. This approach improves defect detection ensuring higher product quality and reduced operational costs.

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Multifunctional Plate Lattice Architectures: Experiments and Simulations

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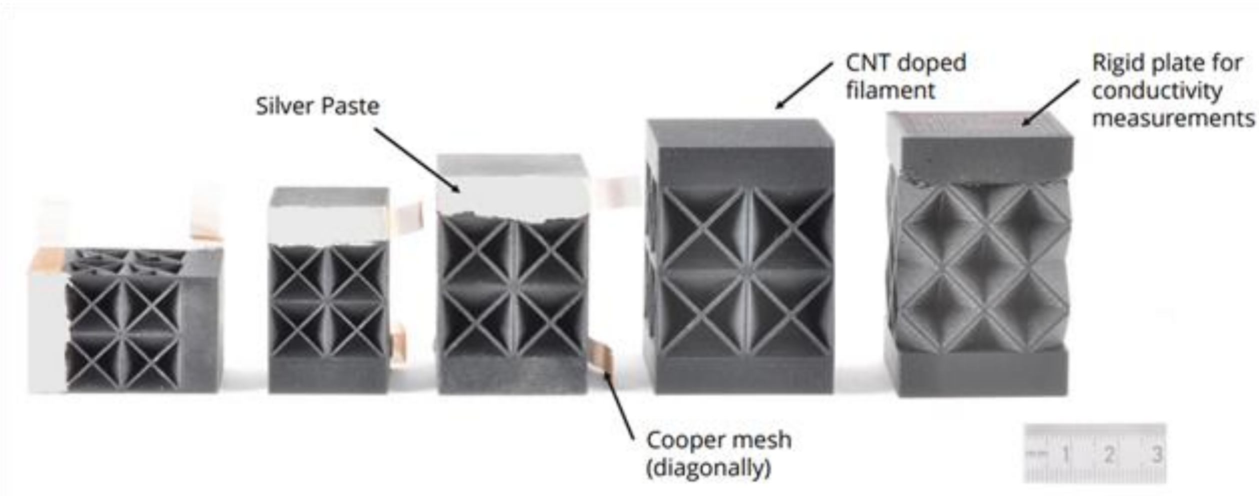
Additive manufacturing has enabled the development of a new generation of materials with advantageous properties derived from their architecture. Lattice structures, in particular, have gained increasing attention due to their high specific stiffness and strength. Among them, plate lattices have demonstrated superior performance, exhibiting large crushing strains and high energy absorption. Meanwhile, carbon nanotubes (CNTs) dispersed in polymers produce composites with enhanced mechanical, electrical, and thermal properties, enabling applications ranging from electromagnetic shielding to strain sensing.

In this work, we evaluate the mechanical and piezoresistive performance of plate lattice architectures for the development of lightweight structures with integrated strain-sensing functionality. Tensile and compressive tests are performed under static conditions for various filament printing orientations to assess the mechanical properties of CNT-doped polylactic acid (PLA), including elastic modulus, strength, and post-peak behavior. Additionally, the piezoresistive properties of PLA are experimentally measured, elucidating the impact of mechanical stress on its electrical resistance. These findings are leveraged to calibrate a finite element method (FEM) model, demonstrating excellent agreement between numerical and experimental results.

Face-centered cubic (FCC) and body-centered cubic (BCC) plate lattice architectures are 3D-printed with the Filament fusion Fabrication method, implementing the previously characterized base material. Compressive tests are conducted to evaluate the effects of printing direction, volume fraction, and unit cell geometry on the mechanical and piezoresistive response of tessellations comprising eight primitive cells (2×2×2). The experimental data obtained are used to validate FEM models, which accurately capture the observed behavior and can be further exploited for parametric analysis and optimization of multifunctional lattice architectures.

This work is supported by the HORIZON-WIDERA-2021-ACCESS03-01 - Twinning COMPECO project, co-funded by the European Commission (Project Number: 101079250).


