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Book of Abstracts

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Portuguese Structural Integrity Society - SPFIE

INEGI - Institute of Science and Innovation in Mechanical and Industrial Engineering

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Preface

This volume gathers the abstracts of the contributions presented at the 2026 edition of the Portuguese Conference on Fracture (PCF2026), hosted at INEGI – Institute of Science and Innovation in Mechanical and Industrial Engineering, in collaboration with the Faculty of Engineering of the University of Porto (FEUP), from March 30 to 31, 2026.

The Portuguese Conference on Fracture has been regularly organized by the Portuguese Structural Integrity Society since 2020, continuing a longstanding tradition of national meetings dedicated to fracture and structural integrity. Over the years, the conference has served as a forum for researchers and engineers to exchange knowledge and foster collaboration within the field.

The main thematic areas of the conference include Fracture, Fatigue, Structural Integrity, Advanced Materials, and Biomaterials. The 2026 edition also features a dedicated symposium on Hydrogen embrittlement and environment effects in materials.

Porto, located in the north of Portugal, is a dynamic economic and industrial centre, characterized by a strong manufacturing heritage alongside a rapidly evolving technological and innovation landscape. The city hosts a vibrant academic and research community, supported by leading universities and research institutions. Its historical heritage, reflected in its architecture and urban fabric, coexists with a modern cultural scene, making Porto an attractive destination for both scientific exchange and international visitors.

The breadth and diversity of the works presented at PCF2026 highlight the strength and dynamism of both the Portuguese and international communities in fatigue, fracture, and structural integrity. The contributions collected in this volume reflect the high scientific standards and innovative approaches currently shaping research in these fields.

The organizing committee expresses its sincere appreciation to all authors for their valuable contributions, to the invited and plenary speakers for enriching the scientific program, and to the executive committee of the Portuguese Structural Integrity Society for its continuous support. Special thanks are also extended to the sponsors and institutional partners, particularly INEGI and FEUP, for their essential role in the successful organization of this conference.

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Plenary Sessions

Structural Integrity Assessment of Biomedical Devices: Relevance and Challenges

Ana Martins Amaro[1]

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Abstract Structural integrity assessment is a fundamental aspect in the development of safe, reliable, and high-performance biomedical devices. This study begins by introducing the concepts of biomedical devices and structural integrity, establishing their relevance in the context of clinical applications. It then provides mechanical characterization techniques, including tensile, compressive, and fatigue testing. Particular emphasis is placed on fatigue behavior, as many biomedical devices are subjected to complex cyclic loading in vivo, which can lead to progressive damage, crack initiation, and eventual failure if not properly assessed. Advanced experimental methodologies, such as DIC, are presented as powerful tools for full-field strain measurement, enabling a deeper understanding of deformation mechanisms and failure processes. In parallel, numerical simulation is discussed as a complementary approach that allows predicting mechanical performance, supporting design optimization, and reducing experimental costs and development/analysis time. The study focuses on three areas: dentistry, orthopedics, and interventional cardiology. In these fields, structural integrity requirements are particularly demanding due to the combination of mechanical loads, biological environments, and long-term functional expectations.

In addition to mechanical performance, the development of new biomedical devices requires rigorous biological evaluation. Therefore, the importance of cytocompatibility assessment is highlighted, including antibacterial assays and hemocompatibility tests, which are essential to ensure safe interactions between materials and biological systems.

Overall, structural integrity is a key factor in the successful development of biomedical devices. Its proper evaluation requires an integrated and multidisciplinary approach combining experimental testing, numerical simulations, and biological assays. Furthermore, the continuous development and validation of new materials offer significant opportunities for innovation, while also introducing complex scientific and engineering challenges, such as replicating physiological conditions, accounting for patient-specific variability, and ensuring long-term reliability. Addressing these challenges is crucial for advancing the next generation of biomedical devices and improving patient outcomes.

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Analysis and Prevention of Mechanical Failures in Industrial Equipment

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Abstract Interest in structural integrity has been inherent to human activity since its earliest beginnings, and may be expressed as a measure of the quality of design, manufacture, and the ability of equipment to perform its function over the intended service life. Furthermore, to design and maintain mechanical equipment, it is essential to anticipate the most probable and critical mechanisms that may lead to its failure and, based on this information, determine the types of potentially dangerous defects and assess their admissible dimensions. Indeed, the failure (malfunction or rupture) of mechanical equipment may have serious human and/or economic consequences. Thus, in general, the causes of equipment failure may be attributed to one or more of the following:

- Design deficiencies, namely lack of knowledge of, or insufficient attention to, stress concentration factors, including surface roughness, notches, weld beads, etc.; Insufficient information regarding service loads; Inaccurate or insufficiently developed stress analysis;
- Deficiencies in material selection, including inadequate data for material selection; poor correlation between service conditions and selection criteria;
- Material defects that may originate from raw materials inherent to their production (inhomogeneities), or introduced during the equipment's manufacture (e.g. porosity, inclusions); defects introduced during service (e.g. cracks);
- Overloads introduced during service;
- Inadequate maintenance or repair procedures;
- Unexpected environmental factors, such as increased severity of the environment.

Therefore, preventing failures and ensuring the safe operation of equipment throughout its service life requires consideration of all the aforementioned factors. This presentation will also examine three case studies of mechanical failures involving the fuel tanks of a high-speed craft, the crankshaft of a marine V12 diesel engine, and the stabilising bilge keels of a ship [1-3].

Keywords: Structural integrity; Failure Analysis; Fatigue & Fracture; Mechanical Design.

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Structural Integrity Evaluation of Welded Structures

4 contributions

Enhancing Metal–Polymer Joining through Mechanical Interlocking

Miguel A.R. Pereira[1], Rui M. Leal[1,2], Ivan Galvão[1,3], José D.M. Costa[1], Ana M. Amaro[1]

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Abstract Joining dissimilar materials such as metals and polymers remains a significant challenge due to their very different thermal and mechanical properties, which often lead to weak interfacial bonding and limited joint performance. In Friction Stir Spot Welding (FSSW) of metal–polymer systems, insufficient adhesion at the interface is a critical issue, particularly when conventional surface preparation methods are used [1]. This work addresses this limitation by introducing a mechanical grooving strategy to modify the metal surface prior to welding [2]. The proposed approach creates a controlled multilinear surface texture designed to promote meso-mechanical interlocking between the metal and the polymer, thereby improving load transfer across the interface. To assess the effectiveness of this strategy, aluminium sheets with mechanically grooved surfaces were joined to polyamide 6 (PA6) using FSSW and compared with joints produced from ground surfaces. The joints were evaluated through tensile–shear testing, morphological and fractographic analyses, axial force monitoring, and FTIR-ATR spectroscopy to examine possible interfacial degradation. The results showed a clear improvement in mechanical performance for the grooved specimens, which achieved higher tensile–shear loads and exhibited mixed adhesive–cohesive failure modes, indicating stronger interfacial anchoring. In contrast, conventionally ground samples mainly failed adhesively and presented lower strength. Overall, the findings demonstrate that introducing meso-mechanical interlocking through mechanical grooving is an effective and robust way to enhance the performance of metal–polymer FSSW joints, contributing to the development of more reliable hybrid structures.

Keywords: Friction Stir Spot Welding, Mechanical Grooving, Texture, Aluminium, Polymer

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Dissimilar Materials Joining Through Friction Stir Riveting

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Abstract Combining dissimilar parts has become imperative for developing structures of lightweight materials, like light metal alloys, that became one of the solutions to reverse the current trend of CO2 emissions in the transport sector. However, given the usual properties disparity, joining dissimilar materials in multi-material structures presents an engineering challenge. Advanced joining processes, such as Friction Stir Riveting (FSR) [1], have emerged and been applied across several sectors as an alternative to conventional joining processes, such as mechanical riveting. Friction stir riveting (FSR) is an advanced solid-state joining technique combining friction stir welding (FSW) and self-piercing riveting to join materials (especially dissimilar metals like aluminum and steel) without pre-drilling [2-3]. In the present work, the FSR process, although with a different approach from the conventional technique, was applied to the production of overlapping dissimilar joints with the following material configurations: AA7075-T6 to Ti-6Al-4V. In order to perform a systematic investigation, orthogonal arrays were selected using the Taguchi Method to evaluate their effects on the produced joints. The joints were quasi statically mechanically tested to assess their mechanical performance. The aluminium-titanium joints were compared to conventionally riveted joints, and those produced by FSW show much higher mechanical strength values. In order to gather more information about the local properties of some of the joint parts to relate them to the fracture locations, hardness tests were also carried out. However, there was no significant change in hardness in the tested areas. Finally, a statistical study was performed to analyse the main effects and interactions of the process parameters in order to identify their influences on the mechanical performance of the joints.

