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O1: Damage & failure mechanisms: deformation, fracture & fatigue					
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O2-02	Wengui	Li	UNSW Sydney	wengui.li@unsw.edu.au	Graphene reinforced cement-based triboelectric nanogenerator for efficient energy harvesting in civil infrastructure
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O5-02	James	Vidler	The University of Adelaide	james.vidler@adelaide.edu.au	Effect of heat treatment on fatigue properties of Stainless Steel and Inconel fabricated using laser powder bed fusion
O5-03	Rais	Taufiq	UNSW Sydney	r.alfiansyah_taufiq@unsw.edu.au	Factors Controlling Residual Stress Formation in Laser Powder Bed Fusion Components
O5-04	Wendy	Ji	UNSW Sydney	j.wendy234@gmail.com	The development and validation of finite element models of additive manufacturing
O5-05	Markus	Domogala	The University of Sydney	markus.domogala@sydney.edu.au	Structural Integrity and Defect Analysis of Wire-Arc Additively Manufactured 316L Stainless Steel Components
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O7-03	Isaac	Field	Defence Science and Technology Group (DSTG)	isaac.field1@defence.gov.au	Recrystallised annealed titanium fatigue crack nucleation and growth in a combat aircraft structure
O7-04	Ben	Main	Defence Science and Technology Group (DSTG)	ben.main1@defence.gov.au	Failure analysis of service fatigue cracks in aircraft structures - going further

O7-05	Aditya	Khanna	The University of Queensland	aditya.khanna@uq.edu.au	Fatigue crack growth rate testing of non-crimp fabric composite laminates
O7-06	Tingyuan	Yin	The University of Adelaide	tingyuan.yin@adelaide.edu.au	Enhancing Electromagnetic Acoustic Transducer (EMAT) Performance Using Amplitude-Modulated Signals for Nonlinear Wave Mixing and Structural Health Monitoring
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O7-08	Kashmira	Raghu	Zeiss	kashmira.raghu@zeiss.com	Analysis of Crystal Defects by Electron Channeling Contrast Imaging (ECCI) for Advanced Failure Analysis

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O8-02	Boyang	Wan	The University of Sydney	boyang.wan@sydney.edu.au	Biomechanical Assessment of fixation Plate used for Mandibular Reconstruction

O9: Civil engineering, geology & mining					
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O9-03	Jiayang	Xu	UNSW Sydney	jiayang.xu@unsw.edu.au	Simultaneous Identification of Bridge Properties and Road Roughness from Drive-By Inspection by Integrating Kalman Filter and Optimization Approach
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O9-07	Arcady	Dyskin	University of Western Australia	arcady.dyskin@uwa.edu.au	Mechanism of rock spallation

<u>Abstracts</u>

Micro-grain Weibull strength distribution and fracture toughness of brittle ceramics

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The "*extrinsic*" Weibull strength distribution equation [1,2] has been employed by generations of engineers and scientists for brittle materials [3-5] containing many microcracks, Fig. 1(a). The Weibull modulus M has a constant value and describes the strength scatter of large, but not small, specimens [6]. The characteristic strength σ_{ch} defines the strength at a failure probability of 63.2% and has no further applications. In this presentation, based on our recent work [7], we have shown that, if the microcracks are suppressed or pre-existing defects are smaller than the average grain size G, an "*intrinsic*" micro-grain Weibull strength distribution can be obtained, Fig. 1(b). Moreover, the characteristic strength σ_{ch}, determined from the micro-grain Weibull plot with a reasonably high M value (>10), and an average G could be used to estimate the fracture toughness K_{IC} *without* testing specimens with sharp long cracks. i.e., $K_{IC} \approx 2 \cdot \sigma_{ch}\sqrt{3 \cdot G}$. This idea is thought-provoking, and we provide supporting evidence from a range of micro/nano grain-size ceramics and micro/nano sized single crystal silicon. In the end, however, is this a breakthrough concept in fracture mechanics or is it purely sheer ignorance? We seek your wise comments.

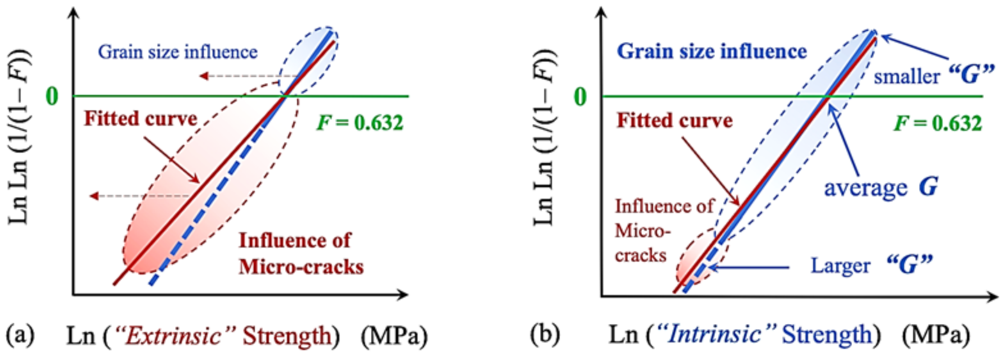

Fig. 1: (a) "*Extrinsic*" micro-crack Weibull strength distribution is controlled by microcracks. The red solid fitted curve contains the effect of "microcracks", which deviates from the dotted line of intrinsic "micro-grain" Weibull strength distribution. (b) "*Intrinsic*" micro-grain Weibull strength distribution is solely determined by the micro-grain structures at the fracture sites. Limited microcrack influence exists at the low strength end. (After Hu and Mai [7])

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Impeding Crack Nucleation and Enabling Crack Healing in Nanocrystalline Metals

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Fatigue failure is the process by which materials break during repetitive loading. In metals and alloys, fatigue cracks nucleate by an atomic-scale process called ‘persistent slip’. Transmission electron microscopy studies of conventional coarse grained metals show persistent slip bands as dislocation ladder structures with dimensions of several 100’s of nanometers to micrometers. However, in nanocrystalline alloys the grain size itself is less than 100 nanometers, thereby suppressing the formation of a persistent slip structure. As a result, these nanocrystalline alloys demonstrate substantial enhancement in fatigue resistance compared to conventional structural metals. The fatigue cracking process of nanocrystalline metals involves room-temperature grain growth. Only when the grains are grown mechanically to several 100’s of nanometers, does crack nucleation occur. This new mechanism has been confirmed by synchrotron x-ray diffraction and in-situ TEM experiments as well as molecular dynamics simulations. To mitigate this new failure mechanism, binary nanocrystalline alloys have been formulated with improved thermodynamic resistance to grain growth. In a first study on these alloys, we find that there are no signs of fatigue damage after 10 billion cycles at cyclic strain amplitudes up to 0.8% corresponding stress amplitudes in excess of 1 GPa. The in-situ TEM experiments also revealed an unexpected phenomena: under certain conditions, nanoscale fatigue cracks were observed to undergo nanoscale crack healing resulting in negative crack growth rates. Atomistic simulations suggest that such crack healing can be induced by local microstructural effects that serve to wedge the crack tip closed and induce local cold welding.

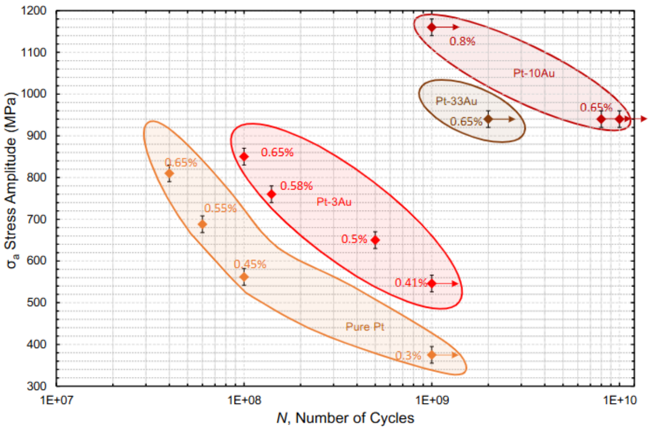

Fig. 1: S-N curves for Pt-Au alloys tested using a MEMS microresonator technique.

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Enhancing the high-cycle fatigue performance of precipitate strengthened Al alloys

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Aluminium alloys are widely used in moving structures due to their high specific strength, stiffness and environmental resistance. The fatigue behaviour is very important in these applications and is often a major design constraint. Unfortunately, the high cycle fatigue performance of the strongest Al alloys, the precipitate strengthened varieties, is relatively poor when compared with steels: the fatigue ratio (σ_e/UTS) of precipitate strengthened Al alloys is typically ~0.3 (Fig. 1a) [1], whereas it is closer to 0.5 for steels.

Precipitate strengthened Al alloys also show some usual behaviour as a function of precipitate state: often the weaker, underaged state has a better high cycle fatigue performance than the stronger, peak aged state [1,2]. This is shown for R=-1 loading for AA7050 in Fig. 1b [2]. Furthermore, this difference in behaviour is seen to disappear at other R-ratio loadings, Fig. 1b [2].

These somewhat unusual behaviours of Al alloys are all tied to the presence of precipitate-free zones (PFZ's) adjacent to the grain boundaries and the effects these have on strain localization during cyclic loading and eventual crack initiation.

In this presentation, we demonstrate how the PFZ's can be 'repaired' by the design of a pre-fatigue 'training' that induces dynamic precipitation in the PFZ's, strengthening them, which then reduces strain partitioning and increases the time for critical crack formation. The result is major increases in the HCF life of these important alloys.

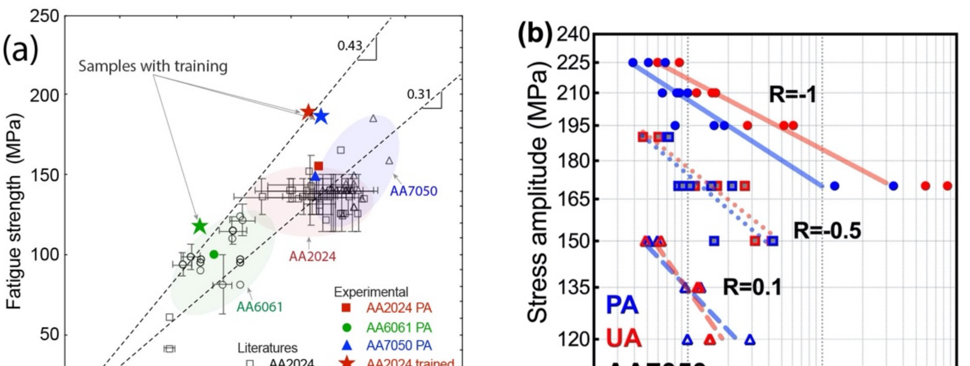

Fig. 1: (a) Fatigue strength (endurance limit) as a function of tensile strength for example 6xxx (AA6061), 2xxx (AA2024) and 7xxx (AA7050) alloys, after peak aging, or training [1], and b) S-N curves for AA7050 in the underaged (UA) and peak aged (PA) states as a function of R-ratio [2].

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High-performance epoxy-based nanocomposite adhesives incorporating carbon nanofibers and carbon nanotubes for enhanced bond strength, fracture toughness, and high-temperature performance

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In this study, high-performance epoxy-based nanocomposite adhesives were developed by incorporating different type of nanofillers including CNTs and CNFs to enhance bond strength, fracture toughness, and high-temperature performance and the effect of CNT and CNF was compared and anlaysed. The high-viscosity aerospace-grade epoxy resin EA9396 was used as the base material which was modified with functionalized CNFs and CNTs, along with a phase-separated poly(styrene)-poly(butadiene)-poly(methyl methacrylate) triblock copolymer (SBM). Functionalization was achieved using polyethyleneimine dendrimer (PEI+OZ-CNTs) and a polyamine hardener (H+OZ-CNTs), resulting in significant improvements in adhesive properties. Single lap shear test was conducted to determine the shear strength of the adhesive materials. At room temperature, the highest single lap shear strength was observed for the CNT-based adhesives, with 52.7 MPa for 0.5% H+OZ-CNT+SBM/EA9396 which is 48% than the unmodified EA9396 (35.6 MPa). The CNF-based adhesives also showed significant improvements, with the highest strength of 50.0 MPa for 0.3% H+OZ-CNF+SBM+EA9396, representing a 40% increase. At 90°C, the CNF-based adhesives exhibited superior performance, with 0.3% H+OZ-CNF+SBM/EA9396 showing a 38% improvement (30.0 MPa). The CNT-based adhesives also exhibited improved strength, with the highest strength of 26.3 MPa for 0.5% H+OZ-CNT+SBM+EA9396, showing a 28% improvement.
Butt joint tests were conducted and the results showed that the CNF-based adhesives outperformed the CNT-based adhesives at both room temperature and 90°C. At room temperature, 0.3% H+OZ-CNF+SBM/EA9396 demonstrated the highest butt joint strength of 76.9 MPa, while the CNT-based adhesives, particularly 0.5% H+OZ-CNT+SBM+EA9396, showed a strength of 69.3 MPa. At 90°C, 0.3% H+OZ-CNF+SBM/EA9396 showed an improvement of 56%, achieving a butt joint strength of 39.4 MPa, while the CNT-based adhesives showed a 49% improvement, with the highest value of 37.6 MPa for 0.3% H+OZ-CNF+SBM+EA9396.

Mode-I fracture toughness testing was conducted and the results revealed significant enhancements for both CNF and CNT-based adhesives, with 0.3% H+OZ-CNF+SBM+EA9396 and 0.5% H+OZ-CNT+SBM+EA9396 showing improvements of 700% and 600%, respectively, compared to the unmodified epoxy. SEM analysis indicated that both CNT and CNF functionalization improved dispersion within the matrix, enhancing energy dissipation mechanisms during crack propagation. This work demonstrates that both CNF and CNT-modified adhesives significantly outperform unmodified EA9396, with CNF-based adhesives showing superior mechanical properties, especially in high-temperature properties. These findings suggest that functionalized CNFs and CNTs are promising for developing high-performance adhesives with enhanced bond strength, fracture toughness, and elevated temperature stability.

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From Nano to Macro: Engineering Fracture Toughness in Multiphase Epoxy Composites

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Epoxy resins serve as the backbone of high-performance composite materials, yet their intrinsic brittleness has long posed a challenge in structural applications. This keynote presentation outlines a body of work on designing and optimising multiphase toughened epoxy matrices for enhanced fracture toughness. By integrating thermoplastic modifiers, carbon nanotubes, and hybrid toughening strategies, this work systematically advances our understanding of reaction-induced phase separation, crack energy dissipation mechanisms, and the role of matrix morphology in fiber-reinforced composites.

The presentation will begin by discussing the fundamental relationships between phase morphology and mechanical performance, as established in earlier studies on polyetherimide-modified epoxy resins. The progression into hybrid toughening systems, incorporating nanoscale carbon nanotubes alongside thermoplastic inclusions, reveals that under specific manufacturing approaches, a synergistic effect is achieved, further enhancing fracture toughness through controlled dispersion and crack-bridging mechanisms. Recent advancements in analytical modelling provide predictive insights into how these mechanisms interact at multiple length scales, enabling the rational design of next-generation epoxy matrices.

A key finding of this research is the divergence in toughening efficiency when these advanced matrices are incorporated into carbon fibre-reinforced polymer (CFRP) composites. While bulk resin modifications show substantial gains in toughness, fibre reinforcement alters phase morphology in ways that can either amplify or suppress these effects. The interplay between matrix functionality, phase separation dynamics, and fibre-matrix interactions are critically examined, highlighting strategies to maximise toughness in aerospace and structural applications. Based on an understanding of the underlying interactions, this keynote will also illustrate the potential for controlling phase separation dynamics to further enhance the fracture toughness of CFRP composites.