Silver Paste
CNT doped filament
Rigid plate for conductivity measurements
Cooper mesh (diagonally)
1 2 3

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Correlation of Normalized Strain from Image-Based Techniques With Optical Fiber Sensor Data in Mechanically Stabilized Earth Systems: Insights from Scaled Physical Modeling

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The current study explores the correlation between normalized strain measurements derived from image-based techniques and optical fiber sensor data in mechanically stabilized earth (MSE) systems, using scaled physical modeling in a geotechnical centrifuge. MSE systems, which consist of soil reinforced with tensile-resistant materials, are known for their enhanced mechanical properties, including improved shear strength and reduced compressibility. These systems are particularly useful in seismic-prone areas and regions with challenging terrains. The composite material's effectiveness relies on the optimal interaction between soil and reinforcement, where the soil provides compressive and shear strength, and the reinforcements contribute tensile strength. This synergy prevents excessive deformation, stabilizing the structure, and making MSE systems effective for geotechnical applications, including roadworks, hydraulic structures, and railways.
To better understand the behavior of MSE systems, accurate strain measurements are essential. Traditional methods, like strain gauges, can be challenging to apply to large or unconventional structures. In contrast, optical fiber sensors, specifically Fiber Bragg Grating (FBG) sensors, are becoming a preferred choice due to their high precision, durability, and ability to multiplex multiple sensors along a single optical fiber. These sensors offer detailed, localized strain measurements along the reinforcement and are particularly valuable for monitoring structural health in experimental setups.
Additionally, image-based techniques like Particle Image Velocimetry (PIV) and its modified version, GeoPIV, are used to analyze soil displacement and strain in geotechnical models. GeoPIV tracks soil particle movement between consecutive images, providing full-field strain visualization across the model. The method involves dividing digital photographs into small patches and monitoring the displacement of these patches over time. This research presents a detailed comparison of strain measurements obtained from optical fiber sensors and the image-based techniques used in geotechnical centrifuge models. The normalized strain values from GeoPIV are scaled to absolute microstrain, enabling direct comparison with the strain measurements from the optical fiber sensors. Through this comparative analysis, the study highlights the complementary nature of both techniques. Optical fiber sensors offer high-resolution, point-specific strain measurements along the reinforcements, while image-based methods provide a broader view of full-field strain across the entire model.

The study's use of a geotechnical centrifuge is crucial for simulating real-world conditions in a scaled, controlled environment. The centrifuge replicates full-scale stress conditions by applying increased gravitational forces to smaller physical models. This approach allows for more accurate modeling of stress distribution and deformation behavior, especially in geotechnical structures where full-scale testing is impractical.

The results of this study demonstrate the potential of combining optical fiber sensor data with image-based techniques to improve the structural monitoring and assessment of MSE systems. The complementary strengths of each method – the detailed, localized measurements from optical fibers and the broad, full-field strain visualization from GeoPIV – can enhance the overall understanding of MSE behavior under various loading conditions. This integrated approach holds promise for optimizing the design and performance of MSE systems, providing valuable insights for future geotechnical applications and structural health monitoring.

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Numerical and Experimental Application of Particle Inverse Method for Crack Monitoring of Composite Structures

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Monitoring the evolution of multiscale crack phenomena through sensor data is essential for the development of reliable crack-informed stress–strain relationships in materials, especially in composites. This study reports the first numerical and experimental verification of the Particle Inverse Method (PIM), a novel particle-based approach for full-field deformation reconstruction and macroscale crack propagation monitoring from discrete sensor measurements. PIM is designed to seamlessly bridge the gap between discrete sensor measurements and localized microscale damage predictions by first providing an accurate reconstruction of global structural behavior. This enables the subsequent transfer of macroscale crack behavior to targeted microscale models to assess spatially variable degraded material properties.

To validate the accuracy of the PIM, two unidirectional composite plates with distinct fiber orientations are fabricated, with an initial centrally located crack introduced in each specimen. The experimental setup incorporated a comprehensive array of sensors, including strain gauges, and Fiber Bragg Grating (FBG) sensors, to capture high-fidelity, discrete strain data during tensile testing. These data are then input into the PIM algorithm, which reconstructs the full-field deformations and tracks the crack propagation at each discrete time step. Detailed comparisons are made between the reconstructed deformation fields and crack evolution patterns against direct experimental observations, thus rigorously assessing the accuracy of the PIM in a realistic testing environment.

The experimental results confirm that PIM reliably reproduces both the global deformation characteristics and the progressive crack development, achieving high accuracy without requiring prior information on the applied loads. This demonstration of PIM's capability underscores its potential as a robust tool for real-time macroscale crack monitoring. Moreover, the validated performance of PIM establishes a critical foundation from macroscale observations to detailed microscale analyses for improved prediction of damaged material properties in future studies. Such an integrated approach holds significant promise for advancing structural health monitoring methodologies and for enhancing the predictive maintenance of engineering structures across multiple scales.