Keywords: Friction Stir Welding (FSW); Dissimilar Materials; Mechanical Interlocking; Overlap Joints; Taguchi Method; Mechanical Performance

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Mechanical Response of Aluminium–Polymer Friction Stir Composite Joints Under Different Strain Rates

Rodrigo J. Coelho [1]*, Beatriz Silva [1], Arménio Correia [2], Ricardo Baptista [3], Virgínia Infante [4], Pedro M.G.P. Moreira [1], Daniel F.O. Braga [1] and Fernando Moreira[5]

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Abstract Friction stir-based joining technologies offer an effective approach for integrating dissimilar materials into single structural components, enabling their use in demanding, safety-critical systems such as alternative fuel management and storage (e.g., hydrogen applications)[1–3]. Ensuring the structural integrity of these hybrid joints is essential, particularly given the inhomogeneous nature of the materials at the interface and the demanding dynamic loading conditions they may encounter.

This study investigates the influence of strain rate on the mechanical performance of dissimilar friction stir lap joints between an aluminum alloy (AA6082-T6) and a 20% glass fiber-reinforced polymer (Noryl™ GFN2). Both base materials were also tested under quasi-static and medium-to-high strain rate conditions to isolate their individual rate-dependent responses.

Results reveal pronounced strain rate sensitivity in the composite joints, with ultimate remote stress and bending stiffness increasing by approximately 29.9% and 26.3%, respectively, as the strain rate rises (as exhibited in Figure 1)[1]. Failure occurred predominantly within the polymer layer, indicating that the overall joint strength is governed by the mechanical limits of the Noryl component[1].

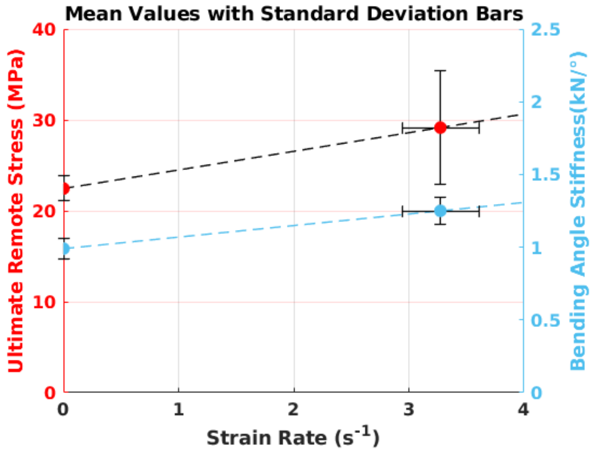

Figure 1. Strength and bend angle stiffness with strain rate in single lap joints[1].

Keywords: Friction Stir Welding; Lap joint; Dissimilar; Noryl GFN2; Aluminum

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3D Elasto-Plastic Simulation of Fatigue Crack Growth in Pure Titanium Using Non-Conforming Finite Element Meshes

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Abstract Fatigue crack growth (FCG) is governed by complex interactions between plastic deformation, crack closure, and three-dimensional stress states along the crack front. Conventional two-dimensional models, which assume either plane stress or plane strain simplifications, fail to capture these coupled effects, particularly in thin specimens where the stress state transitions continuously across the thickness.

In this study, a fully three-dimensional elasto-plastic model is developed to simulate FCG under constant-amplitude loading in a pure titanium specimen. The numerical framework explicitly accounts for crack closure and employs non-conforming finite element meshes with a minimum element size of 8 μm, enabling accurate crack-front evolution without remeshing. Simulations were performed on a 1 mm-thick specimen, allowing direct observation of the stress-state transition and its influence on local fatigue mechanisms.

The results demonstrate strong three-dimensional variations in plastic strain, crack opening displacement, and crack-tip shielding, which cannot be reproduced by conventional 2D approaches. This work represents one of the most advanced numerical implementations of 3D FCG to date, providing new insight into local damage mechanisms and contributing to the predictive modeling of fatigue life.

Keywords: Fatigue crack growth; Crack Front; Non-conforming mesh; Crack Closure

Railway Structures and Components

6 contributions

Experimental Characterization and Fatigue Behaviour of Spot-Welded Joints for Railway Vehicle applications

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Abstract: The structural integrity of railway passenger carbody increasingly relies on large numbers of resistance spot welded joints (RSW) to assemble the carbody shell structure [1]. Although RSW is widely employed in other transportation sectors such as automotive and aircraft industries [2,3], spot welding is a highly nonlinear process involving complex interactions among multiple process parameters, which can introduce a significant degree of variability [4]. Consequently, the fatigue performance of these joints under cyclic loading conditions remains a critical issue for design and assessment, particularly in the context of long-term durability requirements and safety regulations [5]. The limited fatigue test data and design curves for lap shear RSW joints in AISI 301 LN stainless steel sheets motivates the need for a dedicated experimental characterization of these connections. This work addresses this gap by presenting an experimental programme on single- and double-lap shear RSW joint configurations, consisting of two or three 1.5 mm-thick sheets. The experimental campaign combines monotonic tensile tests to quantify the static strength and failure mode of the connection, microhardness measurements to map the hardness profile across the weld nugget, heat-affected zone and base material, and macrographic cross-section analyses to characterise nugget geometry, identify welding defects and document crack paths. Constant-amplitude fatigue tests are performed on the same geometry to establish an S–N curve for the investigated joint configuration, to identify and rationalise the different fatigue failure modes and to quantify the associated scatter in fatigue life. The resulting dataset provides a consistent basis for supporting numerical modelling strategies and for improving the reliability of fatigue assessment procedures for spot welded joints in railway vehicle structures.

Keywords: Resistance spot welding; Fatigue; Railway train; AISI 301 LN; S-N curve.

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Fatigue Behaviour of Railway Applications: Micro- to Macro-scale Characterisation

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Abstract Fatigue crack initiation in historic riveted metallic railway bridges and their constituent structural steels is a significant source of uncertainty regarding structural integrity and life extension decisions, as pronounced local cyclic stress and strain gradients exacerbate variability and raise questions about the microscopic mechanisms that influence macroscopic initiation trends and their interactions. Previous studies have demonstrated that strain life methodologies based on uniaxial strain-controlled testing may effectively characterize initiation behavior and stable cyclic response through established relationships. Nevertheless, a significant portion of the literature and practice continues to depend on conventional frameworks enshrined in standard codes and long cycle testing campaigns, providing minimal adaptability for application to structural specifics beyond those codified. Furthermore, these traditional methods often address microstructural states indirectly and frequently neglect essential microscopic factors, such as crystallographic alterations and dislocation development, thereby prompting research that links materials science measurements to the requirements of structural engineering.

This study employs a comprehensive experimental protocol to characterize fatigue initiation in smooth small-scale metallic specimens under uniaxial strain-controlled fatigue testing across low and high cycle regimes at strain rations R_ε equal to 0 and -1, alongside X-ray diffraction to quantify dislocation densities and microstructural sensitivity analyses to ascertain grain size distributions. Furthermore, stable cyclic elastoplastic behavior is discerned from cyclic response by cyclic curve representations and parameter estimates. The resultant coupled microscale and macroscale dataset is examined using probabilistic inference employing classical and otherwise approaches to correlate stable cyclic parameters with observed microstructural state variables. The results offer a thorough description of cyclic elastoplastic behavior and the microscopic mechanism that trigger fatigue, facilitating the development of more applicable initiation models for both legacy and current steels. This integration facilitates the creation of more resilient diminishing dependence on extensive trial and error cycle testing programs.