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Linking localized plasticity to crack initiation

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Engineering components used in the transport and energy sectors are frequently subjected to high-cycle fatigue (HCF), where the lifespan of a component is primarily determined by the time required for crack initiation. A key example is Titanium alloys used in the aerospace industry, where the absence of inclusions places significant emphasis on localized plasticity within a low-symmetry crystal structure. It is now well established that localized plasticity occurs well below a detectable yield point due to the complex stress conditions in polycrystalline materials. In the dominant α-phase of Titanium alloys, early localized slip is further complicated by the presence of multiple possible slip systems, each with different critical resolved shear values. This study focuses on a near-α Titanium alloy that has been processed to exhibit varying microstructural constituents, ranging from simple equiaxed to more complex duplex microstructures, and subjected to fatigue testing at 90% of the proof stress.

Findings from surface characterization reveal that plasticity at such low stress levels is dominated by the basal slip mode, which is typically not considered the slip mode with the lowest critical resolved shear stress in these Titanium alloys. Using quasi-in-situ studies with interrupted fatigue testing and various imaging techniques, early slip trace formation was successfully linked to crack initiation when specific arrangement and orientation criteria were met. Detailed 3D analysis of microcracks highlighted out-of-plane Burgers vector activity for the observed basal slip associated with crack initiation, aligning with the classical surface roughening mechanism. In particular, for the equiaxed microstructure, twisted grain boundaries were identified as the primary crack initiation sites. Statistical evaluation demonstrated that grains combining a moderately high Schmid factor for basal slip, a high resolved tensile stress along the c-axis, and a Burgers vector strongly oriented out of the surface plane are crucial factors in crack initiation. Based on these observations, new parameters incorporating geometrical factors were developed to predict transgranular and intergranular surface crack initiation sites.

To investigate the root cause of intergranular crack initiation dominance at twisted grain boundaries, high-resolution 2D strain mapping was conducted using digital image correlation in conjunction with grain orientation mapping. The analysis indicates that these intergranular cracks originated from bursts of basal <a> slip, initiating at (0001) twist grain boundaries and penetrating one side of the grain pair in cases of partial (0001) twist grain boundaries.

Further in-depth analysis of localized slip formation and its relationship to crack initiation revealed that the primary driver behind the relative contributions of activated Burgers vectors is the enhanced geometric alignment with neighbouring slip bands, particularly at boundaries that exhibit evident slip transmission. Additionally, slip localization events and their cyclic strain accumulation were found to saturate at the earliest stages of fatigue loading in the low-stress regime. This suggests the potential for rapid prediction of fatigue crack initiation solely based on the characteristics of early plastic slip activity.

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Bridging Scales: Multiscale Insights into Manufacturing, Materials Behavior and Structural Integrity

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Ensuring the structural integrity of engineering components operating under extreme conditions is essential for the safety and reliability of critical systems, such as nuclear reactors. These components are often subjected to high temperatures, corrosive environments, mechanical stresses, and radiation, which can lead to material degradation and failure mechanisms that ultimately determine their service life and performance.

ANSTO's research tackles these challenges by focusing on the multiscale nature of materials (Fig. 1). From atomic-level phenomena to macroscopic engineering structures, materials exhibit behaviours that span multiple scales, and understanding these interactions is crucial for bridging fundamental research with industrial applications. By integrating experimental characterisation techniques with numerical modelling, ANSTO investigates how nanoscale degradation mechanisms—such as microstructure evolution, radiation damage, and corrosion—impact the performance and fitness-for-service of larger-scale components.

Leveraging ANSTO's research infrastructure, our research explores radiation damage, corrosion, microstructure evolution, residual stresses, and damage accumulation under extreme conditions. These investigations inform the development of predictive material models and fitness-for-service assessments, enabling accurate evaluation of the operational lifespan and reliability of engineering components. Key areas of focus include understanding material degradation mechanisms, ensuring structural integrity, and optimising advanced manufacturing processes. Numerical simulations complement experimental insights by addressing challenges like minimising distortions of welded components.

ANSTO's multidisciplinary approach strengthens the performance and reliability of components across industries, including energy, aerospace, and advanced manufacturing. By linking small-scale material phenomena to large-scale engineering applications, our research ensures that materials can meet the demands of advanced engineering systems such as nuclear reactor.

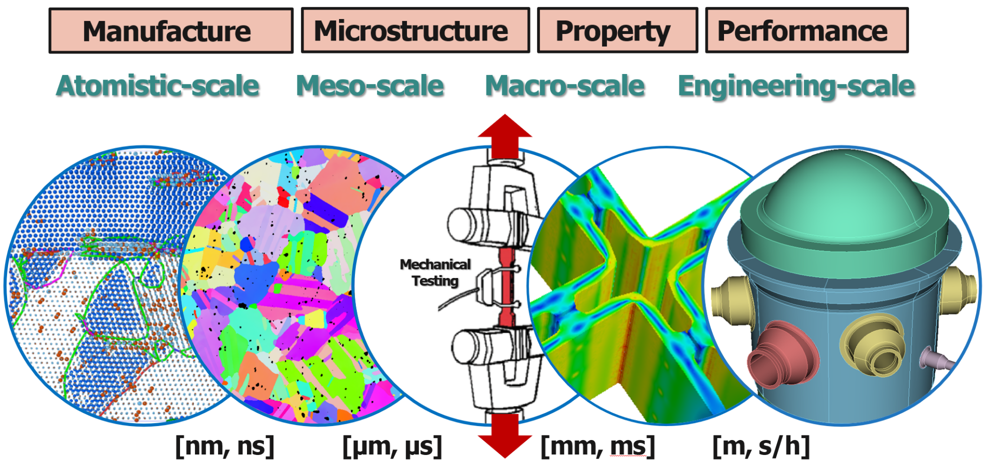

Fig. 1: Multiscale approach illustrating material behaviour from nanoscale phenomena to system-level engineering applications, linking fundamental research to industrial outcomes.

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Topology optimization of lightweight structures for fracture criteria

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Lightweight materials and structures often face significant challenges related to fracture failure, which requires to balance design functionality, material efficiency and structural integrity. A critical question remains: how can we design structural and material layouts to maximise fracture resistance based on specified failure criteria [1]? In this study, a phase-field damage model is integrated into a topology optimization framework to account for crack initiation and propagation in a path-dependent manner [2]. The proposed topological design enhances the fracture resistance of brittle materials such as advanced ceramics, metals and composites. For the first time, a path-dependent shape derivative is developed iteratively within nonlinear fracture analysis, ensuring effective topology optimization. A p-norm function is introduced to aggregate phase-field (PF) variables into a single constraint, providing a quantitative measure of fracture resistance. The effectiveness of the proposed approach is demonstrated through three 2D benchmark examples with single-phase materials and a 3D biomedical example with biphasic materials.

As shown in Fig. 1, the comparisons with conventional topology designs based on linear elastic finite element analysis without a damage model highlight the significant improvements in fracture resistance and material efficiency achieved using the proposed method. The proposed approach offers a robust strategy for path-dependent topological design, reducing stress concentrations and mitigating the risk of fracture failure in advanced structural applications.

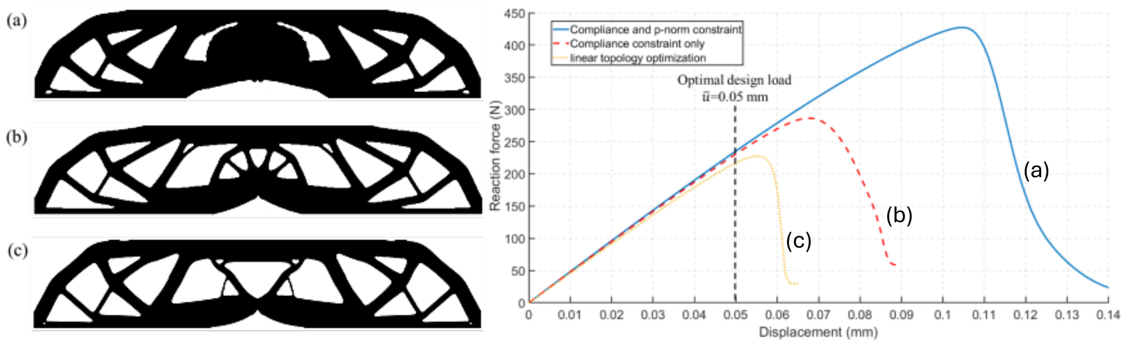

Fig. 1: Comparison of topological designs with different criteria: (a) p-norm PF fracture constraint, (b) PF compliance constraint, and (c) linear compliance constraint.

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Impact of Manufacturing Imperfections on Structural Performance in Advanced Manufacturing

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The geometric and material complexity of engineering structures is rising due to the increased use of advanced manufacturing processes enabling tailored designs for specific application requirements across various industry sectors. Numerical analysis tools, and particularly the finite element method, are commonly employed for the engineering design and validation of such structures. However, the general assumptions of perfect geometries and uniform material properties often result in non-conservative upper bound performance predictions[1,2]. While the introduction of safety factors can account for the uncertainty in loading, geometry deviations, and material property variation to ensure conservative designs, this approach does not enhance our understanding of the underlying mechanisms governing structural performance.

For realistic structural property assessments, it is essential to consider material, geometry, and the manufacturing process holistically. This presentation, based on various case studies of structures produced by advanced manufacturing processes, will describe common manufacturing imperfections and highlight the sensitivity of structural behaviour and associated failure mechanisms to these imperfections. Examples of both composite and additive manufacturing structures will be presented. The talk will emphasise the importance of incorporating experimental observations into numerical analysis methodologies, a crucial step for quantifying the respective influences of various types of manufacturing imperfections on structural performance. Such systematic evaluations have the potential to develop informed quality assurance assessment tools, thereby reducing manufacturing costs.

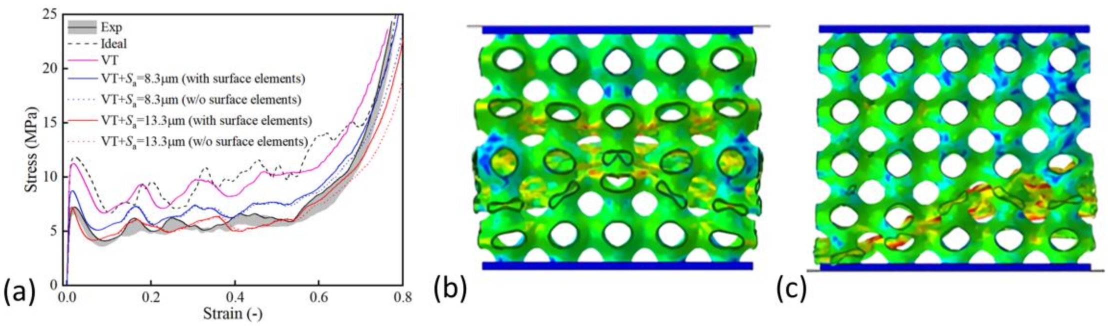

Fig. 1: Stress-strain curves for a triply periodic minimal surface (TPMS) structures under compressive loading[2] showing (a) structural performance reduction due to various structural imperfections, and associated change of failure mode from (b) perfectly symmetric to (c) unsymmetric shear band failure.

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Mechanical behavior of the 3D printed continuous fiber-reinforced composite gyroid structure under quasi-static and dynamic compression

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The mechanical properties of 3D-printed gyroid structures fabricated using continuous fiber-reinforced composites (CFRCs) were investigated experimentally in this study. Two phases of research were conducted to elucidate the structural response: first, a comparative analysis was performed between a pure Onyx gyroid structure and an Onyx structure reinforced with glass fiber under quasi-static loading conditions in three principal directions. Findings revealed significant directional dependency in mechanical performance, demonstrating increased plateau stress and specific energy absorption (SEA) for both structures when subjected to out-of-plane compression. However, the stiffness of the two structures in both in-plane directions was superior to that in the out-of-plane direction. The second phase focused on strain sensitivity analyses of different CFRC gyroid structures made of pure Onyx, Onyx reinforced with glass fiber filament (GFF), Kevlar fiber filament (KFF), and carbon fiber filament (CFF) under both quasi-static and dynamic compression. Results indicated that increasing loading velocity significantly enhanced the mechanical performance of all investigated structures. Key observations of the overall study revealed pronounced directional dependency and strain sensitivity in mechanical properties such as nominal Young's modulus, plateau stress, and specific energy absorption (SEA) of the gyroid structures in quasi-static loading. The KFF/Onyx composite structure exhibited a high strain rate sensitivity. The study provides valuable insights into optimizing and enhancing the mechanical performance of 3D-printed gyroid structures fabricated from CFRCs, emphasizing the crucial roles of directional loading effect and loading velocity in designing resilient and efficient composite cellular structures for advanced manufacturing applications.

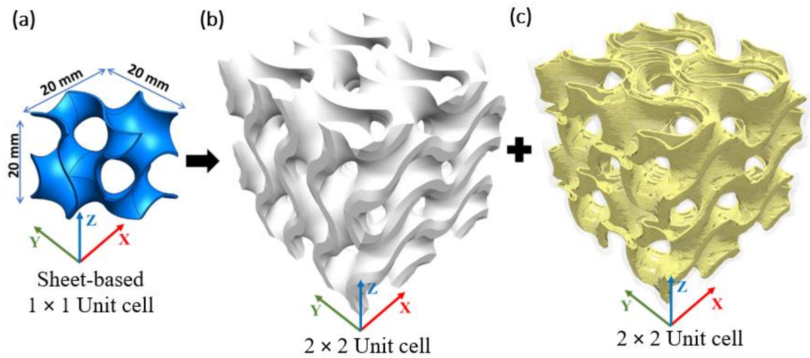

Figure 1. General design flow of a gyroid structure fabrication using Markforged® Mark Two printer: (a) a sheet-based gyroid unit-cell; (b) matrix of the gyroid; (c) fiber-reinforcement inside the matrix of the gyroid.

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Fatigue life evaluation under variable amplitude loading

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Fatigue life evaluation methods under constant amplitude loading are well developed and have been widely utilised in engineering design as well as for scheduling maintenance procedures across many industries and applications. However, this type of loading is quite rare in practical application as most structures are subjected to loading with variable amplitude. Previous studies have demonstrated that theoretical predictions in the case of variable amplitude loading can disagree with the actual fatigue life by an order of magnitude or even more. The latter can significantly affect the cost and efficiency of operation of high-value assists such as aircrafts, wind turbines and pipelines. Therefore, there is a significant gap in the current knowledge, which needs to be addressed, specifically, in order to reduce the large conservatism of the current fatigue life evaluation methods. In this presentation we discuss a new method for the fatigue life evaluation of typical structural components [1]. The method is based on recent advances in experimental techniques, which make possible for the first time, the investigation of crack opening/closure and the crack driving force for large numbers of fatigue cycles representative of real-world loading scenarios (>1 million consecutive cycles of variable load amplitude) [2, 3]. The method has been validated for a specific material (7075-T7351 aluminium alloy), plate thickness (1/2 inch) and variable amplitude loading conditions, which characterised by relatively high R-ratio content and absence of significant overloads and underloads. A typical examples of this type of loading are military and civil aircraft load spectra. The focus of this presentation is on the generalization of this new method, e.g. for more aggressive loading spectra.