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An Inverse Finite Element Method for Modal Assessment and Damage Detection in Aerospace Structures under Random Vibration

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This study introduces an advanced inverse finite element methodology (iFEM) integrated with modal reconstruction (iFEM-MoRe) to perform full-field dynamic assessment and damage detection of structures subjected to random vibration. The proposed study utilizes discrete strain measurements collected from a structure, reconstructing the complete time-domain displacement field without requiring prior knowledge of material properties or excitation inputs. In the presented approach, strain data acquired from strategically positioned sensors on the composite wing are processed using iFEM to recover the structure's full-field deformations. This time-domain solution is then transformed into the frequency domain via Welch's method, yielding normalized frequency response functions (FRFs) that enable accurate identification of natural frequencies and high-fidelity reconstruction of mode shapes. Changes in these modal parameters are subsequently analyzed to detect and localize damage, as deviations from baseline healthy conditions reveal underlying structural anomalies.
The methodology is validated through both numerical simulations and experimental tests on a wing-shaped composite structure under realistic random vibration scenarios. The numerical studies demonstrates that iFEM-MoRe reliably captures the full-field dynamic behavior, while the experimental results confirms its ability to pinpoint localized damage through observable shifts in mode shapes and natural frequencies. The versatility of the method is highlighted by its independence from load or material information, making it particularly attractive for in-service structural health monitoring (SHM) applications in aerospace systems. Overall, the iFEM-MoRe framework offers a robust, cost-effective tool for continuous monitoring and early detection of damage in complex aerospace structures. By providing comprehensive modal assessment through full-field reconstruction from discrete sensor networks, the approach paves the way for improved maintenance strategies and enhanced operational safety in the aviation industry.

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Towards the Determination of the Remaining Life Time in Steel Structures

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In this paper, the determination of the remaining life time of low carbon steels subjected to high cycle fatigue (HCF) stresses is proposed through an innovative technique of measuring magnetic permeability properties. Specimens of S235 structural steel, with a measured actual yield strength of 320 MPa, were used to conduct three HFC stress tests at load levels corresponding to 90% (290MPa), 70% (225 MPa), and 45% (150MPa) of their actual strength. In parallel with stress monitoring during the fatigue tests, a three-dimensional anisotropic magnetoresistance (AMR) sensor was employed to monitor the change of the ambient field during stress cycles. The maximum values of the three AMR field components were recorded with respect to the applied stress cycles. The 290 MPa sample failed at 0.98 million cycles, while the rest of HCF measurements were limited to 2.1 – 2.3 million cycles. The slope of the dominant magnetic field component's dependence on stress cycles found to be approximately linear, while the magnitude of the magnetic field was clearly correlating with the size of the stress field applied on the sample. As expected, the 290 MPa stress loading resulted in the sharpest slope, with the rest of stresses also following a more or less linear slope, decreasing monotonically with the applied stress. Therefore, having as a reference the magnitude of the AMR field component at which the steel sample ultimately failed under the 290 MPa loading, the number of cycles required for the same sample to fail under any other fatigue load can be approximately determined. This technique holds significant promise for non-invasive assessments of the remaining fatigue lifetime of critical components in various industrial and maritime applications, enabling condition-based assessments and enhancing structural reliability

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Tensile Behavior of Romanian 'Țurcană' Sheep Wool Waste-Fibers Influence of Body Region

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Europe generates over 200,000 tones coarse wool each year, frequently regarded as a low-value by-product. However, growing sustainability initiatives are promoting its innovative repurposing. A key application is in construction, where wool offers environmental, economic, and functional benefits. As a renewable, biodegradable, and recyclable material, it helps reduce dependence on non-renewable resources and minimizes construction waste, supporting the development of greener and more resilient infrastructure. This study expands on the previous research by Sosdean et al. [1], presenting the findings of tensile testing conducted on individual "Țurcana" wool fibers obtained from two sheep. The fibers were collected from specific body regions to evaluate variations in strength and assess the influence of sampling location on mechanical properties. Wool fibers were analyzed using SEM and FTIR, providing a comprehensive understanding of their properties before and after failure; SEM revealed the physical structure and surface characteristics, while FTIR identified the chemical composition and molecular interactions. By integrating SEM and FTIR findings, this study offers valuable insights into the potential use of "Țurcana" wool fibers as reinforcement in newly developed composite materials, contributing to the advancement of sustainable and high-performance bio-based composites.