Keywords: Railway bridges, fatigue, crack initiation.

Local Fatigue Assessment of a Y25 Railway Welded Bogie Frame

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Abstract: While railway structural design has advanced significantly through the use of modern materials, the Y25 freight bogie has remained the European industry standard for over 50 years. This success is largely explained by its low manufacturing and maintenance costs [1]. With the evolution of welding technologies and the increased understanding of welded structures, welded-frame Y25 bogies emerged as a viable alternative to the original cast designs. Given that bogies are designed for long service lives under high dynamic loading, these welded details become critical for durability and structural integrity. Among these, the weld that connects the central beam to the side frames is particularly important, as it transmits the entire load to the bearing box supports and is known in the industry for exhibiting significant cracking issues. This context motivates the present work, which focuses on applying the new EN 17149 standard to this weld, using the load spectrum defined in the bogie structural analysis standard EN 13749. Additionally, the study applies structural stress method developed by Dong [2] along the weld path and compares the corresponding results with those obtained from EN 17149 and from more conventional railway standards, such as ERRI B12/B17. The main purpose of this work is to present and compare the results of newer approaches, namely EN 17149 and Dong's structural stress method, with those from established standards, demonstrating their reliability and applicability to railway structures such as the Y25 bogie. Furthermore, the study highlights that fatigue assessment shows the design of Y25 bogie frame to be highly optimized, which may easily lead to fatigue life predictions below expectations when process parameters or safety factors are not defined accurately.

Keywords: Fatigue; Y25 Bogie; Welded Joint; FEA.

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A Global–Local Fatigue Assessment of a Railway Freight Wagon Welded Detail

João Nuno Silva[1], Francisco Portela[3], Leonor Ribeiro[3], Vasco Simões[3], Cláudio S. Horas[2], Pedro Montenegero[2], José A.F.O Correia[2], Abílio de Jesus[3]

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Abstract: Railway freight wagons are designed for long service lives under high payloads and demanding dynamic loading, making underframe welded details critical for durability and structural integrity [1]. Fatigue assessment of welded railway freight wagons must reliably link vehicle-level loading to weld-level damage, yet industrial practice still relies predominantly on nominal-stress verification, which can mask the influence of steep local stress gradients at weld toes. This work presents a global–local multiscale fatigue assessment framework applied to a welded frame of a railway freight-wagon platform. At the global level, a shell-based finite element model is developed with boundary conditions representing wagon–bogie interaction, and load cases are defined in accordance with EN 12663-2 [2]. Nominal stress ranges extracted from this model are used for fatigue verification following the DVS 1612 [3] methodology, enabling systematic identification and ranking of fatigue-critical welded details. A refined local 3D solid submodel of a selected critical detail is subsequently constructed, with boundary displacements transferred from the global model to ensure kinematic consistency. Using a mesh-refinement strategy consistent with IIW recommendations [4], structural hot-spot stresses are obtained by surface extrapolation. In parallel, Dong's structural stress method [5] is applied along a prescribed crack path (cracked weld line), providing an equilibrium-based stress measure designed to reduce mesh and notch-detail sensitivity. On this basis, the proposed framework is employed to perform fatigue verification with each stress concept. The overarching objective is to evaluate the predictive performance of these verification methodologies for welded railway freight-wagon structures, and to demonstrate that a global–local multiscale approach can deliver a more physically consistent basis for code-compliant fatigue assessment under standardised service loading.

Keywords: Multiscale; Fatigue; Railway Freight Wagon; Welded joint; FEM.

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Fatigue Life Extension of Metallic Bridges: a general overview

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Abstract: Structural engineering faces critical challenges regarding decarbonisation targets set by the European Green Deal while preserving ageing transport infrastructure. A large stock of metallic bridges, built through the 20th century, now operate beyond its originally anticipated service life, under conditions markedly different from those assumed in the original design. Consequently, structural integrity and fatigue have emerged as the central concern, particularly for bridges built with early-generation wrought and puddle iron, whose mechanical properties exhibit substantial scatter. Furthermore, variable-amplitude train loading, corrosion, multiaxial stress states, size effects and notch sensitivity are key aspects to evaluate fatigue behaviour. Traditional S-N curve-based design approaches are conservative and have some limitations in the very-high-cycle regime and under complex loading scenarios. This motivates life-extension and strengthening strategies that support a circular economy.

To bridge the gap between life-extension and structural integrity, a paradigm shift is required. Integrating Structural Health Monitoring (SHM) with advanced data processing offers a pathway to move from reactive maintenance to predictive management. Recent developments were accomplished, considering inspections with Unmanned Aerial Vehicles (UAV), deep learning and pattern recognition techniques (for corrosion detection) enabling more accurate fatigue damage characterization at the detail level [1]. Complementing these digital strategies with experimental characterization and numerical modelling leads to high-fidelity data required for accurate reliability assessment. Reinforcement techniques improve fatigue-life of damaged structural details, aligned with sustainable policies. Fibre-reinforced polymer (FRP) systems have already demonstrated high effectiveness [2], while current research increasingly explores additive manufacturing solutions based on topology optimisation as a route to smart material-efficient strengthening components, for which the long-term fatigue performance and practical efficiency still require systematic investigation.

Keywords: Metallic Bridges; Fatigue Damage; Structural Health Monitoring.

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Influence of monotonic and cyclic material behavior on fatigue crack growth predictions under constant and variable amplitude loading

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Abstract In ductile materials, cyclic plastic strain at the crack tip is widely accepted as the primary driving mechanism for fatigue crack growth. Material properties determine the stress and strain fields near the crack tip, thereby influencing the fatigue crack growth rate. Numerical simulation of fatigue crack growth requires accurate material modeling, particularly of elastoplastic behavior. Since cracks propagate under cyclic loading, accurate modeling of cyclic plasticity near the crack tip requires hardening models that incorporate both isotropic and kinematic hardening mechanisms. Conventional approaches typically focus on the cyclic response of the material, using data obtained from low-cycle fatigue tests, thus neglecting monotonic behavior and tensile strength in the material parameter calibration.

This study aims to assess how the material's monotonic behavior and its numerical representation affect fatigue crack growth predictions under constant and variable amplitude loading conditions. Accordingly, the influence of the material constitutive model on fatigue crack growth predictions was analyzed, particularly focused on the data used for calibrating the hardening law. Material parameters were identified using a genetic algorithm to obtain the best fit between numerical and experimental monotonic and cyclic curves. Results show that, under constant amplitude loading, including monotonic tensile data in the material calibration procedure provides minimal benefit. However, under variable amplitude loading, incorporating monotonic behavior increases the overload-affected zone, leading to results that more closely match the experimental observations.

Keywords: Fatigue crack growth; Metallic materials; Finite element method; Constitutive model

Mechanical Performance of Additive Manufactured Components

7 contributions

Quantitative fractography and the fatigue crack propagation behaviour of DED'ed 18Ni300 Maraging steel

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Abstract The fatigue crack propagation behaviour of additively manufactured metals is not entirely understood, particularly in the interactions between the textured microstructure of AM'ed parts, the distribution of process-inherent defects, and the subsequent crack resistance. With the push towards the use of AM'ed components in structural applications, the insight into fatigue and mechanical properties must be furthered. In this work, compact tension specimens comprised of 18Ni300 Maraging steel, obtained via directed energy deposition, were tested at a constant force ratio in a delta K-increasing and a delta K-decreasing methodology according to the ASTM E647 standard. The produced specimens were printed vertically (crack path perpendicular to the building orientation) and horizontally (crack path parallel to the building orientation), in their as-built and heat-treated states. The crack of horizontally printed specimens displayed significant kinking, with the crack warping along inter-dendritic spacing, a behaviour observed in both delta K-increasing and decreasing tests. Vertically printed specimens did not display this behaviour, although a plateau within the stable regime occurred, associated with the transition between printed layers [1]. Besides the crack propagation curves, the resulting crack paths were geometrically characterized in their ruggedness[2] and fractal dimension[3]. Several roughness metrics (arc-to-chord, tortuosity, topological dimension) were computed and compared in the ease of implementation (both *in-situ* and *ex-situ*), associated computation time, and correlation with fatigue crack growth.