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Controlling snapback in indirect tensile testing of brittle materials

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Testing engineering materials for their properties under quasi-static conditions involve different types of control, using load or displacement or other measurable quantities (e.g. strain, Acoustic Emission signal). Snapback behaviour during failure of specimens is the reversal of displacement at the load point, while load carrying capacity is reducing. This is different from snap through behaviour in which displacement keeps increasing under decreasing load carrying capability of the specimen. Controlling snapback behaviour is required to avoid abrupt and extreme dynamic behaviour of the specimens usually involving secondary cracks and ejections of fragmented materials, so that intrinsic properties can be obtained [1]. We explain the cause of such extreme failure followed by a method to control and capture snapback behaviour in indirect tensile testing of brittle materials. Energy concept and localised failure are the keys for the explanation and control of such behaviour in testing. The performance of the method on a range of natural and man-made brittle materials is illustrated along with benefits in obtaining intrinsic material properties by removing or minimising dynamic effects to maintain quasi-static condition.

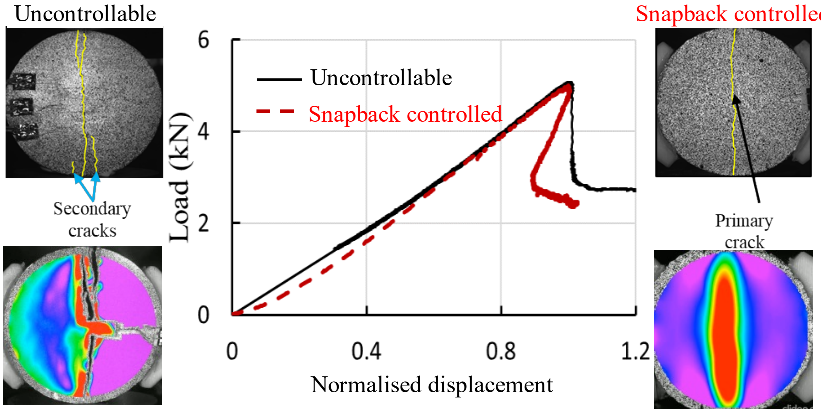

Fig. 1: Failure under indirect tensile testing using the proposed technique vs. uncontrollable one.

Fig. 1 shows snapback behaviour successfully captured in indirect tensile testing on Brazilian disc of sandstone. Lateral deformation is used as feedback to servo-controlled loading machine to enable well controlled fracture process that usually takes a few hours [1]. Uncontrollable behaviour with abrupt failure in a split second together with secondary cracks is also illustrated.

Acknowledgement
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Fracture Analysis and Design Optimisation of Dental Structures: An XFEM-Based Study

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This study investigates fracture behaviours in dental applications, focusing on posterior teeth, monolithic dental crowns, fissural enamel, and prosthetic devices. Using the Extended Finite Element Method (XFEM), we evaluated the influence of design parameters, material properties, and external factors on stress distribution, crack initiation, and fracture resistance. Key findings include the significant impact of fissural caries, cusp angle, and enamel morphology on fracture resistance in teeth, with conservative treatments like resin infiltration restoring up to 90% of mechanical performance. For dental crowns, the analysis demonstrates that rounded occlusal notches combined with zirconia materials provide enhanced fracture resistance. Additionally, fissural enamel with U or IK morphologies exhibited greater durability under occlusal loading, particularly when paired with less steep cusp angles. The analysis further revealed the potential of graded material properties to enhance fracture resistance. In prosthetic devices, such as osteofixation plates and dental implants, optimised design parameters and material selection were shown to be essential for preventing fatigue failure and extending therapeutic longevity. These findings emphasise the need for a multidisciplinary approach in designing dental structures, integrating advanced numerical modelling, material science, and clinical expertise. These comprehensive findings offer practical guidelines for clinicians and researchers, contributing to the advancement of dental applications and the reduction of mechanical failures.

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The Role of Intermetallic Phases on the Damage Tolerance of Crossover Aluminum Alloys

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Crossover aluminum alloys are a new class of materials designed to offer a balance of properties such as high strength and ductility that can otherwise only be found in the various Al-series. In this study, a crossover aluminum alloy was designed from 6xxx and 8xxx foil stock alloys. An Fe-rich intermetallic phase (IMP) mimicking high scrap content to simulate the use of recycled material, was incorporated into Al-Mg-Si alloys to develop an alloy with composition 1.7Fe-1.2Mn-2.3Si, that exhibits a finely distributed structure of IMPs after thermomechanical processing including rolling. The new alloy exhibits improved strength with only minor reduction in ductility compared to the material without IMPs. The fracture behavior was investigated in two orientations relative to the rolling direction. When the crack propagated perpendicular to the rolling direction, the average J_Q value was 54.1 ± 9.6 kJ/m²., equivalent to 66.5 ± 6.0 MPa.m$^{0.5}$. Compared to that, when the crack propagated parallel to the rolling direction, the J_Q value increased to 72.9 ± 16.4 kJ/m², i.e., 77.1 ± 8.8 MPa.m$^{0.5}$. This anisotropic behavior is attributed to the alignments of IMPs with respect to the crack tip and highlights the importance of controlling the size, spacing, and volume fraction of IMPs to optimizing damage tolerance in **crossover aluminum alloys.**

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Impact of processing parameters and base plate preheating on the structure-mechanical performance relationships of a laser powder bed fusion fabricated hot work tool steel

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W333L hot work tool steel (HWTS) was fabricated using laser powder bed fusion (L-PBF) and a processing window based on laser power and scan speed using both preheated and non-preheated baseplates established. The impact of volumetric energy density (VED) and preheating condition on both micro and mesostructure were evaluated and mechanical properties assessed in terms of tensile stress-strain behaviour and crack resistance, *R*-curve behaviour parallel and perpendicular to the build direction. While high energy density (HED) results in wider and deeper melt pools (MPs) compared to low energy density (LED) printing conditions, preheating has an only minor impact on the structural features of the materials. Mechanical performance in terms of tensile stress-strain response yield and strength levels of ~1200-1500 MPa together with failure strains of ~2-17% in both orientations, respectively. The fracture toughness, tested in the same orientations, is ~75-108 MPa√m. While micro and mesostructure are hence primarily controlled by VED, and sample orientation impacts mechanical performance, our results indicate that W333L HWTS can be printed over a wide range of processing parameters that yield excellent damage tolerance independent of the preheating conditions.

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Rapid fatigue evaluation of additive manufacturing specimens containing different types of defects

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Although additive manufacturing specimens can exhibit static mechanical properties that are equal to or even surpass those of conventional materials, their dynamic properties, such as fatigue strength, are generally lower. The primary issues that reduce the fatigue limit in AM parts are defects such as irregular shape lack of fusion, spherical gas pores, and surface roughness, acting as fatigue crack nucleation sites, as illustrated in Figure 1.

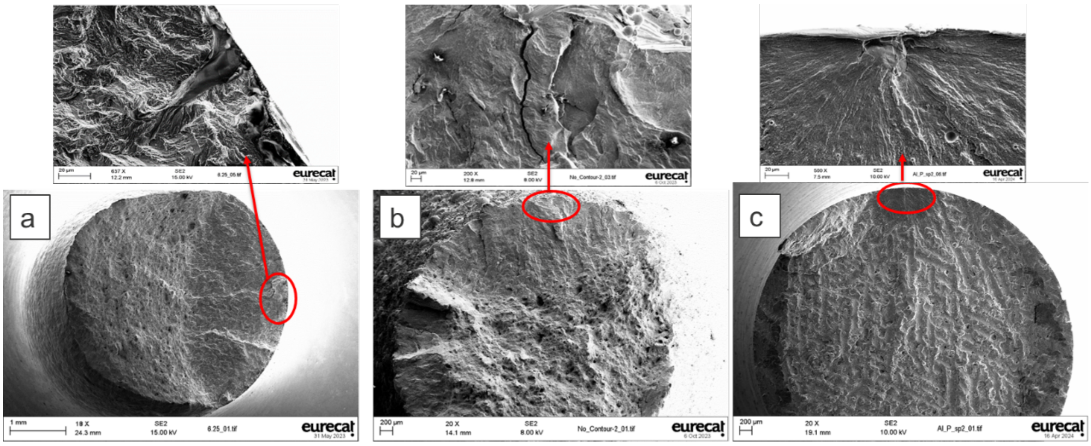

Figure 1. Scanning electron microscopy of the fracture surface of laser powder bed fusion specimens, highlighting the fatigue crack nucleation site from a) Sharp lack of fusion defect, b) surface valley, and c) near-surface spherical gas pores

These defects can either bypass the nucleation stage in the fatigue mechanism if they are large and sharp or reduce the required stress level for crack nucleation in the case of smaller, spherical defects due to stress concentration. Despite the significance of improving fatigue resistance in AM parts, the time-consuming and expensive nature of fatigue testing has been a barrier to further exploration and enhancement of this mechanical property. To address this, rapid fatigue tests can be utilized to reduce the time, cost, and the number of specimens required for a complete study of the fatigue mechanism. In this work, AlSi10Mg aluminum and 316L stainless steel specimens were printed using electron and laser powder bed fusion techniques. These specimens were characterized in terms of fatigue mechanisms and resistance in both as-built and polished surface conditions using rapid fatigue testing via the stiffness method. After validating the accuracy of the rapid fatigue test results, the study focused on the type, size, and location of defects that serve as preferred sites for fatigue crack nucleation. The results demonstrated over 95% accuracy in determining the fatigue limit using the stiffness method when compared to traditional methods like the staircase method. Furthermore, rapid fatigue testing successfully compared the negative effects of various defects during the fatigue nucleation stage, helping to find the balance between the impact of surface roughness and near-surface lack of fusion in providing favorable crack nucleation sites in different surface conditions.

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A study on the thickness-related fatigue resistance, fracture toughness, and ductility of additive manufacturing specimens

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Mechanical properties such as fracture toughness, tensile strength, ductility, and fatigue resistance are critical when designing additive manufacturing components subjected to various loading conditions. Some of these mechanical properties can often depend on component thickness. This study explores the correlation between thickness and mechanical properties in laser powder bed fusion stainless steel AISI 316L specimens.

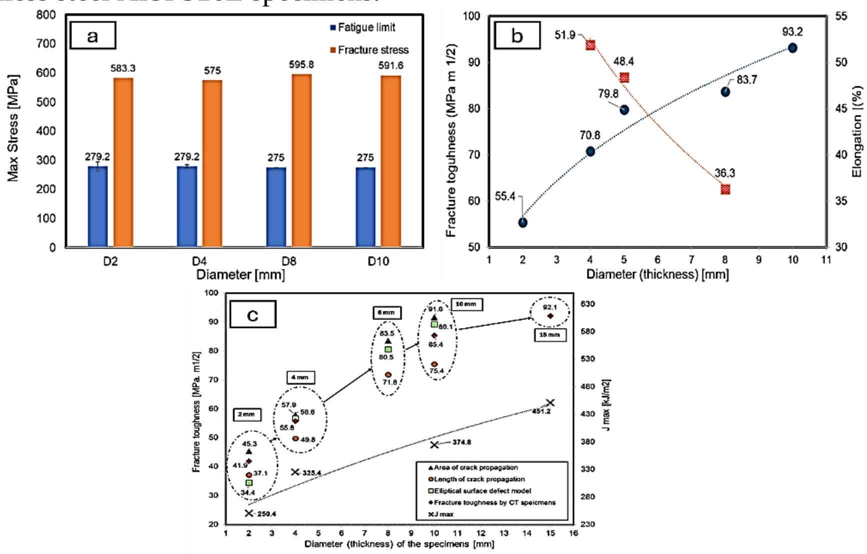

Fig. 1: Relationship between thickness and a) fatigue limit, b)ductility, and c)fracture toughness.

Fatigue specimens with thicknesses ranging from 2 to 10 mm were printed and subjected to rapid fatigue testing. The results revealed no significant differences in the fatigue limit or mechanism. This is because the fatigue mechanism is largely influenced by defects that serve as favourable sites for crack initiation. Fracture toughness tests were carried out on compact tension specimens, and the toughness results from conventional testing methods (using both linear elastic and elasto-plastic fracture mechanics) were compared to those obtained using linear elastic fracture mechanics models, based on the analysis of fracture surfaces and stresses from rapid fatigue test specimens. The fracture toughness was found to increase with specimen thickness, up to 15 mm. However, tensile tests on similarly printed specimens with thicknesses between 4 and 8 mm showed a decrease in elongation, while the tensile strength and reduction in area remained nearly constant. These findings indicate that there is no straightforward relationship between fracture toughness, ductility, and fatigue resistance, and their variation with thickness for AM components, as shown in Fig. 1. Each property must be assessed separately. Lastly, the comparison between the fracture toughness test and the rapid fatigue test results suggests that rapid fatigue test data can provide an accurate initial estimation of fracture toughness, thus offering a quicker and more cost-effective testing method.

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High-Cycle Fatigue Evaluation for High-Strength Grade Blind Bolts as Shear Connectors

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Sustainability and the ability to demount the structural components at the end of their life span, or even in case of any damage, have become increasingly significant, particularly in steel-concrete composite structures which are widely adopted in high-rise buildings and bridges. In such systems, shear connectors are the most critical component responsible for transferring the shear loads at the interface between the flange of the steel beam and the concrete slab. Novel approaches, such as the use of demountable shear connectors, have been introduced as replacements for traditional non-demountable ones, for which a considerable amount of energy and cost were needed to demolish the entire construction after their service life [1]. One-sided assembly blind bolts are promising alternatives not only to meet the sustainable design requirements but also to mitigate the construction and maintenance time [2, 3]. However, a lack of comprehensive data on their fatigue behaviour and failure modes has hindered their widespread adoption in the construction industry. This paper presents experimental research evaluating the high-cycle fatigue performance and its failure modes for one-sided assembly blind bolts being used as shear connectors. The direct shear method is employed to apply the fluctuating shear fatigue loading to the novel shear connector [4, 5]. The results will compare the high-cycle fatigue resistance of one-sided assembly blind bolts with that of conventional fastening methods. The failure modes of the shear connection will also be assessed after the fracture occurs.

Keywords
One-sided assembly blind bolts; demountable shear connectors; high-cycle fatigue; failure modes

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Phase field fracture modelling for elastoplastic shell incorporated with stress-based fracture initiation criterion

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Although phase-field models have been extended to simulate shell fracture propagation, most existing models are validated primarily through benchmark numerical examples rather than experimental data. In the few cases where comparisons are made, the focus is typically only on quantitative analysis, limiting their potential for practical industrial applications. To address this gap, this paper introduces a shell phase-field model with five layers of phase-field variables to accurately predict fracture propagation through the thickness, corresponding directly to the five Simpson stress integration points. Additionally, to accurately capture fracture initiation in real structures, a stress-state-dependent fracture strain formulation was employed in each layer, utilizing the MMC criterion for 316L steel and the Bao-Wierzbicki criterion for Ti-6Al-4V. The proposed model was validated both quantitatively through benchmark numerical examples and qualitatively using experimental data. The simulation of a notched cylinder under axial tension demonstrated that fracture strain significantly affects the load-carrying capacity. The typical "flapping" phenomenon in a cracked cylinder under internal pressure was successfully reproduced. In the three-point bending test of a square tube, the model captured five distinct stages of deformation—elastic deformation, local indentation, side-surface buckling, bulge strap growth, and global bending—all of which closely matched experimental observations. Despite a slight delay in the densification of the Gyroid TPMS structure under axial compression, the two characteristic deformation modes were accurately captured, and the global force-displacement curve aligned well with experimental results.