[1] Sosdean C, Galatanu SV. Tensile properties of Romanian “Țurcana” sheep wool farm-waste fibers. InIOP Conference Series: Materials Science and Engineering 2024 Oct 1 (Vol. 1319, No. 1, p. 012034). IOP Publishing.

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Development of a Method for Monitoring the Condition of a Remotely Controlled Demolition Robot to Prevent Structural Failures

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This paper presents a method of a novel numerical and experimental approach to developing a system aimed at preventing structural failures in remotely controlled demolition robots. These machines are typically operated in rugged conditions, and in some cases, inefficiencies arise due to inexperienced operators. Such improper operation can lead to excessive structural loading, increasing the risk of cracks and failures, particularly in critical components such as the working boom or undercarriage.

The use of this type of machinery in demolition work, carried out in various environmental conditions and involving different material characteristics, results in the machine structure operating under diverse loading conditions. Such variability in working conditions requires a highly experienced operator to optimize the machine's kinematic system for efficient operation while avoiding critical loading states that could compromise the structural strength and, most importantly, the durability of the working mechanism.

To mitigate the risks associated with adverse operating conditions, particularly critical structural stresses, a method has been developed that combines numerical analysis with real-time measurements and experimental data from various types of operations. This approach enables the identification of the most heavily loaded areas of the machine's structure, allowing for real-time monitoring of structural stress levels and notifying the operator in the event of critical threshold exceedance.

Within this method, the finite element method (FEM) is used to determine the most critical points in the machine's structure (both the working and the load-carying structure) and to numerically define the maximum safe stress levels from the perspective of short-term strength. The numerical model is subsequently validated through experimental testing, utilizing strain gauges and accelerometers to measure stress and vibration levels in real time. At this stage, the numerical model of the machine's structure is fine-tuned based on the experimental data. The finite element strength analysis identifies the most critical stress points, which are then used to determine optimal sensor placement for real-time experimental testing.

As a result, the developed system enables continuous monitoring of structural integrity parameters, ensuring that operational stress limits are not exceeded. Sensor data is processed using dedicated algorithms and communicated to the operator via a Human-Machine Interface (HMI), which provides visual warnings either on the machine structure itself or on the operator's control panel. The developed real-time monitoring system provides continuous feedback to the operator regarding the structural integrity of the machine, as well as alerting to undesirable operating conditions, such as excessive vibrations that could lead to resonance.

The results obtained from this study, integrated into the developed algorithm-based system, demonstrate the potential of this method to improve operational efficiency, and extend the service life of the machine's structure. By reducing the likelihood of structural failures and preventing operation in extreme conditions, this approach contributes to increased reliability and sustainability of demolition robots in demanding environments. By minimizing the risk of structural failures and mitigating the effects of extreme operating conditions, this approach enhances the reliability, operational efficiency, and long-term structural integrity of demolition robots, thereby improving their sustainability in highly demanding environments.

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Applying Deep-Learning Techniques to Evaluating Risk of Damage to Masonry Buildings in Mining Areas

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The thesis is about evaluating the risk of damage to masonry single-family houses. The described group of buildings was located in a mining area, which increased the risk of damage. All of them were subjected to mining impacts to varying degrees, which consisted of continuous terrain deformations and mining tremors. An original intensity index was used to describe the damage, which has been used many times in practice to assess the technical condition and resistance of buildings in mining areas. An in-situ field study was used to create a database of buildings that were affected by mining impacts and suffered damage. The database contains data on building geometry, construction and material solutions, maintenance quality (renovations, repairs, reinforcements) and structural protections used to transfer additional impacts from the ground induced by mining. Subsequently, this data allowed to undertake the research to create a predictive model to assess the degree of damage intensity. The necessity of the assessment is dictated by mining and geological law and rests with the mine operators, who must have registered information about the resistance of the buildings. By determining the resistance or the risk of damage of a certain intensity for a group of buildings, it is possible to estimate the costs of potential repairs in advance or to decide on the preliminary protection of the most vulnerable structures.

For many years, the authors continue work on the development of a system for predicting the risk of damage to buildings in mining areas, using machine learning (ML) algorithms. As the results of numerical studies and multiple simulations, some algorithms can be considered highly effective in this field. One of them is the SVM (Support Vector Machine) algorithm. It is a method with a structure similar to artificial neural networks (ANN) with radial kernels (Radial Basis Function). Unlike classic ANNs, it allows to eliminate the effect of chaotic fine-tuning of network weight values. The process of determining weights, as well as extracting the network structure, is unambiguous in the SVM approach, which is determined by formulating the optimisation problem during learning.