Keywords: Fatigue, Crack Propagation, Quantitative Fractography, Additive Manufacturing

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Mechanical Behavior of Biocompatible Titanium alloys with Bulk and Porous Structure Produced by Powder Bed Fusion-Laser Beam

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Abstract Biocompatible titanium-based alloys were manufactured by Powder Bed Fusion-Laser Beam (PBF-LB/M) to evaluate the effects of alloy composition, engineered porosity and build orientation on mechanical behavior and fracture response for orthopedic implant applications. Pure Ti (Grade 2), Ti-6Al-4V ELI (Grade 23) and a β-type Ti-39Nb alloy were produced as bulk specimens and as porous lattices with gyroid and Voronoi architectures with porosity levels of 50%, 65% and 75%. The mechanical performance was assessed through tensile and compression tests. Bulk Ti-39Nb specimens showed a reduced Young's modulus of 77 ± 2 GPa, ultimate tensile strength of 754 ± 18 MPa, and total elongation of 19 ± 3%, while Ti-6Al-4V ELI exhibited higher stiffness and strength (E = 109 ± 1 GPa, σ_{UTS} = 1165 ± 53 MPa) with lower ductility. Gyroid lattices demonstrated superior compressive stability compared to Voronoi structures. Fractographic analysis revealed predominantly ductile fracture in Ti-39Nb and mixed ductile–brittle features in Ti-6Al-4V, highlighting the relevance of all these factors for structural integrity.

Keywords: additive manufacturing, Powder Bed Fusion-Laser Beam, biocompatible titanium alloys, porous structures.

Melt Pool Monitoring as an In-situ Defect Detection Method for AlSi10Mg Parts Produced by PBF-LB/M

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Abstract

Additive Manufacturing (AM) by Laser Powder Bed Fusion of Metals (PBF-LB/M) continues to expand within several sectors such as the aeronautical industry, where the ability to monitor process stability and detect defects during fabrication is essential for ensuring part reliability and compliance with aeronautical requirements. Among the available in-situ monitoring strategies, Melt Pool Monitoring (MPM) analysis has emerged as a promising tool for capturing local variations in thermal behavior that may be associated with defect formation.

This work explores the use of melt pool emission data acquired during the fabrication of AlSi10Mg components as a base line for assessing process anomalies. Statistical descriptors derived from the emission signals were compared with defect information obtained through high-resolution X-ray microtomography (μCT), enabling the identification of emission patterns that may reflect changes in process conditions.

Components were produced under optimized conditions and intentionally varied parameter sets to generate a range of defect scenarios and evaluate the sensitivity of the monitoring approach. The results illustrate how emission-based analysis can provide complementary insight into the manufacturing process and support early identification of regions of interest for further inspection. This methodology highlights the potential of MPM as a practical element within AM quality-assurance workflows.

Keywords: Additive Manufacturing (AM); Powder Bed Fusion Laser Beam of Metals (PBF-LB/M); X-Ray Computed Micrography (mCT); Melt Pool Monitoring (MPM); AlSi10Mg

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Effect of Printing Strategies on the Mechanical Performance of PLA and PLA/Kahili Ginger Biocomposites obtained by fused deposition modelling

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Abstract:

Kahili ginger (KG) is a native plant from the Hawaiian rainforest and is currently recognized as one of the most invasive species worldwide. Identifying sustainable and economically viable applications for this biomass is therefore essential to help control its spread. KG stem fibres exhibit mechanical properties comparable to conventional natural fibres such as kenaf, sisal, and bamboo, which are commonly used as reinforcements in polymer composites [1]. This work investigates the effect of fused deposition modelling (FDM) printing strategies on the mechanical performance of PLA/KG biocomposites. KG stems collected in the Azores archipelago were dried, ground, and chemically treated prior to compounding with polylactic acid (PLA) in a twin-screw extruder. The resulting material was pelletized and subsequently re-extruded using a single-screw extruder to produce 3D printing filaments. Test specimens were produced by FDM using different deposition strategies. Density measurements, tensile tests, and flexural tests were performed to evaluate mechanical performance. Fractured surfaces were analyzed by scanning electron microscopy (SEM). The results showed that, regardless of the printing strategy, the incorporation of KG fibres increased both tensile and flexural moduli compared to printed PLA. Fractographic analysis revealed good interfacial adhesion between KG fibres and the PLA matrix. Overall, the findings demonstrate the potential of Kahili ginger fibres as a sustainable reinforcement material for FDM polymeric composites

Keywords: Mechanical Performance, Additive Manufacturing, PLA/Kahili Ginger.

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Production of thin features by Additive Manufacturing

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Abstract: Laser Powder Bed Fusion (LPBF) enables the fabrication of ultra-thin metallic structures, but their mechanical performance and defect sensitivity remain critical challenges, particularly below 0.5 mm thickness. This work investigates the fracture behaviour of AlSi10Mg dog-bone specimens with gauge thicknesses under 0.4 mm, produced in different parameters, combined with an analysis of a 0.2 mm-thick gyroid thin-wall structure manufactured under equivalent process parameters. Tensile testing of the dog-bone samples was followed by a multi-scale fracture characterization using optical microscopy, scanning electron microscopy (SEM). The results show limited ductility and premature fracture dominated by process-induced defects, particularly lack-of-fusion features aligned with melt-pool boundaries, which become increasingly critical as wall thickness decreases. To complement these findings, the gyroid thin-wall was analysed using high-resolution micro-computed tomography (micro-CT), enabling a non-destructive assessment of porosity, thin-wall integrity, and defect morphology. Micro-CT revealed localized regions of incomplete fusion and irregular wall thinning consistent with the fracture-initiating defects observed in tensile specimens. The combined analysis highlights the strong sensitivity of sub-millimetric LPBF AlSi10Mg geometries to insufficient energy input and melt-pool instabilities. These insights underscore the need for optimized scanning strategies and thermal management approaches when manufacturing ultra-thin features for applications such as lattice structures, heat-exchanger fins, and lightweight aerospace components**.**

Keywords: Metal Laser Powder Bed Fusion; Thin Walls; AlSi10Mg

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Failure Analysis of an Aeronautical Component Produced by Metal Additive Manufacturing

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Abstract: Additive Manufacturing (AM) has emerged as a transformative technology, enabling the production of highly optimized components that were previously unattainable through conventional manufacturing routes. Among the various AM techniques, Laser Powder Bed Fusion for metals (PBF-LB/M) has gained particular prominence, especially for the aerospace components, due to its ability to manufacture lightweight, topologically complex structures with excellent dimensional accuracy and material efficiency. Although the mechanical behaviour of metal components produced by Laser Powder Bed Fusion (PBF-LB/M) is usually assessed using standardized test coupons, these specimens sometimes do not fully represent how parts with intricate geometries will perform in service. Factors such as residual stresses, process-driven distortions, and local variations in microstructure, characteristic of the PBF-LB/M process, can significantly influence the actual response and create discrepancies when compared with numerical models that assume idealized material properties. In this study it's presented the development of an aerospace part, thought topological optimization with a full set of qualification tests. The part was produced via PBF-LB/M process, with optimized parameters for quality and productivity. Tests of the build job include coupon level, produced with the component, to access density, hardness, microstructure and mechanical properties. The test program involved also full size testing of the component, first non-destructive testing as liquid penetrant, micro-CT and loading up to 120% design load. At the end the component was tested until failure, being analysed the behaviour of the component and fracture surfaces. The results demonstrated that the numerical model predict well the failure location and that the

component reveal a safe failure behaviour, with limit load above the specified limit, without catastrophic failure.

Keywords: Failure Analysis, Additive Manufacturing, PBF-LB/M, Full Scale Testing.