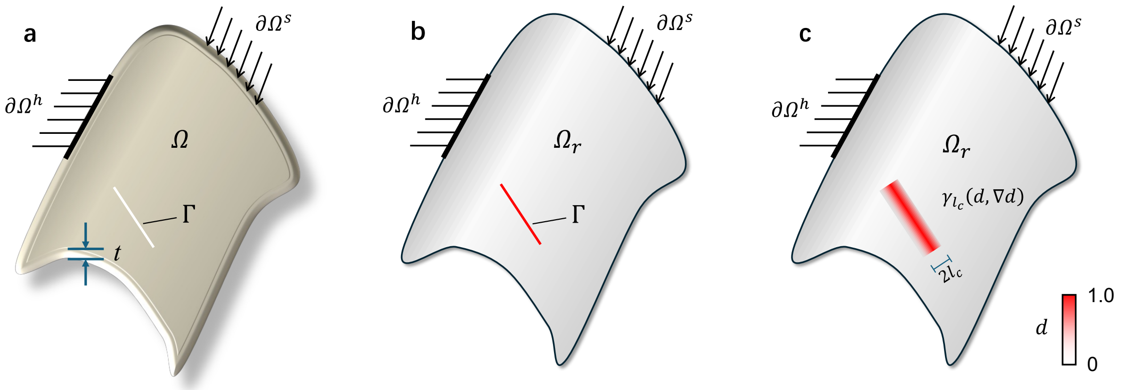

Figure 1 Regularisation of sharp crack to damage zone based on l_c. (a) fracture topology of the shell (b) sharp crack on shell reference surface; (c) regularised phase field distribution on shell reference surface

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On the development of compliance-based techniques for the evaluation of crack tip opening loads and effective stress intensity factor range

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The concept of compliance has a fundamental significance in fracture and fatigue. Compliance-based experimental techniques have been (and are currently) extensively used to evaluate the crack length, residual stresses, crack tip opening loads and the effective stress intensity factor range during fatigue testing. These experimental techniques are often based on linear-elastic considerations and, in the absence of exact analytical and numerical elasto-plastic solutions for propagating cracks, are largely reliant on empirical criteria, previous experience or best practice approaches. This work utilises the strip-yield model to investigate the changes in compliance for an edge crack propagating under constant amplitude cyclic loading in a semi-infinite plate [1,2]. This model is the only theoretical result which is suitable for analysis of the nonlinear response of a fatigue crack to the applied loading. The present modelling results are in general agreement with the current and past experimental studies. Moreover, these new results provide a foundation for a more accurate evaluation of the crack tip opening loads and development of new experimental techniques based on compliance and its changes during fatigue crack propagation [3].

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Experimental and numerical study of the inelastic and failure behaviour of IG-110 nuclear graphite

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Understanding the inelastic behaviour of nuclear graphite is of technological importance for current and future reactor technologies [1]. This work studies the inelastic and failure behaviour of IG-110 graphite [2] experimentally using uniaxial compression (UC) and splitting tensile (ST) tests and numerically using a finite element (FE) model. The concrete damaged plasticity (CDP) material model was used with the dilation angle (ψ) parameter selected by an optimisation process that compared the predicted load-displacement curve with the experimental average curves using objective functions. A decoupled optimisation was run on the UC and ST models separately to obtain ψ_c and ψ_t, respectively. In addition, a coupled optimisation was run on the UC and ST models running simultaneously to obtain ψ_{ct} (Fig. 1a). The relative percentage error R_{pe} of the peak force (P_p) and the displacement at peak force (D_{atFp}) were used to compare the different optimised ψ. The results show that when ψ_{ct} is used, the CDP model predicts well the peak force for both UC (R_{pe}=5.8%) and (R_{pe}=11.6%) ST tests (Fig. 1b). When ψ_c is used, the model predicts better the compressive response (R_{pe}=3%); however, it largely underestimates the peak force for the ST test (R_{pe}=23.3%). When ψ_t is used, the R_{pe} is below 10% for both UC (8.6%) and ST (5.8%) tests; however, R_{pe} is slightly higher for the compressive response compared to the results when using ψ_{ct}. Good agreement between the experimental and predicted failure modes was observed (Fig. 1c). These results show that the CDP model predicts the inelastic and failure behaviour of IG-110 graphite well in both UC and ST loading conditions.

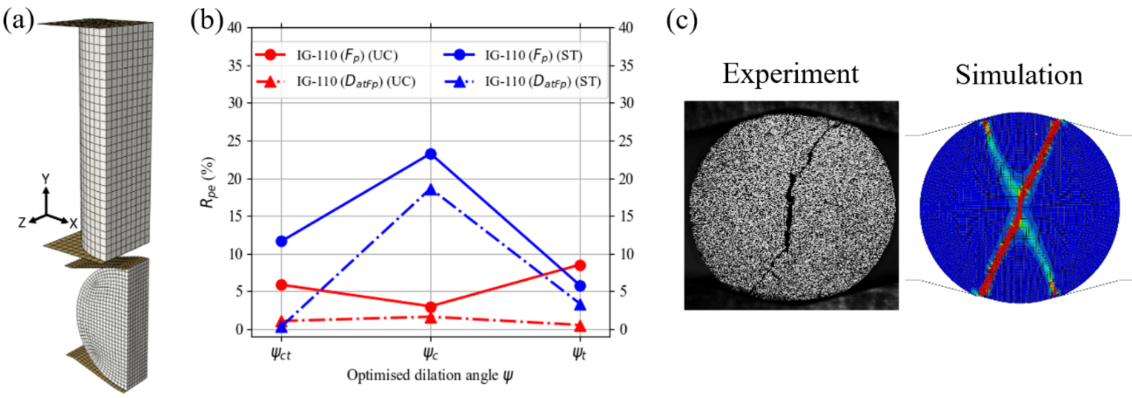

Fig. 1: (a) FE mesh of the combined UC and ST tests model, (b) R_{pe} using various ψ for both UC and ST simulations, (c) comparison of experimental failure mode with the predicted one.

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Graphene reinforced cement-based triboelectric nanogenerator for efficient energy harvesting in civil infrastructure

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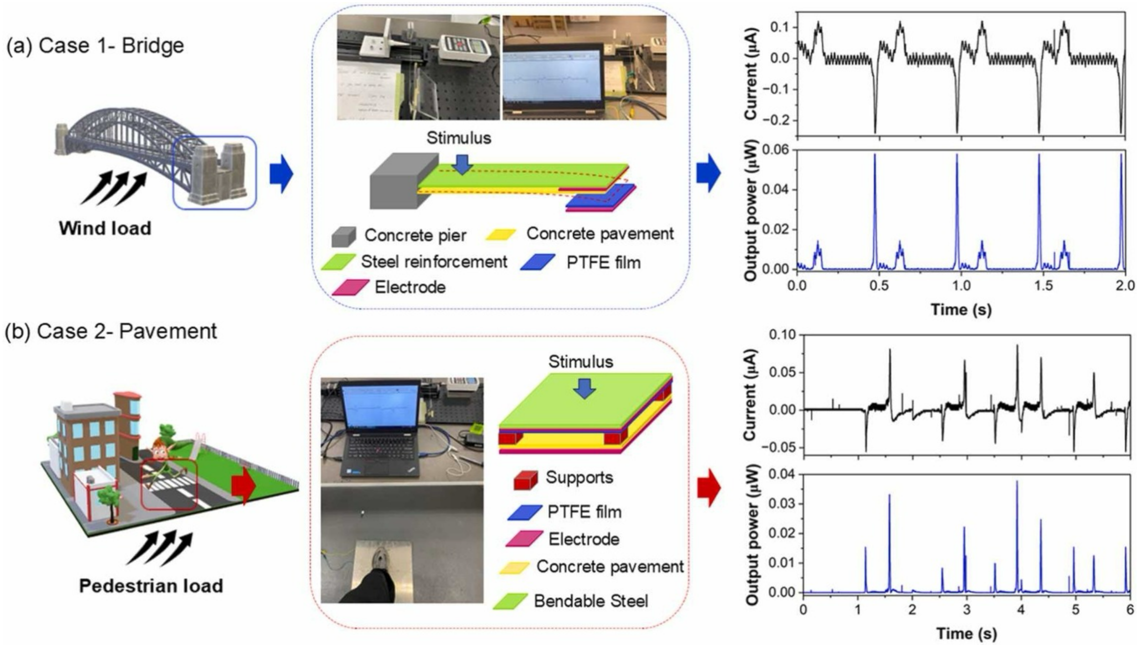
This paper investigated a graphene reinforced cement-based triboelectric nanogenerator (TENG) aimed at harvesting mechanical energies in infrastructure, such as pedestrians, vehicles, human-induced vibrations, and natural stimulus like wind and earthquakes. The triboelectric layers of the cement-based TENG consisted of a fully cured graphene modified cement-based plate and a polytetrafluoroethylene (PTFE) film, which were tested under a contact-separation mode. Microstructural analysis indicated that the graphene was well-dispersed in the cementitious matrix, and the graphene-cement composites achieved excellent compressive and flexural strengths of 53.0 and 3.5 MPa, respectively. The electrical characteristics of the graphene-cement composites, specifically their resistivity and impedance, showed that they did not reach the percolation threshold, making them ideal dielectric materials with a dielectric constant of 100 at 1 kHz. The performance of the cement-based triboelectric nanogenerator (TENG) varied depending on the amplitude and frequency of the contact-separation cycle. At a frequency of 10 Hz and under a force of 100 N, the short-circuit current and open-circuit voltage peaked at 3.62 μA and 279.4 V, respectively, achieving a maximum power density of 95 mW/m2 with a 100 MΩ resistor. In practical applications, this TENG charged a 10 μF capacitor to 3.1 V within one minute and to 57.2 V in one hour. Additionally, manual operation of the TENG enabled the lighting of 29 LEDs with one minute of hand pressure. By utilizing triboelectric effects, the results provide the feasibility of self-powering concrete structures and pavements for future smart cities.



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Void-Free Phenolic-Epoxy Composites with Enhanced Thermal and Mechanical Capabilities

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Carbon fibre/phenolic resin (CF/PR) composites have been extensively employed as thermal protection systems (TPS) in aerospace and defence industries [1]. These composites are highly regarded for their remarkable strength-to-weight ratio, lightweight nature, and exceptional ablative properties, making them prime candidates for shielding structures from the harsh thermal and aerodynamic conditions [2]. Phenolic resin is a crucial component of the composite, as it can form a char layer that is capable of withstanding high temperatures, thereby protecting the main structure from destruction or degradation [3]. However, the releasing of water vapor and low molecular weight gases during phenolic curing process leads to high porosity [4]. This inherent porosity contributes to the brittleness and low strength of phenolic resin, significantly limiting its mechanical reliability and making it unsuitable for applications that demand durable and tough materials. Consequently, enhancing the mechanical performance of phenolic resin while preserving its excellent flame retardancy and thermal stability is of great practical importance.In this study, we aim to systematically investigate the effects of varying the ratios of phenolic and epoxy resin to develop an optimized resin blend. By fine-tuning the resin composition, our goal is to achieve a material that exhibits superior mechanical properties, characterized by reduced porosity, while still retaining the critical thermal and flame-retardant characteristics essential for high-performance applications.

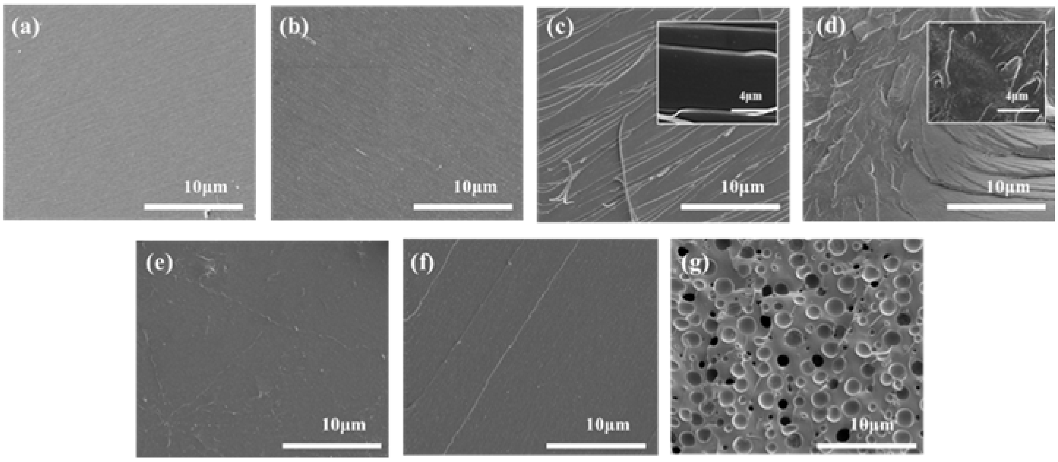

Fig. 1: Fracture surfaces of the (a) P95, (b) P90, (c) P75, (d) P50, (e) P25, (f) Epoxy (g) Phenolic.

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Effect of continuous wave laser irradiation power and beam diameter on thermal degradation of carbon fibre-reinforced polymer (CFRP) composites

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Carbon fibre-reinforced polymer (CFRP) composites are increasingly used in aerospace, defence, and automotive applications, raising concerns about their ability to withstand thermal damage caused by high-energy laser exposure. However, the interaction between laser parameters and the resulting damage mechanisms remains poorly understood, hindering the development of robust and resilient materials. This study addresses these research gaps by investigating the effects of laser parameters including power and beam diameter on thermal damage of CFRP composites, focusing on the underlying damage mechanisms through advanced characterization techniques. Continuous wave laser irradiation was applied to CFRP samples with beam diameters of 3.18 mm and 5.70 mm at different power levels up to 365 W. High-resolution thermal imaging was used to capture temperature distribution on the CFRP surfaces, revealing the relationship between laser parameters and thermal damage. The extent of damage was evaluated using ultrasonic C-scan imaging. For the 3.18 mm beam, perforation times decreased significantly from 46 seconds at 215 W to 7 seconds at 365 W, with the damaged area reducing from 1204 mm² (48.2%) at 215 W to 372 mm² (14.9%) at 365 W. In comparison, the 5.70 mm beam resulted in longer perforation times, ranging from 393 seconds at 215 W to 269 seconds at 365 W, and a larger damage area, increasing from 1299 mm² (52.0%) to 1712 mm² (68.5%). The mass loss trends were also dependent on the beam diameter. For the smaller beam, mass loss decreased as laser power increased, while the larger beam exhibited an increase in mass loss. Further analysis using micro-computed tomography (micro-CT), scanning electron microscopy (SEM), and infrared micro-spectroscopy (IRM beamline) provided detailed insights into the internal structural changes, surface damage, and chemical modifications, which helped to elucidate the degradation mechanisms and residual stresses within the composite matrix. These findings contribute to a deeper understanding of thermal damage in CFRP composites and offer important insights for the development of more resilient materials for aerospace and other high-performance applications.

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Experimental and numerical study of laser paint stripping on CFRP

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Laser stripping technology is an emerging method for removing paint/coatings especially for carbon fibre reinforced polymer (CFRP) substrates, offering precise removal and minimising potential substrate damage and environmental impact. The efficiency of laser paint stripping depends on laser parameters and the material properties of the target. This study presents experimental and numerical investigations of the laser paint stripping of CFRP. The effects of laser fluence and overlap ratio on paint removal are experimentally investigated using a femtosecond IR laser, as shown in Fig. 1. The removal depth, processing temperature and surface damage are monitored during the laser paint removal process. A finite element model is developed and the transient thermal responses during laser irradiation are simulated. The developed numerical model is validated with tests by checking ablation depth and peak temperature. Parametric analyses are conducted to investigate the impact of paint absorptivity on laser paint stripping efficiency and substrate integrity.