In view of the constantly changing trends in the field of modern ML techniques and the increasing use of deep learning (DL) methods, an attempt has been made to verify this approach for the current problem. It was decided to use the Convolution Neural Network (CNN), which until now has only been used for image classification. For this purpose, it was necessary to map the input vector onto a monochromatic array in the form of quasi pixels. All the numerical variables have been encoded as a sequence of dichotomous values of 0 and 1 and presented combined together to form a quasi-image. This approach has not been used in this way before, especially when evaluating the risk of damage to building structures. To validate the test results, the aforementioned SVM network was used as a basis for comparison. Ultimately, obtained results show that the DL approach proposed in the study can be further developed and tested.

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A Multi-Criteria Decision-Support Tool for the Selection of Sustainable Composite Recycling Processes

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The increasing demand for sustainable recycling solutions in composite materials, particularly carbon fiber-reinforced plastics (CFRP), necessitates a comprehensive approach to decision-making. A significant challenge in evaluating recycling processes lies in the inherent trade-offs between different sustainability dimensions. While existing studies often focus on single parameters, such as mechanical performance, cost, or environmental impact, real-world applications require a more holistic assessment that considers multiple, often conflicting, factors.

This research presents a novel decision support tool designed to evaluate and compare recycling processes based on sustainability criteria. The tool is developed within a proposed framework for the assessment of recycling processes, utilizing Multi-Criteria Decision-Making (MCDM) methodologies. To this end, it integrates key performance indicators such as mechanical performance metrics, environmental impact, economic viability, circular economy principles, and social aspects to provide a balanced sustainability assessment. By incorporating these diverse criteria, the tool ensures a comprehensive evaluation that aids stakeholders in making informed decisions regarding composite material recycling.

To address trade-offs between different sustainability pillars, the tool employs the Analytic Hierarchy Process (AHP), a structured decision-making approach that enables stakeholders to assign relative weights to each criterion based on their priorities. This process ensures that critical aspects of sustainability are appropriately represented in the final assessment. After weight determination, min-max normalization is applied to standardize values across diverse metrics, ensuring meaningful comparisons between different recycling processes. Following normalization, the tool applies multiple ranking and scoring methodologies to generate a comprehensive sustainability index for each recycling process, including the weighted sum method and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution).

To demonstrate the applicability of the tool, novel recycling processes investigated within the EURECOMP research project, such as the plasma-enhanced solvolysis, along with conventional composite recycling methods, are assessed and compared. Sensitivity analysis on weights and data variation are also investigated, to assess different what-if scenarios.

The above comparative analysis highlights the tool's ability to assess trade-offs between sustainability-related factors, offering an evidence-based approach to decision-making in composite recycling, and assist identification of the most sustainable solutions for composite material recovery. aterial management.

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Sustainability-Driven Assessment of Insulation Materials for Fuel Storage Applications in the Maritime Sector

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Identifying and selecting suitable insulation materials for fuel storage tanks in the maritime sector requires careful assessment of performance criteria alongside sustainability considerations. This study explores candidate insulation materials currently used across various industries and evaluates their potential for maritime applications, specifically focusing on membrane panel insulation.

By integrating multidisciplinary sustainability criteria, the current research highlights the necessity of a sector-specific approach in adopting novel insulation solutions, ultimately guiding sustainable innovation in maritime insulation technology. An extensive data collection effort has been performed, compiling thermal and mechanical performance characteristics, circularity aspects, environmental considerations, social implications, and economic aspects. Data from diverse sectors such as aerospace, automotive, construction, and energy storage have been analyzed critically, revealing common uses, material compatibility, and existing knowledge gaps when transitioning materials to maritime-specific applications.

To this end, this work proposes dedicated metrics explicitly designed for early-stage assessment of candidate materials, also reflecting maritime industry's unique operational, safety and regulatory concerns among others. These metrics enable a comprehensive assessment of materials, balancing insulation performance, lifecycle circularity, economic feasibility, environmental impact, and social implications.

Ultimately, this research supports sustainable innovation by ensuring that insulation solutions not only fulfill performance demands but also align with the broader objectives of sustainability.