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Optimisation Models to Predict the SN curves of Ti10Ta alloy Obtained by Additive Manufacturing

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Abstract: This research introduces a new approach to predict the fatigue behaviour (S-N curve) of additive-manufactured Ti-10Ta alloys based on the intrinsic manufacturing defects collected from nanotomography and optical microscopy. To overcome the lack of characterization by the state-of-the-art models of the impact of internal defects on fatigue performance [1]. This methodology proposed the use of optimisation algorithms such as Nelder-Mead, SLSQP, and L-BFGS-B to define new equation parameters, which could improve the solution proposed by Murakami & Endo [2]. The fitted curves, including intrinsic manufacturing defect characteristics, revealed a high prediction accuracy (R^2=91.2%) comparable to Basquin's equation (R^2= 92%). The final results showed significant improvements from all the algorithms, with three distinctive fatigue prediction models, built to consider the characteristics of the defects, both from nanotomography and optical microscopy. These findings underline the impact of defect size and distribution in the fatigue response, while providing a practical and empirical solution to characterise Ti10Ta alloys' behaviour, considering the defects intrinsically associated with additive manufacturing. Offering enhanced precision and adaptability for biomedical and engineering applications. [3].

Keywords: Additive manufacturing, Fatigue Prediction Models, Ti-10Ta, Manufacturing Defects

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Fatigue Behaviour of Metallic Alloys

7 contributions

Local fatigue modelling considering corrosion degradation effects

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Abstract. As is well known, the long-term corrosion degradation of metallic structures occurs electrochemically in the presence of oxygen and water. Therefore, fatigue properties are affected by reductions in effective cross-sectional area, which reduce the mechanical properties of structural element sections, impacting the stability of the structural elements and, in turn, the overall structure. Sonsino (Schönowitz et al., 2023) investigated the effects of wet-dry cycles and continuous irrigation using 5% NaCl on the fatigue behaviour of various forged, welded, and cast aluminum components used in vehicle safety, where a 50% reduction in fatigue strength after 5×10^6 load cycles, along with a slightly steeper slope of the S–N curve due to the corrosive environment.

$$N = 5 \times 10^6 \Rightarrow \sigma_{a,c} = 0.5 \cdot \sigma_{a,air}$$

Based on the studies conducted between 2017 and 2019 by Adasooriya, Hemmingsen, and Pavlou (*ADASOORIYA et al., 2019*), Basquin fatigue curves considering the long-term corrosion degradation effect can be expressed as

$$\sigma_{a,c} = \left[\sigma_f' \cdot \left(2N_{f,LCF}\right)^a\right] \cdot \left(2N_f\right)^{(b-a)}$$

where, $\sigma_{a,c}$ is the stress amplitude for the corroded material, $N_{f,LCF}$ is the fatigue life of uncorroded materials at the yield stress, σ_y, and a is the material exponent at the corrosion current state ($a \geq 0$). In this research, proposals for generalising local fatigue models that account for long-term degradation effects, based on various fatigue criteria under uniaxial loading conditions, are presented. These proposals belong to the families of stress-, strain-, and energy-based methods.

Keywords: Fatigue; Local Approaches; Corrosion Degradation Effects; Structural Steels.

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Probabilistic fatigue prediction of metals at variable amplitude loading based on the non-linear damage

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Abstract. In 1924, Palmgren first proposed the Linear Damage Rule (LDR). Due to these shortcomings and the limitations of the Linear Damage Rule (LDR) model, Marco and Starkey introduced the first non-linear load-dependent damage theory in 1954. In 1960, Grover proposed a two-stage linear damage approach that accounted for stress cycle ratios in two distinct stages of the fatigue damage process under constant-amplitude loading. In a study conducted from 1966 to 1981, Manson and Halford introduced the Double Linear Damage Rule (DLDR). This rule facilitates the evaluation of cumulative fatigue damage for high-low (H-L) and low-high (L-H) loading sequences. In 1998, Fatemi & Yang (1998) presented a review of fatigue-life prediction theories and fatigue-damage accumulation models for homogeneous materials. Huffman and Beckman (2013), which models non-linear damage by calculating the damage incurred during each loading cycle, considers the damage state at the time of that cycle. Aeran et al. (2017) introduced a new nonlinear fatigue damage model based on S-N curves, which relies on a specific model parameter. Dias et al. (2019) presented a parametric probabilistic approach for evaluating cumulative fatigue damage. Chen et al. (2023) examined a nonlinear fatigue-damage accumulation model under variable-amplitude loading. Yu et al. (2025) introduced an enhanced cumulative fatigue damage model that incorporates toughness exhaustion and new considerations of residual strength, treating these as dual-state parameters. In this work, a probabilistic fatigue-life approach to nonlinear damage accumulation for variable-amplitude fatigue, based on Huffman & Beckman principles and CFC probabilistic modelling, as well as local sub-modelling by means of finite element method, is developed for metallic materials and components.

Keywords: Fatigue; Non-Linear Damage; Probabilistic Modelling; Metals; Components.

Evaluating fatigue properties based on classical and hybrid estimation methods

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Abstract. Typically, a fatigue failure is called "low-cycle fatigue" if the number of cycles to failure is less than 10^4. The low-cycle fatigue (LCF) regime was proposed independently by Coffin (1954) and Manson (1953), relating the plastic strain amplitude, $\Delta\varepsilon_p/2$, with the number of reversals to failure, $2N_f$, or life cycles, N_f. In the 1960s, George Morrow (MORROW, 1965) combined the Basquin and Coffin-Manson relations to account for elastic and plastic strain amplitudes in the LCF and HCF regimes. Several research works have been developed establishing relationships between fatigue properties and monotonic tensile strength properties (MANSON, 1965; MANSON & HIRSCHBERG, 1970; SOCIE, MITCHELL & CAULFIELD, 1977; MURALIDHARAN & MANSON, 1988; BÄUMEL & SEEGER, 1990; ONG, 1993; PARK & SONG, 1995; MEGGIOLARO & CASTRO, 2004; LI, ZHANG & LI, 2018; CAO, SUN & CHEN, 2024). A new proposal of a hybrid estimation method for evaluating fatigue properties (σ_f', b, ε_f', c) is based on a weighted average of the evaluated fatigue properties by the 10 estimation methods under consideration, by means of evolutionary search, where an objective function based on MARE or $log-$average m with restrictions associated with the quality criteria of these indicators, but also knowledge of the correlation coefficient between fatigue and monotonic tensile strength properties is used, and considering the most appropriate mathematical formulations, is presented.

Keywords: Fatigue; Strain-life, Estimation Methods; Mean Value Theorem; Evolutionary Search; Metallic Materials.

Effect of thread geometry on the fatigue life of high-strength bolt steels

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Abstract

Offshore wind energy production has emerged as a key solution to reduce greenhouse gas emissions in the energy sector [1]. Although the marine environment offers favourable conditions for energy production, it also exposes these structures to adverse environmental conditions. Wind and waves introduce cyclic loads in these structures, leading to fatigue damage [2]. Among the elements most affected by this phenomenon are bolted connections, due to stress concentration. Bolt steel of strength class 10.9 is the material most commonly used in bolts for wind turbines. However, new options should be investigated to increase the durability and structural integrity of these connections. According to the literature, bolt steels with strength classes higher than 10.9 are not commonly applied. Since grade 12.9 bolt steel has higher yield and ultimate stress values, theoretically, it could have a better fatigue resistance. However, the lack of data on its cyclic behaviour highlights the need for detailed fatigue characterisation.

In this context, the fatigue behaviour of high-strength bolt steels with strength classes 10.9 and 12.9 was investigated. Compared with grade 10.9, bolt steel 12.9 demonstrated a superior mechanical strength, while displaying a lower ductility. The fatigue results revealed a higher fatigue resistance for bolt steel 12.9. One of the main goals of this investigation was to assess the effect of a thread on the fatigue life of the bolt steels under study. To do that, threaded specimens were designed. The stress concentration factor of these specimens was determined both numerically and analytically. In contrast with the results for smooth specimens, the fatigue results for threaded specimens demonstrated a similar fatigue resistance for both steels. These results indicate a higher notch sensitivity of bolt steel 12.9. A

probabilistic band of the experimental results was determined using the Castillo and Fernández-Canteli (CFC) [3] model. The fatigue fracture surfaces were analysed by scanning electron microscopy (SEM).