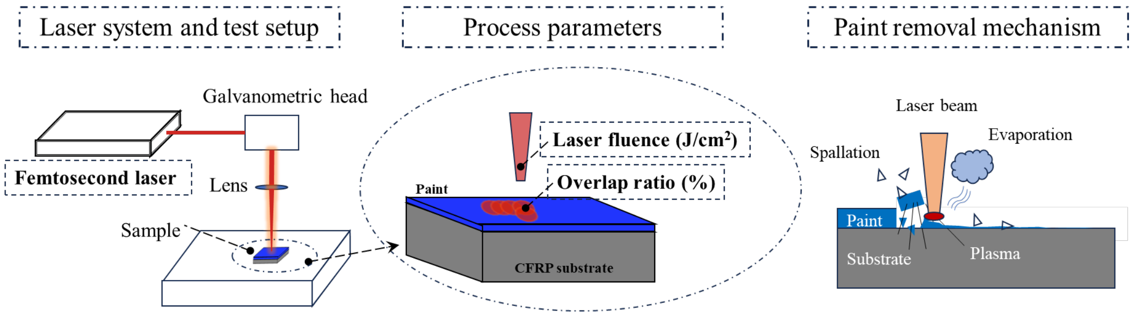

Fig. 1: Schematic diagram of femtosecond laser system and laser paint stripping on CFRP

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Improving the Fracture Toughness and Flame Retardancy of Epoxy Polymers by Polydopamine Nanoparticles

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Matrix modification by incorporating nanoparticles has demonstrated significant potential in suppressing matrix microcracking in epoxy-base carbon fibre composites under cryogenic temperatures. However, the modified epoxy matrix's high flammability remains a major challenge. Composite storage tanks must meet stringent fire resistance standards to be used for transporting liquid hydrogen.

In this study, we introduce a new dual-functional technique for incorporating polydopamine (PDA) nanoparticles to simultaneously enhance the flame retardancy and cryogenic fracture toughness of an epoxy. PDA nanoparticles were synthesised by self-polymerizing dopamine over 12 hours, yielding particles with a size of 200–250 nm. They were then dispersed in an epoxy using a probe sonication method. Experimental results show that PDA nanoparticles can achieve uniform distribution at high concentrations due to their high compatibility with epoxy. The addition of 10 wt% PDA nanoparticles led to a remarkable increase in the fracture energy of the epoxy by 521% and 612% at 23°C and -196°C, respectively. In the meantime, the peak heat release rate and total heat release were reduced by 44.75% and 24.81%, respectively. These results indicate that PDA nanoparticles are effective in toughening and improving flame retardancy of epoxy. This unique combination of dual improvements positions PDA nanoparticles as a highly effective multifunctional modifier for the epoxy polymer matrices of carbon fibre composites. The results of this research provide a novel strategy to address the significant challenges in lightweight, high-performance, and flame-retardant composite materials capable of withstanding both cryogenic temperatures and fire, which is crucial for future net-zero aviation applications.

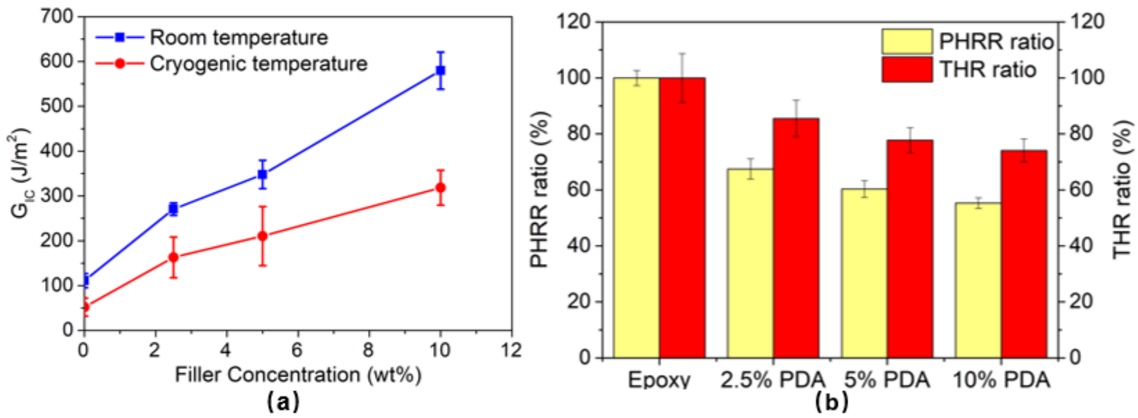

Fig. 1: (a) Fracture energy versus filler concentration, and (b) PHRR ratio and THR ratio versus Filler concentration

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Can delaminations be modelled as a reduction in bending stiffness?

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ABSTRACT

It is sometimes stated that delaminations reduce the bending stiffness of fibre-composite laminates. This statement is not quite correct: more correctly, delaminations reduce the flexural stiffness. The crucial difference is that flexure involves a nonzero shear force, whereas pure bending entails zero shear. A split-beam model is employed to clarify quantitatively this distinction between bending and flexural stiffness. The implications of this distinction are further discussed for the correct modelling of the vibrational response of laminates containing delamination damage. It is shown that an inhomogeneity model, in which the delaminated portion is modelled as having a reduced bending stiffness, can provide correct predictions of mode shapes and natural frequencies provided that the average curvature over the length of the delamination is zero, or negligibly small, which can happen for some particular symmetrical configurations. For all other cases, results based on the inhomogeneity model become increasingly inaccurate as the configuration departs from one where the average curvature across the delamination is zero. These observations provide a sound basis for interpreting recent experimental measurements of curvature profiles that appeared puzzling from the viewpoint of the inhomogeneity model. They also indicate that in situ imaging of delaminations cannot be based on the inhomogeneity model, but should recognise that delaminations are flexural inhomogeneities.

Keywords: A. Delamination modelling; B. Split-beam model; C. Curvature mode shapes.

A new approach to calibrate Goldak's heat source model for additive manufacturing

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Goldak's ellipsoidal heat source model is widely accepted in laser powder bed fusion (LPBF) process simulations. The model is dependent on three inherent flux distribution parameters and absorptivity which need to be calibrated before application. However, the uniqueness of the calibrated heat source parameters has not been established. We proposed a novel parametric optimization method that can uniquely calibrate these four heat source parameters with high accuracy. Both the simulated cross-sectional (CS) profile and the mid-front (MF) profile of the melt pool were used during calibration. The differences between the experimental and simulated profiles formed the objective function of the parametric optimization problem. A genetic algorithm was employed to optimize the heat source parameters by minimizing this single objective function value. A unique solution of Goldak's heat source parameters with less than 2% error can be achieved within 50 generations of the optimization process in our verification. A single-track experiment was conducted to demonstrate the application of the proposed method in a real scenario. The profiles from simulation with the calibrated heat source parameters exhibited a good agreement with experimental results. The calibrated parameters were used to simulate multi-track printing on a single layer for validation of the proposed method. The CS melt pool profiles obtained from the multi-track simulation and multi-track experiment agreed well, which validated the accuracy of the proposed calibration method and its utility in obtaining the key Goldak heat source parameters for LPBF simulation. The details of the research have been published in the journal Additive Manufacturing (2024, vol 92, No. 104379).

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Topology Optimization for Multi-Component Robotic Arms under Time-Varying Loads

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High structural performance of robotic arms is essential for positioning precision and energy efficiency in industrial applications. This study presents a design-dependent topology optimization framework for multi-component robotic arms, addressing dynamic multi-load scenarios during motion. Utilizing the Bi-directional Evolutionary Structural Optimization (BESO) method, the framework incorporates self-weight and inertia loads, and takes into account the time-varying acceleration of serial robotic arms in a forward manner. The objective is to minimize mean compliance under a transient context. Three numerical examples, namely a 2D single robotic arm, 3D two-arm in-plane rotation, and 3D three-arm spatial movement are presented to demonstrate the efficacy of the proposed framework. The optimization results highlight the necessity of considering design-dependent loads and different robotic configurations in topological evolution. Comparative studies on motion strategies and travel times further emphasize the importance of integrating structural performance with movement dynamics. This approach offers significant insights into the topological design of robotic arms, potentially improving their operational efficiency and precision in various industrial applications.

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Hemispherical hollow dome crashworthiness analysis

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Submarine collisions and groundings have been responsible for a significant percentage of submarine incidents, often leading to significant consequences such as property damage, high repair costs, and lengthy out-of-service periods[1]. The crashworthiness of a submarine's pressure hull is crucial to understanding the structural integrity of the vessel in the event of a collision or grounding. This study presents an explicit numerical model for predicting the structural integrity of a hemispherical dome, a critical section of a submarine pressure hull, during a dynamic axial collision. The model considers significant influencing factors on structural responses, such as manufacturing imperfections, high strain-rate material properties, and strain hardening effects. The numerical model is evaluated and validated by comparison with experimental results performed at the Underwater Collision Research Facility (UCRF)[2], showing good agreement at different impact energies/momentums. This study contributes to the advancement of submarine crashworthiness and survivability during a collision or grounding incident.

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Prediction of Micro-Crack Networks in Carbon Fibre Composites at Cryogenic Temperatures

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Carbon fibre composite tanks present a tremendous opportunity for the storage of cryogenic liquid hydrogen (LH2). However, the formation of through-thickness microcrack percolation network in carbon fibre composites at the ultracold LH2 temperature remains the most significant challenge to the use of all-composite hydrogen tanks. While previous work has characterized the cryogenic matrix cracking and delamination behaviour of carbon fibre composites, there is still a lack of knowledge and predictive modelling techniques regarding the formation and progression of complex stitch cracks and crack percolation networks in composite laminates at cryogenic temperatures, specifically under thermomechanical loading conditions.

To address this critical gap, the present research develops a novel integrated computational materials engineering (ICME) framework, integrating nano-micro-macro-scale modelling, to analyse the formation and progression of complex cracking and delamination networks in composite hydrogen tanks. Experimental investigations of progressive damage, including fibre debonding, matrix crack coalescence and interlaminar delamination under increasing strain have been carried out at cryogenic temperatures and characterized using micro-computed tomography (μCT). Both the onset of microcracks and the formation of the eventual percolation network correlate well with the predictions of the developed computational model. Analysis results will be presented, demonstrating the effects of epoxy matrix toughening, ply thickness, and ply layup on matrix crack onset, delamination area and formation of crack percolation networks in quasi-isotropic composite laminates.

These analysis results are then leveraged to propose new failure criteria, which for the first time define: (i) "conservative" design allowable parameters for microcrack onset and (ii) "higher limit" allowables for the formation of crack percolation networks. These failure criteria also provide failure envelopes for composite laminates at cryogenic temperatures. The proposed failure criteria, along with the novel multiscale model, offer practical guidance for the design and optimization of composite hydrogen tanks, representing a significant advancement toward net-zero emission aviation.

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Topology optimization of CFRP laminated structures considering Tsai-Wu failure criterion and experimental validation

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This study introduces a topology optimization method for carbon fiber reinforced plastic (CFRP) laminated structures, emphasizing two optimization strategies: one based on structural compliance and the other incorporating the Tsai-Wu failure criterion. The optimization process utilizes the Discrete Material and Thickness Optimization (DMTO) method, enabling the simultaneous optimization of fiber orientation and thickness for each layer. Gradient-based algorithms, specifically the Method of Moving Asymptotes (MMA), are employed to drive the optimization process efficiently. Both optimized designs are subsequently fabricated using 3D printing for experimental validation.

The experiments compare the mechanical performance of the two structures, providing detailed analysis of their fracture surfaces to investigate the underlying failure mechanisms. Results reveal that the structure optimized with the Tsai-Wu failure criterion achieves a 30% reduction in the maximum failure index, significantly outperforming the compliance-only optimized structure. The incorporation of the failure criterion ensures enhanced structural reliability and robustness under loading conditions.

Furthermore, the study delves into fracture mechanism analysis, offering insights into the critical role of failure criteria in composite structure design. This work highlights the importance of integrating advanced failure models into topology optimization to improve the structural performance of CFRP laminated systems. These findings provide a valuable framework for future research and development of lightweight, high-performance composite structures.

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Wearable Ultrasound with Sensor Array for Doppler-Based Blood Flow Monitoring

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Abstract

Continuous and accurate blood flow velocity measurement is essential for diagnosing cardiovascular diseases. However, current ultrasound systems rely on manual Doppler angle input by clinicians, leading to variability and reduced accuracy. Additionally, their rigid designs hinder long-term monitoring in dynamic, real-world conditions. Unlike conventional systems, our approach leverages real-time computational analysis for automated Doppler angle detection, offering unprecedented accuracy and adaptability in blood flow monitoring.

We present a flexible and wearable ultrasound device incorporating a self-adaptive sensor array for real-time vascular geometry analysis. By dynamically detecting vascular orientation, the system autonomously estimates the Doppler angle, eliminating manual input and significantly enhancing measurement accuracy. This sensor array further ensures robust adaptability across diverse anatomical structures and motion conditions, enabling reliable performance in dynamic environments. Constructed with soft, bio-conforming materials, the device provides prolonged skin adherence and comfort, supporting continuous high-resolution vascular imaging and real-time blood flow velocity measurement through Doppler frequency shifts.

This wearable device provides a precise and user-friendly solution for cardiovascular monitoring, addressing critical limitations of traditional ultrasound technologies. Its ability to perform dynamic, real-time measurements makes it particularly suited for applications such as thrombosis detection, arterial stenosis diagnosis, and postoperative vascular care. By enabling long-term, accessible monitoring, it holds significant potential to advance non-invasive healthcare, particularly in personalized and preventive medicine.

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Multiobjective column layout optimisation to balance structural performance and resource efficiency whilst ensuring structural integrity

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Ensuring the structural integrity of concrete slabs under vertical loads requires careful placement of the supporting columns to balance the structural performance and resource efficiency. This paper presents a novel method for the multiobjective optimisation of column layouts, aiming to simultaneously minimise the number of columns and strain energy of a slab. Structural integrity is ensured throughout the optimisation process by utilising a displacement constraint, and columns are restricted to architecturally acceptable locations to ensure an architecturally acceptable layout. The optimisation process is split into an inner and outer optimisation problem. The inner problem involves finding the positions of a fixed number of columns which minimise the strain energy in the slab. It is a continuous problem and is solved with a gradient-based approach. The outer problem involves choosing the number of columns for each architectural region to find the Pareto front of number of columns versus strain energy. It is a combinatorial problem and is solved with a genetic algorithm approach.

The identified Pareto front provides structural engineers with a trade-off curve between structural efficiency of the slab (reduced strain energy) and economic considerations (fewer columns). The proposed optimisation process also enhances structural integrity by finding the column locations which minimise the strain energy in the slab. These layouts support the slab evenly and do not possess localised areas of excessive displacement which reduce structural integrity. Results are demonstrated through benchmark examples and a large real-life residential slab, with a comparison to a manual design by a structural engineer. These examples demonstrate the method's capability to find the Pareto front of number of columns versus strain energy and find solutions which improve upon a manual design. This work contributes to the broader goal of improving structural performance and sustainability in engineering design, providing a robust tool for enhancing structural integrity in reinforced concrete buildings.

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Design of Simultaneous Energy Harvesting and Sensing Systems for Bridge Health Monitoring

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With the emergence and rapid development of the Internet of Things (IoT), wireless sensor networks (WSNs) have gained attention in Structural Health Monitoring (SHM). Recently, Piezoelectric Energy Harvesters (PEHs) have emerged as dual-functional devices that not only provide a sustainable energy solution for the IoT but also serve sensing purposes through voltage signals. This study focuses on designing and optimizing PEHs as a compact Simultaneous Energy Harvesting and Sensing (SEHS) component for bridge SHM.