Keywords: Insulation materials, Fuel Storage, Sustainability, Membrane Tanks, Maritime

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AI-Driven Predictive Modeling and Optimization of FDM Mechanical Properties Under Variable Static Strain Conditions

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This study presents an AI-driven computational framework designed to unravel and optimize the complex relationships between Fused Deposition Modelling (FDM) process parameters and the resulting mechanical properties of printed components. FDM, widely adopted for its cost-effectiveness and customizability, often encounters challenges due to the intertwined effects of multiple printing parameters and testing conditions, such as strain rate. Our approach addresses these challenges by integrating advanced statistical modeling and evolutionary optimization techniques.

In the first phase, we developed a boosting statistical AI model using a subset of data collected from over 1,500 printed specimens. These specimens were fabricated using a broad range of commercial polymers—including PLA, PETG, and PP—as well as specialized composites like carbon fiber-reinforced PEKK. Each sample was produced under varied printing conditions and tested at different strain rates to capture the interplay between process variables and mechanical outcomes, such as tensile strength, modulus, and elongation at break. Despite using a limited version of the whole dataset, the AI model successfully captured the nonlinear interactions inherent to the FDM process. Furthermore, the model was capable of statistically quantifying its predictions by calculating confidence regions through quartile estimations (e.g., Q{2.5} and Q{97.5}), and even identifying printing defects that significantly impact mechanical performance.

Building upon these encouraging preliminary findings, the second phase focused on integrating a Genetic Algorithm (GA) to optimize the printing parameters. In this stage, the various print settings and testing conditions were encoded into a genetic representation. An initial population of parameter sets was randomly generated within the physical constraints of the 3D printing system and material properties. This population evolved over successive generations via crossover, mutation, and gene inversion strategies, following a modified Non-Dominated Sorting Genetic Algorithm (NSGA-II) framework. Since the optimization was multi-objective, traditional single-metric evaluation was insufficient; hence, the NSGA-II criteria were employed to identify Pareto-front solutions that balanced competing performance metrics.

The optimization framework demonstrated rapid convergence towards parameter sets that met predefined performance constraints. In a practical case study, the algorithm was used to maximize the force yield of specimens composed of the same PLA matrix but reinforced with different fibers and the results consistently revealed that one material outperformed the other, suggesting a weak or absent interface in the latter. To confirm this hypothesis, we used Scanning Electron Microscopy (SEM) to observe the samples' fracture interfaces, and we confirmed the presence of the aforementioned weak interphase between polymer and fibers.

In summary, our dual-phase framework effectively combines statistical AI modeling with genetic optimization to predict and enhance the mechanical performance of FDM-produced parts. This integrated approach not only deepens the understanding of the interdependent effects of print and testing parameters but also provides a practical tool for achieving application-specific production targets. By enabling rapid optimization and detailed performance prediction, the framework holds promise for advancing the precision and reliability of additive manufacturing processes in industrial settings.

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Augmenting Fatigue Datasets to Enhance Neural Network-Based Multiaxial Fatigue Strength Prediction

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Reliable fatigue strength prediction is essential for maintaining the durability of machine components subjected to multiaxial loading. Traditional fatigue strength models typically depend on empirical equations and fixed criteria, which, although useful, may have difficulty adapting to a broad spectrum of materials and loading conditions. Recent advancements in artificial intelligent has demonstrated the potential to enhance fatigue stress prediction by learning complex multiaxial loading data. However, the effectiveness of these models is significantly constrained by the limitation of testing data. A fatigue stress dataset provides valuable experimental data but is inherently limited in size, restricting the capabilities of machine learning models. This research enhances fatigue strength prediction by systematically expanding the fatigue dataset through data augmentation techniques. The augmentation process involves generating additional stress loading scenarios through tensor transformations, ensuring that the fundamental mechanical properties of the material remain unchanged. Additionally, new uniaxial stress scenarios are introduced based on existing experimental data, allowing for a more comprehensive representation of fatigue under various loading conditions. As such, the dataset was systematically expanded from its original size, incorporating a broader range of stress conditions and orientations. To evaluate the effectiveness of this augmentation, two artificial neural network models were trained: one on the original dataset and another on the augmented dataset. Both models were tested on identical evaluation datasets to ensure a fair comparison. The results demonstrate that the model trained on the augmented dataset achieved better predictive performance, indicating enhanced accuracy in its fatigue strength estimations.

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