Keywords: Fatigue; High strength bolts; Probabilistic analysis; Thread effect

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Multiaxial fatigue performance of S690 QL steel in HCF and VHCF regimes

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Abstract. Nowadays, high-cycle (HCF) and very high-cycle (VHCF) fatigue regimes have attracted significant interest, as engineers seek to extend the service lives of components and structures to accomplish sustainable goals. The assessment of regimes of longer lives sometimes requires higher frequencies of testing to reduce the time needed to achieve the region beyond 10 million cycles, which can represent additional challenges in terms of experimental testing [1,2]. Moreover, in real-world scenarios, structures are subjected to complex loadings or present geometries that induce local multiaxial stress states [3]. Hence, in this work, the influence of a biaxial stress state on the fatigue performance of S690 QL steel in both high-cycle and very high-cycle fatigue regimes was analysed. To assess the VHCF regime, cruciform specimens were tested using an ultrasonic testing machine. The geometry was designed based on a finite-element model that helped to perform a frequency analysis. Meanwhile, for the HCF regime, hourglass specimens were tested under combined and proportional torsional and axial loadings using an electromechanical fatigue machine. Different multiaxial damage-parameter models were applied and compared to assess fatigue performance. The frequency effect was also addressed by combining a probabilistic regression model with a multiaxial damage parameter.

Keywords: very high cycle fatigue, high cycle fatigue, multiaxial, S690 steel

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Statistical Fatigue Life Characterization of Additively Manufactured Maraging Steel

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Abstract Parts fabricated by additively manufactured methods have currently achieved densification level as high as 99.99%. Despite this high densification level, several studies from literature concluded that defects such as pores cannot be fully eliminated, even when subjected to post-treatment[1], [2], [3]. The focus of this study is to present statistical investigation into fatigue variability of maraging steel M300 samples produced by laser powder bed fusion (LPBF) in as-built condition. During the samples fabrication, substrate was maintained at 170 °C. To evaluate the fatigue scattering, a fatigue testing campaign with R=-1 was conducted across stress amplitudes level which ranges from 300 to 800 MPa. However, among these ranges, two primary loading levels were selected for statistical analysis, and at each of the level 10-12 samples were tested for statistical significance. The resulting fatigue will be analyzed using two parameter Weibull distribution, which will provide a framework to characterize material reliability at these two stress amplitudes.

Keywords: fatigue life; weibull distribution, computed tomography, laser powder bed fusion, Deep learning segmentation

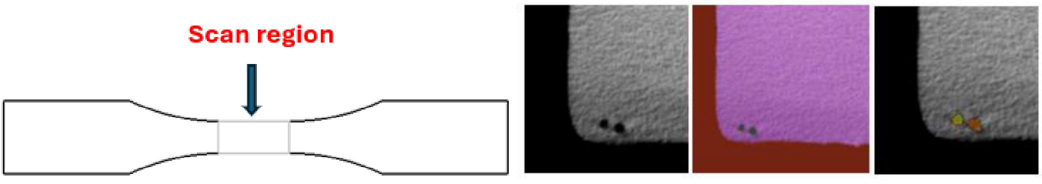

Figure 1. Fatigue specimen geometry, (b) sequential pipeline for defect segmentation and quantification (high resolution grayscale image, segmented image and colour code porosity)

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Obtaining fatigue properties of the Várzeas bridge steel using an optimization technique through estimation methods

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Abstract Railway infrastructure is essential for modern transportation, so predicting fatigue life accurately is important for keeping structural components/connections safe under repeated loads. Traditional design codes mostly use global fatigue assessment methods based on nominal stresses and standard S–N curves of structural components/connections, but these may not fully account for local geometry or mechanical properties of metallic materials. To address this, empirical methods have been developed to estimate fatigue properties of metallic materials from monotonic tensile strength or hardness measurement data using simplified heuristics. In this study, an improved approach to evaluating the fatigue properties of metallic materials, based on an optimization technique using empirical estimation methods, was implemented. In this study, the fatigue properties of the Várzeas railway bridge steel were evaluated using the proposed improved approach. The optimized results, obtained through an evolutionary search, were validated against experimental fatigue data for S235 steel and compared with traditional estimation methods - Manson's universal slopes (1965), four-point correlation (1965), Mitchell method (1977, 1979), modified universal slopes (1988), uniform material law (1993), modified four-point correlation (1993), modified Mitchell method (1996), Meggiolaro's Median (2004), modified Park-Song method (2018), and GP-symbolic regression (2024). The results were evaluated using two error indicators – mean absolute relative error (MARE, %) and logaverage m. The proposed optimization approach yielded better results than several traditional estimation methods, demonstrating strong potential for evaluating the fatigue properties of ancient bridge steels.

Keywords: Fatigue; Estimation Methods; Evolutionary Algorithm; Railway Bridge Steel.

Hydrogen Embrittlement and Environment Effects in Materials

5 contributions

An Open-Source Phase Field Framework for Hydrogen Assisted Fatigue Crack Growth

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Abstract We present an open source, MOOSE based phase field framework that couples fatigue fracture and hydrogen transport to simulate hydrogen assisted fatigue crack initiation and growth under high cycle loading, with an emphasis on frequency effects and exposure history. The method extends the Felino phase field fatigue infrastructure with stress assisted diffusion and a hydrogen dependent fracture resistance, while retaining an efficient envelope based mean load formulation to avoid costly cycle by cycle resolution. A consistent cycle to time mapping links cycle blocks to physical time so that hydrogen redistribution evolves on the appropriate time scale and crack growth becomes sensitive to loading frequency and pre charging. Pre charging is treated as a dedicated diffusion stage whose concentration field is transferred to subsequent fatigue simulations, enabling a clean separation between long term charging and fatigue driven propagation. To robustly represent rapid transport along newly created crack surfaces, a damage dependent mobility enhancement is introduced in highly degraded regions, improving numerical stability in the presence of steep concentration gradients. The coupled multi-physics problem is solved with a staggered partitioned strategy and demonstrated on SENT and an multi crack benchmark to verify complex crack path capabilities, and on compact tension specimens where simulations reproduce the experimentally observed downward shift of da/dN versus ΔK with increasing frequency under high pressure hydrogen. Sensitivity studies highlight how segregation and hydrogen damage parameters and the fatigue degradation controls govern acceleration trends, providing practical guidance for calibration and for reproducible assessment of hydrogen environment effects in structural integrity applications.

Keywords: Hydrogen-assisted fatigue; Phase field fracture; Open source multiphysics modeling

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A Coupled Elastoplastic–Diffusion Damage Model for Predicting Hydrogen-Assisted Fracture Regimes

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Abstract Hydrogen embrittlement remains one of the most critical challenges to the safe and reliable use of metallic materials in hydrogen-based energy systems. Its complexity arises from the interplay of multiple microscopic mechanisms, such as hydrogen-enhanced localized plasticity (HELP), adsorption-induced dislocation emission (AIDE), hydrogen-enhanced strain-induced vacancy formation (HESIV), and hydrogen-enhanced decohesion (HEDE). The competition between these mechanisms governs whether fracture occurs through decohesion-driven intergranular failure or through microvoid coalescence leading to transgranular fracture.

This work presents a continuum mechanics-based numerical framework, implemented within the finite element method, to predict fracture and identify the governing fracture regime in high-strength steels exposed to pressurized gaseous hydrogen. The elastoplastic constitutive behaviour is described using a yield function based on the one proposed by Gao et al. [1], in which the equivalent stress scalar depends on the stress invariants I1, J2, and J3. This formulation is coupled to a modified Gurson-type continuum damage model capable of representing both microvoid-coalescence-driven and decohesion-driven fracture. The mechanical formulation is further coupled with a hydrogen diffusion model to compute the spatial distribution of hydrogen concentration. Hydrogen transport is influenced by the local stress state, while the elastoplastic response and damage evolution are, in turn, dependent on hydrogen concentration, enabling a fully coupled description of hydrogen-assisted fracture.