A comprehensive platform based on an unsupervised algorithm (convolutional variational autoencoders) is proposed, which enables the use of voltage signals from healthy bridges as input without requiring labelled data. This platform also includes a three-layer cantilevered Kirchhoff-Love PEH plate model with IsoGeometric Analysis (IGA) to simulate voltage signals during energy harvesting. Two case studies, involving numerical and lab-scale vehicle-bridge interaction (VBI), are conducted. The results demonstrate the effectiveness of the proposed framework in identifying optimal PEH configurations for bridge damage detection, while also emphasizing the significant impact of geometric parameters of piezoelectric devices on SEHS performance. Case studies further explore the impact of damage severity, location, and PEH placement, revealing the stability and applicability of the optimization framework in enhancing sensing accuracy and energy output.

These findings lead to design guidelines for piezoelectric devices in SHM applications, highlighting the critical principle of matching PEH frequencies with bridge modal frequencies that contain damage information to achieve efficient sensing. Additionally, based on experimental data, PEHs exhibit superior performance over acceleration-based sensing, which greatly improves the accuracy of bridge damage detection. Overall, this study validates the potential of PEHs to effectively perform SEHS under diverse damage scenarios of bridge, offering a practical solution for implementing self-powered systems in SHM applications.

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Surrogate-Model-Assisted Multi-Objective Calibration of Crystal Plasticity Finite Element Method (CPFEM) Models

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Crystal plasticity finite element method (CPFEM) models are powerful tools for simulating the deformation behaviour of polycrystalline materials, capturing the influence of a material's microstructure on its macroscopic properties. However, identifying a unique set of crystal plasticity parameters presents significant challenges due to the vast parameter space and the high computational cost associated with microstructure-informed finite element simulations. To address these challenges, a deep neural network (DNN) surrogate model is developed to approximate the CPFEM response, which is then integrated with a multi-objective genetic algorithm (MOGA) to determine the crystal plasticity parameters. This approach optimises the material parameters using multiple objective functions, such as for the stress-strain curve and grain rotation measurements obtained via in-situ electron backscatter diffraction (EBSD) during tensile loading. The calibration workflow is demonstrated using Alloy 617 at room temperature, showing that the calibrated CPFEM model can accurately capture the stress-strain behaviour, overall texture evolution, and reorientation trajectories of individual grains. Plots of the experimental and calibrated stress-strain response and reorientation trajectories are shown in Fig. 1.

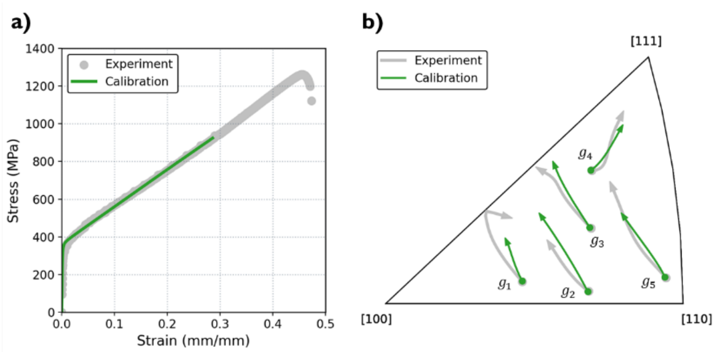

Fig. 1: Plots of the experimental and calibrated (a) stress-strain response and (b) reorientation trajectories of five grains, $g_{1..5}$.

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Damage Assessment of Fibre Reinforced Polymer Composite Laminates Subjected to Laser Irradiation

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Fibre reinforced polymer (FRP) composites are widely used in the aerospace and shipbuilding industries due to their superior strength and stiffness to weight ratio, higher fatigue life, and lower thermal expansion properties compared with traditional metal alloys. Lasers have been an emerging threat to military infrastructures such as aircraft due to their ability to penetrate FRP structures [1-6]. Hence, it is critical that the effects of laser irradiation to FRPs can be predicted.

Laser irradiation consists of highly concentrated, energetic electromagnetic beams of monochromatic and coherent light that can cause reversible and permanent damage to the polymer matrix and fibres of FRPs via local heating. The extent and nature of damage by lasers depends on many parameters including the laser power, beam diameter, wavelength, exposure duration, and the inherent properties of the composites. Upon a FRP being subjected to laser irradiation, it begins to absorb the energy, resulting in intense heating. This leads to a combination of thermal, mechanical, and chemical effects with damage modes including cracks, internal delamination, and fibre-matrix separation [1-6]. In this study, a numerical modelling framework (NMF) is developed to model the thermal effects of FRPs subjected to continuous wave laser irradiation, which could be expanded to model the thermomechanical effects. The commercial finite element analysis software ABAQUS is employed to simulate the effect of laser irradiation on a carbon fibre reinforced polymer (CFRP) laminate of IM7/977-3, which is a prepreg material consisting of unidirectional fibres and is widely used in aerospace structures. The NMF developed in this study predicts the trends of the temperature change and profile of the IM7/977-3 samples under laser irradiation well compared to experimental results.

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Creep-fatigue damage evaluation of very high-temperature reactor systems by ASME BPVC rules

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Generation IV nuclear reactors are the forefront of fission reactor design and technology. One of the six proposed reactor designs is the very high temperature reactor (VHTR), which reaches steady state temperatures of up to 900°C, significantly higher than other generation III, III+ and IV designs. These conditions support industrial applications such as hydrogen production. However, this subjects components to substantial thermo-mechanical stresses.

A key challenge in VHTR design is the evaluation of creep-fatigue (C-F) damage caused by sustained high-temperature operation and cyclic loading. Standards such as the ASME BPVC Section III Division 5 and the R5 assessment procedure outline guidelines for evaluating C-F damage, but few published studies apply these codes to VHTR conditions and specialised materials. Consequently, this study aims to address the need for robust computational C-F lifing analysis specific to the operating conditions of VHTRs.

In this study, an intermediate heat exchanger (IHX) based on the design of the Japanese high temperature test reactor (HTTR), shown in Figure 1(a), is evaluated using the ASME BPVC Section III Division 5 HBB-T-1400 Creep-Fatigue Evaluation guidelines. Structural analyses were performed using the open-source MOOSE (Multiphysics Object-Oriented Simulation Environment) framework alongside NEML (Nuclear Engineering Material model Library). Code guidelines were subsequently implemented using Python scripts, including both elastic and inelastic methodologies.

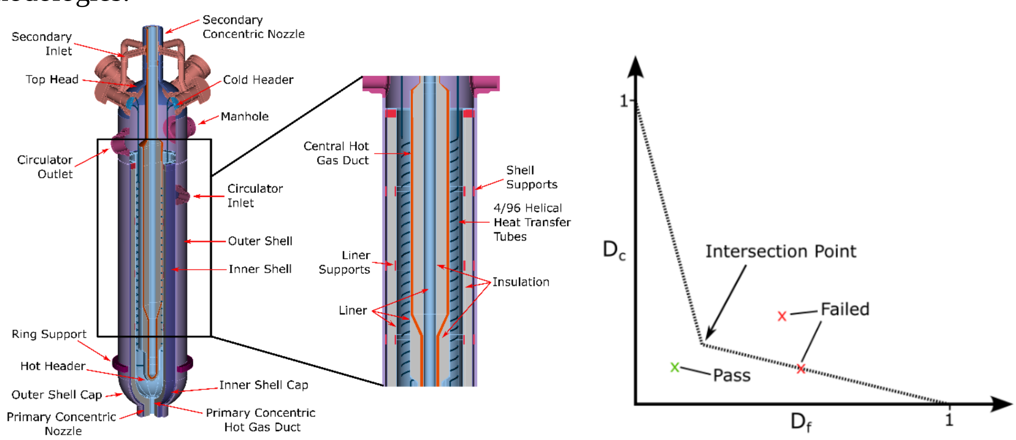

***Fig. 1**: (a) HTTR IHX Schematic (b) Creep-Fatigue Damage Envelope Schematic*

The ASME approach assumes a bilinear interaction between creep and fatigue, called the 'damage envelope', as shown in Figure 1(b). Creep and fatigue components of damage are evaluated and plotted to determine whether the allowable damage limit is exceeded.

Creep damage was found to be the dominant contributor to overall C-F damage under VHTR conditions. Comparisons between evaluation methods additionally reveal how elastic approaches generally produce more conservative lifing estimates, while inelastic methods yield more accurate predictions, but require significantly greater resources. These findings provide valuable insights into the operational life of VHTR components while also highlighting the ongoing challenges, particularly the limited availability of high-temperature material data.

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Virtual modelling framework based elastoplastic analysis on mechanical metamaterials

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Abstract

Mechanical metamaterials have become a critical research focus across various engineering fields. As a main category of mechanical metamaterials, auxetic structures in recent years have become a spotlight in various engineering industries due to their unique mechanical characteristics during deformation. They can exhibit a negative Poisson's ratio characteristic during compression, which has a huge potential in numerous advanced engineering applications. This paper presents a stochastic elastoplastic analysis of the re-entrant honeycomb, which is a main category of the auxetic structure, under external compression loads. By implementing the extended support vector regression (XSVR) techniques on the samplings calculated by numerical simulations, a reliable surrogate model is established to provide an efficient prediction of the elastoplastic performance of the structure. Error studies including R square and RMSE are conducted to verify the credibility of the virtual model. Meanwhile, the results are compared with those from the Monte Carlo simulation (MCS) for further validation. After that, the probability density function (PDF) of important indicators of the elastoplastic behaviours of the structure, namely, yielding stress and Specific Energy Absorption (SEA) are assessed to explore its uncertain performance.

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Numerical Simulations of the Wire-Arc Additive Manufacturing (WAAM) Process

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Keywords: Additive Manufacturing, WAAM, Simulations, 316L Stainless Steel, Phase-Field

Wire Arc Additive Manufacturing (WAAM) is a direct energy deposition additive manufacturing process that uses well-established welding technology. It consists of a sequential deposition of weld passes and layers to form bases of engineering components later machined to the final shape. The WAAM process is characterised by high heat input, high deposition rate, high surface roughness and the anisotropy of material properties.

The uneven heating during the deposition process leads to the residual stresses and macroscopic distortion of the manufactured component. While distortion can cause issues with following step of the manufacturing process, the residual stresses might negatively affect the performance of a component in service conditions. Furthermore, the post-deposition solidification of the alloy leads to the development of a highly textured microstructure which might also have a negative effect of the performance of the component. Hence, it is of the technological importance to be able to predict distortion, residual stresses and microstructure associated with the complexity of the WAAM process.

In this project, the WAAM process has been employed to manufacture multipass, multilayer walls made using 316LSi stainless steel consumable on a 316L substrate. An array of thermocouples on the base plate has been used to monitor the transient temperature field during the WAAM manufacturing of test specimens. The thermocouple readings are used to calibrate the thermal model, which we then used in a phase-field model capturing the solidification process and formation of weld-like microstructure associated with the WAAM process. Furthermore, the same thermal model was used in the mechanical model capturing material response to the heat source, thus predicting the macroscopic distortion and residual stresses. The modelling work is being validated via various experimental techniques and an innovative open-source framework (MOOSE Framework) and a Cellular Automata models are used to develop and verify the code.

Enhancing the mechanical properties of a laser powder bed fusion fabricated bulk metallic glass

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Laser powder bed fusion (LPBF) enables the fabrication of large-dimensioned bulk metallic glass (BMG) components; however, we are only just learning how to control the LPBF process to obtain specific mechanical properties. Furthermore, for potential commercial applications it is of upmost importance to fabricate BMG components with good fracture toughness. LPBF was used to produce dense and fully amorphous $Zr_{59.3}Cu_{28.8}Nb_{1.5}Al_{10.4}$ BMG samples from two different commercially produced starting powders. One powder had a relatively finer particle size range of 10-45 µm and the other had a relatively coarser particle size range of 25-63 µm. Fully amorphous samples were achieved for both powders within a large processing window of laser power and scanning speed combinations. When the LPBF volumetric energy density was raised above ~30-33 J/mm^3, high relative density (> 99%) was maintained along with devitrification and embrittlement. Low LPBF energy densities below ~20 J/mm^3 produced low relative density (< 99%) and fully amorphous samples. Strength and hardness generally increased with increasing LPBF energy density while the relaxation enthalpy, ductility, and fracture toughness decreased. Furthermore, the coarser powder had four times lower oxygen content and gave better glass forming ability, compression ductility up to 6% plastic strain, and fracture toughness up to ~38 MPa√m. These findings demonstrate that it is possible to enhance the mechanical properties of BMGs compared to previous studies (Fig. 1) by tuning the LPBF process parameters within a wide processing window and by controlling the feedstock powder oxygen content.

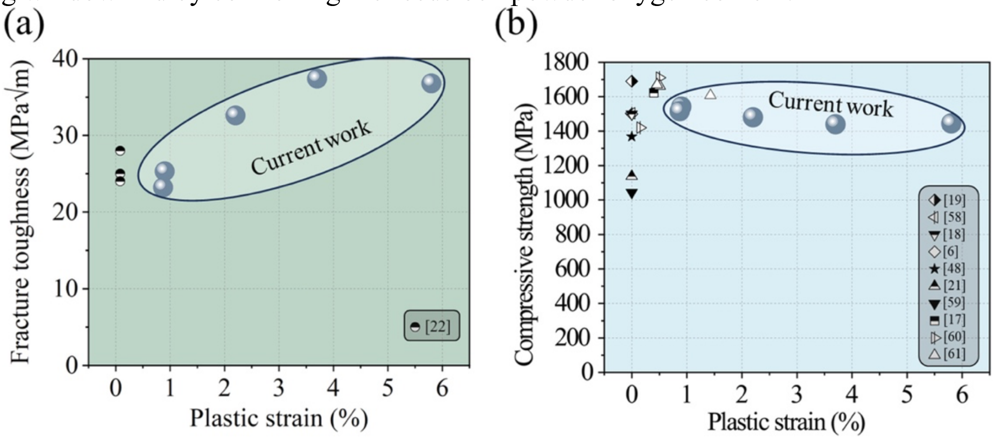

Fig. 1: Mechanical properties of the LPBF fabricated BMG samples obtained in the current study (sphere symbols) compared to other reports for LPBF BMGs. (a) Fracture toughness vs. plastic strain and (b) compressive strength vs. plastic strain. Figure reproduced from [1] with CC BY license.

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Effect of heat treatment on fatigue properties of Stainless Steel and Inconel fabricated using laser powder bed fusion

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Laser powder bed fusion (L-PBF) is one of widely used additive manufacturing techniques for printing metals, which offers many benefits, such as flexibility, allowed shape complexity, and waste reduction. However, L-PBF induces extensive thermal-induced stresses in metal materials. To reduce such stresses, stress-relief heat treatment is often applied after L-PBF processes. As most metal structures are subject to cyclic loading conditions, the fatigue behavior of the manufactured metals is critical to the quality and integrity assurance in their load-bearing applications. Therefore, there is a pressing need of a comprehensive investigation of L-PBF processed and post heat-treated metal materials. This work investigates the effect of heat treatment on fatigue properties of two important metal materials, stainless steel and Inconel, fabricated using L-PBF and stress-relief heat treatment procedures. Fatigue properties were obtained from the testing CT specimens at different R-ratios. Fracture surfaces were examined using digital optical microscopy and scanning electron microscopy. The presentation describes the preliminary outcomes of the testing progress and discusses the effect of the heat treatment on crack growth rates under constant amplitude loading conditions.