Finally, the parameter calibration procedure is discussed. Once calibrated, the model is applied to ongoing numerical studies and validated against experimental data for high-strength steels tested in air and in pressurized hydrogen environments, providing insight into the governing mechanisms of hydrogen-assisted fracture.

Keywords: Continuum Mechanics, Hydrogen Embrittlement, Fracture, Finite Element Method, Constitutive Modeling

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Influence of hydrogen embrittlement on the fatigue behaviour of 316L stainless steel TIG welded joints

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Abstract Hydrogen embrittlement (HE) is a critical phenomenon that undermines the structural integrity of metallic materials, particularly those employed in hydrogen storage and transportation systems. This vulnerability is even more pronounced in welded joints, where microstructural heterogeneities and residual stresses can further increase susceptibility to hydrogen-assisted damage. In this study, the effect of HE on the fatigue behaviour of 316L austenitic stainless-steel welded joints was examined. Tensile and fatigue tests were carried out on the base material, on welded joints, and on welded joints previously charged with hydrogen, allowing for a comprehensive assessment of the degradation in their mechanical performance. The results demonstrated that the welding process itself substantially decreased the fatigue strength of 316L stainless steel, while the introduction of hydrogen caused an additional and more severe decline in fatigue life. Microstructural analyses revealed the presence of austenitic–ferritic duplex structures within the weld bead. Although the δ-ferrite phase contributed favourably to reducing the risk of hot cracking, it simultaneously increased the material's susceptibility to hydrogen embrittlement. Fractographic observations of hydrogen-charged weld beads exhibited clear features associated with hydrogen-induced cracking, including characteristic fracture morphologies indicative of hydrogen-assisted damage mechanisms [1].

Keywords: Hydrogen embrittlement, 316L stainless steel, Austenitic-ferritic microstructure, TIG weld, Fatigue behaviour

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A novel specimen geometry to study the effect of environment on FCG

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Abstract Fatigue crack growth (FCG) in metals is typically studied using da/dN-DK plots obtained experimentally in C(T) or M(T) specimens. These geometries have through-thickness cracks, and the crack front may be divided into one interior region, two near-surface regions and two corner points. Specimens with a thickness lower than 4 mm are usually assumed to be under plane stress state, while specimens with a thickness higher than 10 mm are considered to have a dominance of plane strain state. However, even very thick specimens have surface regions, which may be expected to influence FCG rate. On the other hand, thin specimens still have interior regions.

A novel cylindrical specimen with a central crack was proposed by the authors to study FCG under nearly pure plane strain conditions in both air and inert environments. The specimen is produced by additive manufacturing, which permits the positioning of the crack at a central position. The crack grows keeping a circular shape, without corner points, avoiding crack shape issues. Moreover, any departure from pure circular shape is an indication of incorrect loading alignment. The specimens are very interesting to to study the effect of atmosphere on FCG without complex equipment.

The use of this novel specimen was organized in three steps: (a) Prove the validity of the concept [1]; (b) Setting the experimental procedure, namely the accurate determination of crack length inside the specimen [2,3]; (c) Apply the geometry to study different issues of FCG under plane strain conditions.

The first two steps were completed with success and the specimens are currently being used to study the effects of the environment and overloads in AlSi10Mn alloy.

Keywords: Fatigue crack growth; Metallic materials; CCC specimen; Environmental effect

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Phase Field Fracture and free energy formulations

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Abstract This work presents Felino, a modular and open-source finite element framework developed for the simulation of fatigue fracture using phase-field models. Built on the MOOSE (Multiphysics Object-Oriented Simulation Environment) platform, Felino provides an extensible and computationally efficient environment for modeling crack nucleation and propagation under cyclic and thermomechanical loading conditions. The framework incorporates several advanced modeling capabilities, including temperature coupling in fatigue simulations, the integration of mean-load effects, and an adaptive cycle-jump algorithm designed to accelerate simulations involving high-cycle fatigue [1]. Felino supports both staggered and monolithic solution strategies, enabling flexibility in solving the coupled mechanical and fracture evolution equations. In addition, the framework allows users to customize material models and degradation laws, making it adaptable to a wide range of structural materials and loading scenarios. Validation against benchmark problems and literature results demonstrates the framework's ability to accurately predict fatigue crack initiation and growth across different geometries and loading conditions. The results highlight Felino's robustness, flexibility, and computational efficiency, establishing it as a promising tool for advancing predictive fatigue modeling in engineering materials.

Keywords: High-Cycle Fatigue, Phase-Field Modeling, Crack Nucleation, Crack Propagation, Felino

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Structural Health Monitoring

7 contributions

Non-contact stereo-vision monitoring of a transformer enclosure

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Abstract The industrial transformers must be thoroughly tested prior to their implementation in electrical grids, it is important to perform integrity tests on industrial transformer's enclosures, ensuring they are structurally sound. Non-contact optical techniques provide a promising approach for the three-dimensional monitoring of these industrial parts.

In this research, an industrial transformer enclosure is gradually filled with water, increasing its internal pressure and deforming its walls. Three stereo optical setups and a phase-shifting (PS) terrestrial laser scanner (TLS) were used to monitor the deformation of two enclosure walls and the enclosure cover. The stereo camera setups were used to monitor the surfaces with digital image correlation (DIC), while the laser scanner obtained point clouds of the same walls and cover. The measurements were taken with an empty enclosure and with varying volumes of water. The measurements were subsequently compared against simulation data.

The solutions presented in this research support the use of non-contact optical techniques for industrial structural monitoring, offering an alternative for mechanical performance verification.

This work is a result of Agenda "ATE – Aliança para a Transição Energética", nr C644914747-00000023, investment project nr 56, financed by the Recovery and Resilience Plan (PRR) and by European Union – NextGeneration EU.

Keywords: Digital Image Correlation; Non-Destructive Testing; Structural Analysis

Dynamic Mode I Fracture Testing of Aluminum Alloys Using a Modified SHPB System

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Abstract

An experimental methodology was developed to study Mode I fracture behavior of the aluminum alloy AA2024 under high strain-rate loading conditions. The approach combines quasi-static Single Edge Notch Bend (SENB) testing with a custom-designed dynamic three-point bending configuration integrated into a Split Hopkinson Pressure Bar (SHPB) system. Full-field deformation measurements were obtained using Digital Image Correlation (DIC) to monitor crack opening and specimen compliance during loading. Quasi-static fracture experiments were conducted in accordance with ASTM E399 to establish a reference response, yielding conditional fracture toughness values. Dynamic bending tests were subsequently performed to explore the strain-rate sensitivity of fracture behavior. While the experimental setup successfully enabled dynamic crack loading and deformation measurement, discrepancies were observed between static and dynamic force levels, suggesting limitations in load transmission or force measurement within the SHPB configuration. Overall, the proposed experimental framework demonstrates the feasibility of dynamic three-point bending fracture testing using SHPB techniques, while highlighting key challenges related to force measurement accuracy and optical diagnostics. These findings provide a foundation for ongoing improvements toward reliable high strain-rate fracture characterization of structural aluminum alloys.

Keywords: Fracture toughness, High Strain Rate, Split Hopkinson Pressure Bar

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Digital Image Correlation as a Defect Assessment Technique for Thin Specimens Produced by PBF-LB/M

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Abstract

Laser Powder Bed Fusion of Metals (PBF-LB/M) enables the fabrication of complex lightweight geometries, yet thin features remain particularly susceptible to process-induced defects and variability in mechanical performance. This study investigates the use of Digital Image Correlation (DIC) as a non-contact technique to assess defect-driven strain localization in thin AlSi10Mg specimens manufactured by (PBF-LB/M). Dogbone tensile specimens with thicknesses of approximately 0.4 mm were produced using identical processing parameters. Uniaxial tensile tests were conducted while surface strain measurements were obtained using VIC2D. In parallel, a finite element (FEM) model of the analysed specimens was developed to enable comparison with the strain fields measured by DIC. The reduced thickness of the specimens introduces significant experimental challenges, as defect sizes may be comparable to the specimen thickness. Furthermore, the high slenderness of the samples and residual distortions introduced during the manufacturing process can lead to slight warping, hindering alignment and affecting accuracy of DIC. Despite these limitations, the application of DIC enabled the exploration of spatial strain distributions across the analysed region and provided insight into strain heterogeneity associated with process-induced imperfections. Comparison with FEM data provided additional context for understanding the observed deformation patterns. Although the methodology is still exploratory for such thin geometries, the results indicate that DIC remains a promising approach for defect assessment and structural qualification of thin metal additive manufacturing components,

supporting future refinement of experimental procedures and measurement strategies.