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Factors Controlling Residual Stress Formation in Laser Powder Bed Fusion Components

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Residual stresses in laser powder bed fusion (LPBF) fabricated components can cause significant problems with part distortion and reduced mechanical properties. LPBF process parameters are usually selected to achieve high relative density and specific mechanical properties without much thought about their impact on residual stresses. LPBF process parameter choices are most often based on the volumetric laser energy density, which poorly correlates with cooling rate and residual stresses. Accordingly, this study aims to increase our understanding of how to control residual stresses when selecting LPBF parameters, which in turn can help avoid excessive part distortion and/or negative effects on mechanical properties such as fatigue crack growth resistance.
This study employed a bridge curvature technique to compare residual stress magnitudes in LPBF fabricated AlSi10Mg and Ti6Al4V materials when using a range of LPBF process parameters known to give high relative density and good mechanical properties. Measuring the bridge sample distortion enables quick semi-quantitative assessments directly related to the material's residual stress state. Various factors (selected LPBF parameters, laser energy density, melt pool cooling rates, in-situ monitoring photodiode intensity, build plate position, etc.) potentially affecting residual stress were examined to identify how they affect the residual stress magnitude. Our findings (Fig. 1) demonstrate a strong positive correlation between solidification cooling rates and the residual stress distortion (FLTt) measured on bridge-shaped AlSi10Mg samples, highlighting the importance of precise thermal management during the LPBF process. We also found that the relative residual stress of the AlSi10Mg samples could be predicted, to some degree, by the in-situ monitoring system photodiode intensity. In contrast, while FLTt values were generally higher for Ti6Al4V compared to AlSi10Mg, there was less variability for the different LPBF process parameters. The study offers practical guidance for fine-tuning LPBF parameters in applications sensitive to residual stress, with the aim of striking a balance between density, microstructure, and residual stresses to achieve an optimal LPBF manufacturing process.

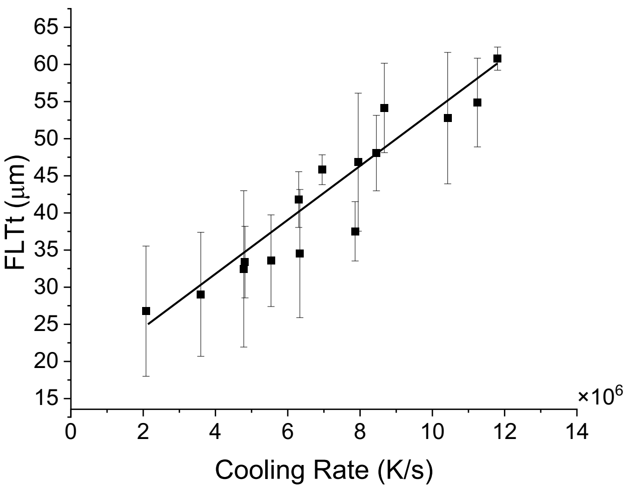

Fig. 1: Bridge sample distortion (FLTt) vs. solidification cooling rates using 15 different LPBF process parameters for AlSi10Mg samples (R^2= 0.89).

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The development and validation of finite element models of additive manufacturing

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This project focuses on the development and experimental validation of thermo-metallurgical-mechanical (TMM) models of additive manufacturing (AM) processes, for the accurate prediction of residual stress fields. Residual stresses can reduce the service life of engineering components, but the use of experimental trials to measure the residual stress fields of different deposition strategies is time-consuming and costly. Thus numerical models are used instead to optimise residual stresses by varying different process parameters.

The initial phase of this project used the SYSWELD software to build a multi-pass, laser metal deposition (LMD) of 300M steel [1]. This material undergoes solid state phase transformations (SSPT) during manufacturing, thus requiring a TMM model for accurate predictions. The thermal and metallurgical models were calibrated with temperature and hardness measurements, and the mechanical model was validated with X-ray diffraction measurements of residual stresses. The final validated model was then used to vary the LMD process parameters, demonstrating the impact of inter-pass delays and preheating on the resulting stress distributions. The TMM model also shows the improvements in optimisation efficiency when using numerical models.

The next phase of this project uses the MOOSE (Multiphysics Object-Oriented Simulation Environment) finite-element framework to build TMM models of AM. This necessitates the development of objects in the open-source software to model material behaviours, such as softening in the mechanical model. The initial models are of austenitic steels which do not undergo SSPTs, and are validated with measurements of residual stresses. These thermo-mechanical models provide the foundation for building TMM models of ferritic steels with SSPTs, which require the coding of objects for the SSPT kinetics and the resulting mechanical strains. These models demonstrate the advantage of using MOOSE over commercial alternatives as the models can be highly parallelised, which is critical when optimising processes on engineering-scale components.

Numerical models of the additive manufacturing process allow for an efficient way to test different deposition strategies, and reduce the time, difficulty and cost of experimentally measuring residual stress fields. The validated TMM models also support the importance of including SSPTs for accurate predictions of residual stresses in ferritic steels. Using open-source software additionally improves upon the capabilities and computational efficiencies of these simulations.

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Structural Integrity and Defect Analysis of Wire-Arc Additively Manufactured 316L Stainless Steel Components

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The structural integrity of additively manufactured (AM) components is critical for their implementation in critical applications such as pressure vessels, aerospace, and within the construction industry. Wire-Arc Additive Manufacturing (WAAM) offers a cost-effective solution for producing large-scale components with high deposition rates. However, the process introduces residual stresses, microstructural heterogeneities, and defects that can compromise mechanical performance and lead to premature failure. This study investigates the structural performance of WAAM-printed 316L stainless steel by analysing residual stresses, mechanical properties, and defect-characterisation.

A multi-method approach is employed to characterize and quantify residual stresses using neutron diffraction and the contour method. The mechanical performance is assessed through tensile testing, hardness mapping, and a simulative approach. Additionally, the reliability of small punch tests for estimating material properties is examined. Advanced defect assessments using neutron tomography and microscopic analyses reveal internal voids and defects, with a focus on process steady-state versus start-stop region comparison.

Preliminary findings confirm the reliability of neutron diffraction and contour method residual stress measurements when compared to simulations. The microstructural analysis indicates a complex texture with localized variations in grain size, which influences mechanical anisotropy. While hardness measurements remain relatively uniform, tensile properties exhibit orientation-dependent variations, complicating failure predictions and design optimization. These insights contribute to a better understanding of the structural integrity challenges in WAAM components and inform strategies for mitigating failure risks through process optimization and post-processing treatments. This research advances the use of AM in structural applications by addressing key reliability concerns, ultimately improving component lifespan and failure resistance in critical engineering applications

Quantifying Hydrogen-induced Nano-Void Coalescence in Additively Manufactured Stainless Steel

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Abstract

Hydrogen energy is a promising pathway for sustainable development, with significant applications in storage and transportation. Among structural materials, 316L stainless steel has garnered attention due to its durability and austenitic structure, which exhibits low hydrogen diffusivity and high hydrogen solubility, rendering it less susceptible to hydrogen embrittlement (HE). Large scale additive manufacturing could be an important solution for complex connection in hydrogen environment. The advent of wire and arc additive manufacturing (WAAM), a scalable and cost-effective fabrication method, further enhances its appeal for industrial applications. However, the behavior of WAAM-produced 316L stainless steel under hydrogen exposure remains underexplored, particularly regarding mechanisms like nanovoid coalescence (NVC), which are central to HE in ductile materials.

NVC involves the formation and growth of nanoscale voids during deformation, exacerbated by hydrogen-induced dislocation pile-ups. While pre-existing large pores are unrelated to NVC, hydrogen exposure facilitates strain-dependent void evolution, altering the void size and distribution.

This study aims to investigate potential differences in void formation between hydrogen-charged and uncharged samples at various strain levels. It hypothesizes that hydrogen charging accelerates nanovoid initiation and growth, influencing NVC and its correlation with strain. By analyzing these interactions, the research seeks to enhance the understanding the mechanism of hydrogen embrittlement in WAAM-produced 316L stainless steel.

The expected insights from this research could contribute to developing strategies for mitigating HE in WAAM-fabricated components, thereby optimizing their performance and safety for hydrogen storage and pipeline applications.

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Influence of Laser Cladding In Microstructural Evolution of Stellite 21 On Light Rail

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The swift advancement of high-speed railways has led to an abundance of incipient wear and fatigue cracks in wheels and rails. Rolling contact fatigue (RCF), along with other wear processes, necessitates the recurrent restoration of deteriorated railway tracks and wheels. The expenses related to their periodic repair or replacement are substantial. This entails an economic burden on rail service providers, contributes to a significant carbon footprint associated with track and wheel remanufacturing, and disrupts railway operations. It is proposed that the practical use of laser cladding could minimize costs related to replacing worn rail components by prolonging the lifespan of newly manufactured components (initial stage) and facilitating the repair of various rail sections vulnerable to severe wear (in operation stage). This will result in a more economical, reliable, and environmentally friendly train infrastructure.

The present work addresses the microstructural evolution of Co-based multi-layer cladding (Stellite 21) through laser-directed energy deposition concerning the wear and fatigue of railway wheels and rails. Laser cladding can enhance the surface properties of railway components by forming a wear-resistant layer, thereby reducing the frequency of maintenance and replacement. The microstructural characteristics of laser-cladded Stellite 21 were investigated and compared between single-layer and double-layers, using advanced characterization techniques such as high-resolution scanning electron microscopy and electron backscattered diffraction. Analysis of the metallurgical bonding through phase transformation and metal carbide precipitations within different regions of the heat-affected zone, and interfacial region was undertaken to develop a comprehensive understanding of the influence of the laser cladding.

The distinctive results between single and double layers of Stellite 21 demonstrate that laser cladding can significantly influence the physical metallurgy and solidification dynamics, leading to consolidated maintenance resolution and a more sustainable rail infrastructure. This research provides valuable insights into the potential of laser cladding technology to address the aspects of microstructural changes to control the wear and fatigue in high-speed rail systems, contributing to the advancement of railway sustainability.

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Automated Image-Based Analysis of Deleterious Phases in Stainless Steel and Correlation with Mechanical Properties

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The microstructural evolution of stainless steels significantly influences their mechanical properties, particularly in the presence of deleterious phases such as sigma and chi phases, which are enriched in chromium and molybdenum. These phases often lead to a deterioration of material performance, reducing ductility, toughness, and corrosion resistance while increasing embrittlement. This study presents a novel image-based analysis technique for quantifying phase transformations and correlating these findings with mechanical performance. We extract key particle metrics, including area fraction, morphology, and spatial distribution, and density from Scanning Electron Microscopy (SEM) micrographs. This enables precise characterization of phase evolution across varying thermal aging conditions. These quantitative microstructural parameters are then used to assess the impact of this phases on the mechanical performance with results from tensile tests, allowing us to establish correlations between phase content and material properties such as toughness, ductility, yield strength, and ultimate tensile strength. Initial findings suggest a strong relationship between increased deleterious phase fraction and reduced ductility, while trends in strength-related properties exhibit more complex dependencies. This research provides an efficient, scalable, and rapid automated approach to microstructural characterization, enabling enhanced predictive capabilities for material performance evaluation. Furthermore, the ability to generate structured, high-resolution datasets presents a promising opportunity for future machine learning integration, enabling predictive modelling of microstructural degradation and failure mechanisms. The findings offer insights into quality control, lifetime prediction, and potential integration with machine learning models for advanced material diagnostics and providing valuable insights for industries relying on stainless steel components, including energy systems, marine, aerospace, and nuclear applications.

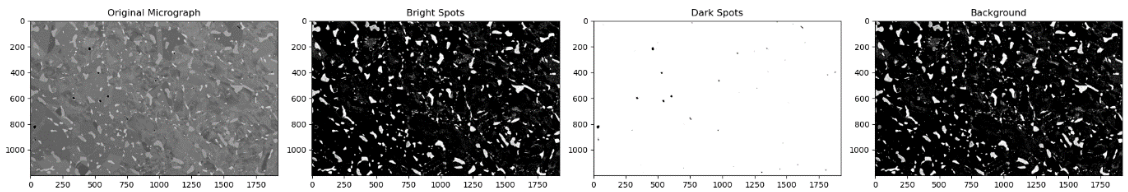

Fig. 1: Four subfigures for thermally aged 316L stainless steel at 650 °C for 3000 hours for segmentation: Original micrograph, Bright spots, Dark spots, and Background image

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Structural Reliability Analysis Through Adaptive Sampling Surrogate-assisted Most Probable Point Capturing Method

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The Most Probable Point (MPP) is a critical task in structural reliability analysis and design. Traditionally, the First Order Reliability Method (FORM) is used for MPP-capturing. However, for implicit limit state functions that are time-consuming, the high computational cost of capturing the MPP becomes a significant challenge. This study presents an advanced MPP capturing method using a supervised machine learning technique called Extended Support Vector Regression (X-SVR) [1,2]. The strong regression performance of X-SVR is theoretically supported by the inherent convexity of its optimization formulation. To enhance the robustness of X-SVR, a newly developed generalized kernel function is introduced as an additional option for kernel mapping.

Furthermore, embedded cross-validation and automated hyperparameter tuning improve X-SVR's ability to prevent overfitting while enhancing user-friendliness. The X-SVR technique facilitates the development of a virtual model by mathematically mapping the relationship between system uncertainties and structural responses with an explicit function. An adaptive sampling strategy is proposed to focus on achieving the accuracy of the surrogate model close to the limit state function. Further, an important region concept is proposed to improve the accuracy of the surrogate model around the vicinity of the MPP in the U-space. The proposed learning scheme largely ensures that the most valuable sample point can be selected as the new training sample for each enrichment iteration. The proposed method greatly enhances computational efficiency compared to traditional FORM-based MPP-searching methods, and its effectiveness and efficiency are demonstrated through a numerical case study featuring an implicit limit state function [3].

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Innovative Data-Driven Approaches for Bridge Structural Health Monitoring via Drive-By Inspection

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Keywords: bridge damage assessment, drive-by inspection, autoencoders, optimization, Kriging metamodel

Bridge structural health monitoring (BSHM) via drive-by inspection provides a cost-effective approach for assessing bridge damage through the analysis of vehicle-bridge interactions. This study integrates three innovative methodologies to advance damage detection and monitoring capabilities. First, an adversarial autoencoder (AAE)-based framework is developed for unsupervised damage detection, utilizing a frequency domain representation of vehicle responses from healthy bridge states for training. The reconstruction error serves as a damage index, facilitating accurate detection and severity estimation, validated through experimental data. Second, a novel computer vision-based approach analyzes the time-frequency domain of signals using Empirical Fourier Decomposition (EFD) and Wavelet Synchro-Squeezed Transform (WSST) for feature extraction. The extracted features are fed into autoencoders, which classify bridge states as healthy or damaged. These techniques demonstrate robustness under varying damage scenarios and road surface conditions. Finally, a sensing vehicle design optimization framework is introduced to enhance damage detection during drive-by inspections. A Kriging-based model optimizes vehicle parameters by maximizing the statistical distance between the probability distributions of healthy and damaged states. The findings underscore the potential of advanced sensing vehicles and data-driven methodologies to revolutionize bridge monitoring practices, offering scalable and efficient solutions for infrastructure health management.

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TOWARDS UNCERTAINTY QUANTIFICATION OF THE ASTM E1921 REFERENCE TEMPERATURE, T0.

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Fast brittle fracture poses a significant threat to the structural integrity of components constructed from ferritic steels, such as pressure vessels or piping systems. Achieving increased accuracy in predicting the lower-bound fracture toughness in the ductile-to-brittle transition region is desirable for both technical reasons and economic considerations.

The Master Curve (MC) method, standardised as ASTM E1921 [1], is currently the only codified fracture mechanics-based procedure that allows generation of a probabilistic lower-bound fracture toughness. It has been widely adopted in numerous structural integrity assessment codes and guidelines, such as the ASME Boiler and Pressure Vessel Code, the BS7910 guide, and the FITNET procedure [2-4].

The uncertainties emerging from the application of the Master Curve model, with its fixed standard parameter values, to different materials remain unquantified. It is known, however, that steels within the ferritic family can exhibit differences in behaviour, such as the rate at which the fracture toughness increases with temperature [5,6].