Keywords: PBF-LB/M; Thin-walled structures; DIC; Process-induced defects; Tensile testing

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A Novel Seven-Point Bending Method to Predict Equivalent Distributed Service Loads in Copper Electrical Conductors

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Abstract Electrical conductors subjected to service currents experience distributed mechanical loads arising from electromagnetic forces, which requires reliable estimation of their load-bearing capacity. This work proposes an experimental methodology to determine the equivalent uniformly distributed load that copper electrical conductors can sustain using a seven-point bending configuration.

The test setup consists of three upper loading points and four lower supports, enabling controlled introduction of three concentrated forces while allowing measurement of the individual applied loads through instrumented load cells. Focusing on the central span of the configuration, the boundary conditions provided by the adjacent supports are approximated as nearly fixed, allowing the flexural moment to be expressed as $M{=}PL/8$, where P is the central applied load and L the distance between adjacent supports. By equating this moment to the maximum moment associated with an equivalent uniformly distributed load, $M{=}wL^2/12$, the distributed load capacity w is calculated for each tested conductor. Experimental identification of the transition from elastic to plastic response is obtained from the deviation between the linear elastic load–displacement trend and the measured load.

To validate this transition as the onset of plasticity, finite element simulations were conducted to determine the initiation of yielding and assess whether it coincided with the end of the linear load–displacement response. Additionally, digital image correlation measurements were performed to detect full-field strain evolution and confirm the correspondence between the end of the linear load–displacement regime and the initiation of plastic deformation. The combined approach provides a consistent framework for translating concentrated-load bending results into equivalent distributed load capacities for copper conductors.

Keywords: copper electrical conductor; seven-point bending; elastic–plastic transition; digital image correlation; finite element analysis

Ultrasonic Fatigue Testing of a Cantilevered Bending Specimen in the VHCF regime

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Aircraft structural accidents often take place due to fatigue damage accumulation over time [1]. Many aerospace parts are subjected to complex high-frequency vibrations for long periods of time, executing billions of cycles in their service life, thus entering the under-explored regime of Very High Cycle Fatigue [2]. New components produced using the emergent metal Additive Manufacturing (AM) technologies are, henceforth, expected to withstand these loading conditions. Therefore, to ensure the safety of aviation, there's a need for faster and more efficient testing methodologies.

The present work applies recent findings in Ultrasonic Fatigue Testing (UFT) to the development of a novel cantilevered bending ultrasonic fatigue specimen geometry, made in Additively Manufactured aluminium alloy (AlSi10Mg) and to the devising of its testing methodology. The objective lies with bridging the gap between material and component testing in UFT through the replication of stress states similar to those found in aerospace components, thereby improving and speeding up the characterization of AM materials.

Numerical analysis guided the design process, ensuring excitation of the intended bending mode at the frequency of 20 kHz and an appropriate distribution of bending stresses across all designs. Experimental testing followed using the setup present in *Instituto Superior Técnico* (*IST*), validating the proposed methodology and confirming the linear relationship between the machine power and the specimen's displacement and stress amplitudes. Finally, fatigue tests were conducted to the AlSi10Mg specimens and the S-N curve was obtained and compared to literature data, verifying the appearance of a fatigue limit above 10^6 cycles.

Keywords: Very High Cycle Fatigue; Ultrasonic Fatigue Testing; Bending; Metal Additive Manufacturing; Specimen design

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Ultrasonic characterization of internal cooling channels produced by Friction Stir Channeling

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Abstract

Friction Stir Channeling (FSC) is a solid-state manufacturing process capable of producing internal channels within metallic components. This technique enables the integration of internal cooling channels directly into structural parts, such as plastic injection molds, improving heat dissipation, thermal control, and overall process efficiency. The ability to produce embedded channels without compromising the mechanical integrity of the component makes this technology particularly attractive for thermal management applications. These channels are also of significant interest in heat exchangers, cooling systems for electronic and mechanical components, and lightweight engineering structures where efficient thermal regulation and weight reduction are critical design requirements. However, due to their internal location and inaccessibility to direct visual inspection, non-destructive testing (NDT) techniques are required to assess their presence, position, geometry, and dimensional accuracy.

Ultrasonic testing (UT) is a suitable inspection method due to its high sensitivity to internal interfaces and material discontinuities, as well as its capability to provide information about subsurface features.

In this work, ultrasonic inspections were performed on aluminum specimens containing internal channels produced by FSC. Pulse-echo measurements were carried out using high-frequency ultrasonic probes, and contact inspection methods were applied to acquire reflected ultrasonic signals from internal interfaces. Signal analysis was performed to evaluate the detectability and localization of the channels, as well as to assess their dimensional characteristics and consistency with the parameters defined during the FSC manufacturing process.

The use of ultrasonic testing in this context aims to contribute to the development of reliable inspection procedures for the non-destructive evaluation of friction stir channeled components, supporting their implementation in engineering applications where internal cooling channels play a critical functional role.

.**Keywords**: Friction Stir Channeling, Ultrasonic Testing, Non-Destructive Testing, Internal Channels

Multi-impact behaviour of cylindrical composite tubes governed by matrix characteristics: A comparative study

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Abstract Cylindrical composite structures produced through filament winding technology have gained growing attention in engineering fields because of their excellent structural performance and long service life. They are widely used in hydrocarbon pipeline systems [1], seawater transport pipelines for desalination processes, drinking water distribution networks, wastewater conveyance systems [2, 3], as well as high-pressure storage vessels [4, 5]. Their extensive adoption is largely driven by their outstanding mechanical characteristics, such as a high strength-to-weight ratio, elevated specific stiffness, good machinability [4], and strong resistance to corrosion in harsh environments [1, 3]. However, in practical service conditions, filament-wound composite tubes may experience low-velocity impacts that can generate internal damage that is not easily detectable. This type of damage can progressively compromise structural integrity, ultimately posing significant risks to safety and overall performance.

Within this context, the present study investigates how the selection of the resin system influences the mechanical response of cylindrical composite tubes subjected to both single and repeated impact loading. For this purpose, two matrix systems, epoxy and polyester, were analysed, reflecting their distinct mechanical properties and economic relevance. Under a single impact energy of 20 J, epoxy-based specimens demonstrated superior structural performance, achieving a peak load of 3.63 kN, a maximum displacement of 10.73 mm, and an initial impact bending stiffness of 238 N/mm^2. In contrast, polyester-based tubes exhibited lower peak load (2.06 kN), reduced impact bending stiffness (91.8 N/mm^2), and smaller displacement (8.61 mm), accompanied by more diffuse and progressive damage mechanisms. In the case of repeated impacts, a reduction in fatigue life was observed with increasing the impact energy for both material systems. Epoxy composites endured up to 24 impact events prior to perforation at an energy level of 30.7 J, whereas polyester specimens failed at 24.3 J. Notably, within the lower energy regime (below 9 J, corresponding to approximately 200 impact cycles), polyester-based tubes exhibited comparatively enhanced durability, indicating a trade-off between mechanical performance and cost efficiency. The improved impact resistance of epoxy systems is attributed to stronger fibre–matrix interfacial bonding and higher inherent stiffness, while polyester matrices offer economic

advantages in applications involving lower energy impacts. These results demonstrate that matrix selection is a critical parameter governing energy absorption capacity, damage tolerance, and impact fatigue behaviour in composite tubular structures, thereby providing a basis for the design of structurally efficient and cost-effective components under repeated impact conditions.

Keywords: Composite tubes, Resin type, Filament winding, Multiple impacts, Damage mechanisms.

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