This work aims to enhance the understanding of the accuracy of the lower bound fracture toughness predictions based on the reference temperature, T0. The Monte Carlo method and variance-based sensitivity analysis techniques are applied to quantify the effect of MC model parameter uncertainties, observation uncertainties, and maximum likelihood estimation error on the overall uncertainty of the reference temperature estimate. Their impact on the lower bound fracture toughness values is studied. The effect of using non-optimal parameters to describe the temperature dependence of fracture toughness in the transition region on the outcome of the ASTM E1921 homogeneity screening procedure was also investigated.

The results of this analysis should contribute to advancing the reliability of structural integrity assessments of ferritic steel components, and provide safety assessors with increased confidence in the fracture toughness predictions made with the ASTM E1921 procedure.

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Structural Integrity and Vibration Analysis of Pressurised Liquid Container Brackets: Numerical and Experimental Insights

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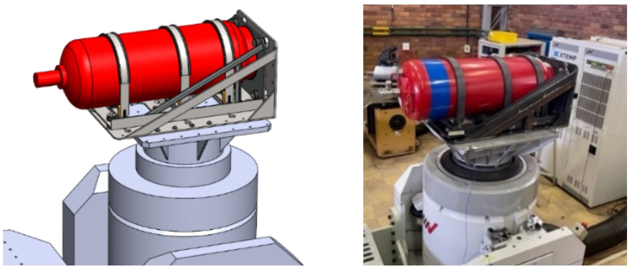
Abstract. Muster® is a global original engineering manufacturer (OEM) of Fire Suppression System (FSS), specialising in mining, construction, agriculture, and civil sectors. Muster® adheres to stringent industrial standards to ensure reliability and conformance. AS5062 [1] is an Australian standard that gives comprehensive requirements of fire suppression systems for mobile and transportable equipment with an emphasis on endurance and reliability of FSS under harsh operating environments. The design of mounting bracket for fire-fighting agent storage containers has been extremely challenging [2], as it must carry the substantial mass of the filled container whilst meeting rigorous dimensional and installation ergonomic requirements. There was no literature found on structural integrity and vibration analysis of such liquid container brackets and it is an urgent need for design engineers to understand their static and dynamic responses.
This study presents the design, analysis, and testing of the pressurised liquid container bracket of Muster fire suppression system in line with two standards: IEC60068-2-6 and IEC60068-2-27 [3,4]. A combination of numerical simulations and experimental tests was utilised to evaluate the bracket's structural integrity and vibration response. A spring mass system was defined to mimic the liquid sloshing phenomenon, and stress stiffening effects were pre-applied to components that are meant to be fastened in assembly. Furthermore, a stage based sub-assembly simulation scheme was employed to investigate the lowest natural frequency. Results from the study confirmed that the design completely excelled the AS5062 requirements, demonstrating its reliability and suitability for real-world applications. Figure 1 shows the CAD model and the physical product of the designed mounting bracket.



(a) CAD model of test setup (b) Physical test setup

Fig. 1: Representations of (a) CAD model of designed mounting bracket and test setup and (b) physical mounting bracket and test setup.

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Early Crack Detection with Distributed Fibre Optic Sensors on an F/A-18 Hornet Centre-barrel.

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Monitoring the changes of strain throughout a structure is important in understanding the load paths to determine areas susceptible to fatigue damage. However, with the use of traditional sensors such as foil strain gauges (FSG), any damage at a distance from the sensor will not be detected. Distributed fibre optic sensors (FOS) offer an alternative sensing technique which enables significantly more strain information across the features of a structure in a cost effective and lightweight package.
FSG were installed at discrete high strain locations on the bulkheads of an F/A-18 Hornet centre-barrel that was undergoing a full-scale fatigue test. Distributed FOS with a spatial resolution of 1.6 mm, were adhered along the length of the flanges, adjacent to the individual FSG. Artificial damage was imparted at high strain loading areas on the centre-barrel and strain measurements were recorded during peak loading. The distributed FOS were able to detect a change in strain due to crack propagation from the notch approximately 300 simulated flight hours before failure and prior to the detection by the FSG.
Automation of the analytical process would enable real-time monitoring of a component and bring attention to any areas with abnormal strain readings caused by developing structural damage. Implementing the use of machine learning to monitor the trends of strain across a structure would provide technicians the information to investigate potentially damaged area.

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Monitoring fatigue crack growth through the use of automated crack cameras in a full-scale component damage tolerance test

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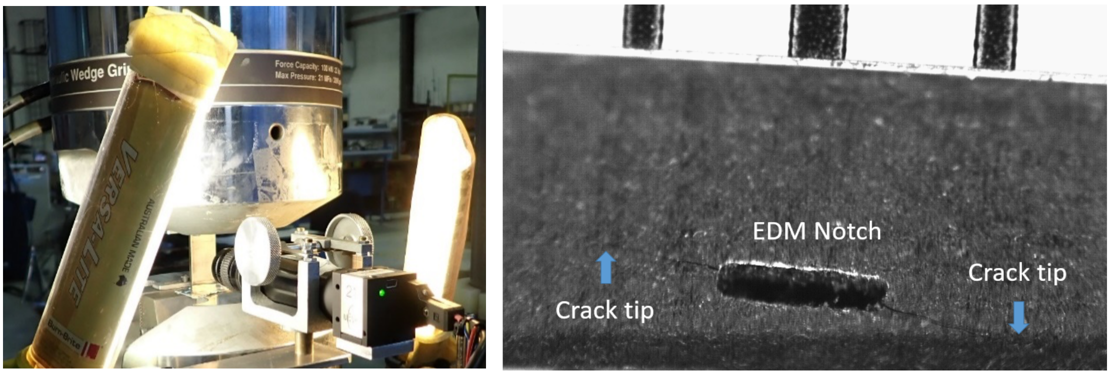
Full-scale structural tests of aircraft components are an essential part of ensuring aircraft structural integrity (ASI) and safe fleet operations. The Defence Science and Technology group, in a partnership with RMIT University, armasuisse and RUAG AG undertook a full-scale component damage tolerance (DT) test of an F/A-18 C/D horizontal tail spindle subjected to representative maneuver loading. The aim of the test was to generate experimental fatigue crack growth (FCG) rate data at two independent hotspot locations with significantly different analytical critical crack lengths. The fatigue cracks were grown from electrical-discharge machining (EDM) notches inserted at specific test times to maximize FCG results at both locations. Whilst analytical FCG predictions guided the timing of the introduction of the EDM notches, in-situ FCG monitoring was essential to 'fine tuning' these decisions and closely monitoring progress of the test. This was achieved through the use of crack cameras, where triggers were automated through the test control system at peak loads when the crack was most visible. This paper provides an overview of the full-scale component test and the challenges of conducting a DT test with multiple objectives with only one test article. The crack camera method is detailed and the FCG results and their correlation with post-test quantitative fractography (QF) results are presented. The crack cameras were able to confirm crack lengths down to below 0.1 mm surface length and were vital for the successful completion of the DT test. The outcomes of this test and the in-situ crack growth monitoring method used provided invaluable evidence and data to armasuisse for the ASI management of their F/A-18C/D fleet.



(a) (b)

Fig. 1: (a) Example photograph of the crack camera method being developed during coupon testing, and (b) example crack camera photograph of the fatigue crack emanating from the electro-discharge machining notch

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Recrystallised annealed titanium fatigue crack nucleation and growth in a combat aircraft structure

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Recrystallised annealed (RA) Ti-6Al-4V is a common high-strength aerospace alloy used in primary, safety-of-flight (SOF) critical, combat aircraft structural applications for its advantageous combination of strength, weight, durability and damage tolerance (DaDT) [1-3]. In the Swiss Air Force (SAF) F/A-18C/D Hornet fleet, RA Ti-6Al-4V was the material selected for the wing carry through bulkheads in order to meet demanding SAF operational requirements and overcome fatigue life shortcomings of the earlier aluminium alloy (AA) 7050-T7451 configurations [4]. Defence Science and Technology Group (DSTG) in partnership with RMIT University, RUAG and armasuisse completed a full-scale DaDT test program of this structure, known as STRETCH [5] to support SAF F/A-18C/D life extension activities. In this paper, the authors outline the major types of fatigue crack nucleating discontinuities observed in RA Ti-6Al-4V bulkheads from this test, as well as their equivalent initial damage size (EIDS) and small fatigue crack growth morphology as measured by quantitative fractography (QF) after destructive teardown of the test article. These include observations of cracks nucleating from surface mechanical damage as well as internal grains. Findings were compared with DaDT analysis underpinning SAF F/A-18C/D fleet certification. In general, it was found that QF measurements could significantly improve the DaDT lifing of the aircraft since the analytical assessment tended to underpredict small crack growth rates and overpredict long crack growth rates.

A

B

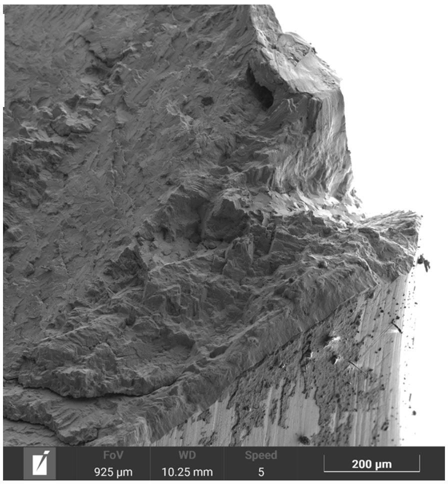

Fig. 1: (A) The STRETCH full-scale DaDT test article undergoing testing at DSTG, and (B) a Ti-6Al-4V crack nucleation site near a fastener hole location in the bulkhead, examined with a scanning electron microscope (SEM) following destructive teardown and inspection of the test article.

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Failure analysis of service fatigue cracks in aircraft structures - going further

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Approaches to failure analysis of fatigue cracking in service aircraft structure are generally straight forward. The size and extent of the cracking is assessed, the fracture is confirmed to be a fatigue crack, generally using microscopy to identify striations or progression markings, and the origin region is examined to identify crack nucleating discontinuities or features. Finally, the material is assessed along with the dimensions of the part, to ensure they conform to expected material specifications and engineering designs. What is often sought by aircraft structural integrity (ASI) managers beyond this, however, are assessments or advice on when fatigue cracking nucleated, how fast it was growing, and if it was close to failure. Answering these questions can vary from being reasonably straight forward, to very difficult depending on the case. In this paper the authors present fleet examples of failed aircraft structural components where attempts to answer these questions have been made. The authors shall offer a number of techniques, considerations and approaches to infer qualitative, and sometimes quantitative, answers to these questions backed by a wealth of experience in such investigations [1-7] and a large body of research into the way fatigue cracks grow in service.

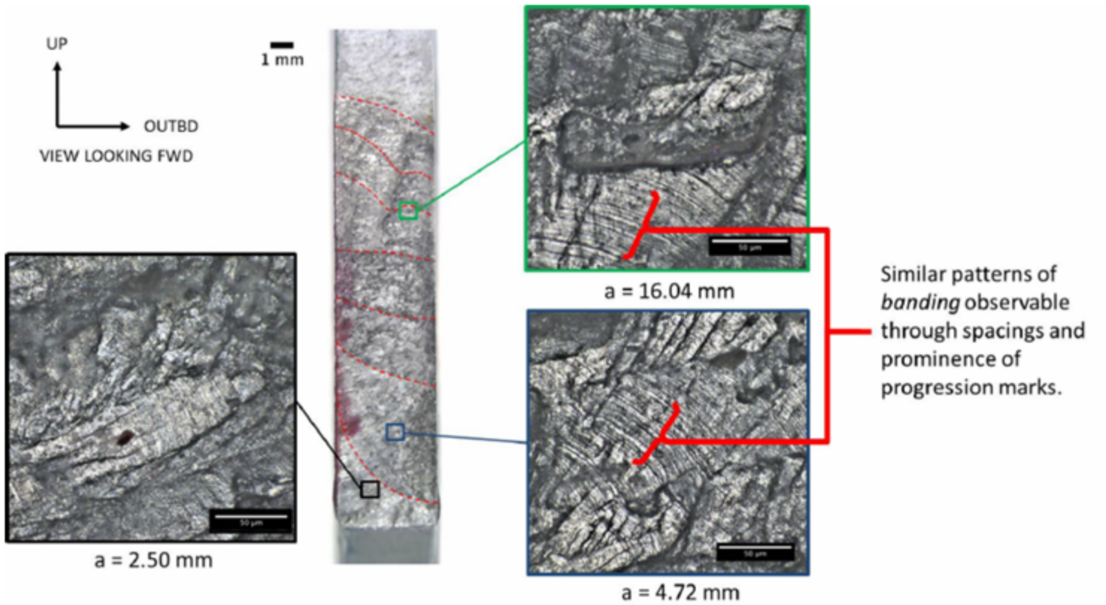

Fig. 1: Variations in fatigue crack growth rates (FCGRs) for a service crack. as indicated by changes in prominent progression markings through a range of crack depth scales.

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Fatigue crack growth rate testing of non-crimp fabric composite laminates

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Translaminar through-thickness crack growth is an important failure mechanism for thin ply laminate composites. Current numerical failure models used for structural design (including recent developments in data-driven surrogate models) are typically calibrated against fracture tests under monotonic, quasi-static loading. Their performance under cyclic loading remains poorly validated, largely due to the lack of suitable experimental data. According to a recent review on translaminar fracture damage propagation, quasi-static tests account for over 90% of experimental studies found in the literature [1]. Among studies focused on cyclic testing, most relate to the stress life approach and it is difficult to separate the influence of various damage mechanisms. The present work aims to demonstrate an experimental method for determining the long crack growth behavior of quasi-isotropic composite laminates using deeply notched specimens. It is proposed that the standardised quasi-static fracture testing method (ASTM E1922) can be adapted for cyclic testing by replacing the eccentric pin loading condition with clamped (rotationally constrained) end conditions. The latter is expected to suppress unrelated failure modes during cyclic testing

The proposed method is demonstrated on $[(90/45/0/-45)_3]_s$ Non-Crimp Fabric (NCF) laminates made from carbon fibres and thermoplastic particle toughened thermoset epoxy. The compliance and energy release rate relationships for the specimen geometry are obtained using finite element modelling of the laminates containing an idealised sharp crack. Subsequently, the crack length and crack growth rate are obtained from the experimental load-displacement curves using the compliance method (ASTM E647). Crack growth rates vs. Energy Release Rate curves are obtained at two different stress ratios ($R = 0$ and $R = 0.5$). A compliance-based method is used to estimate crack closure during part of the cyclic loading and to correlate the fatigue crack growth rate curves at different R-ratios. The proposed method and the obtained results can be useful for calibration and validation of numerical and data-driven models for damage progression in thin-ply composite laminates subjected to cyclic testing.

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Enhancing Electromagnetic Acoustic Transducer (EMAT) Performance Using Amplitude-Modulated Signals for Nonlinear Wave Mixing and Structural Health Monitoring

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Electromagnetic acoustic transducers (EMATs) have gained increasing attention in non-destructive evaluation (NDE) and structural health monitoring (SHM) due to their ability to generate and receive ultrasonic waves without direct contact with the test material. This study investigates the use of amplitude-modulated signals in EMAT-based ultrasonic wave propagation to enhance sensitivity for material characterization. A comparative analysis is conducted between double-sideband suppressed carrier (DSB-SC) amplitude-modulated signals, and conventional single-frequency Hanning window pulses. Theoretical analysis, numerical simulations using COMSOL, and experimental validation are employed to assess wave interactions, frequency components, and nonlinear effects. Special attention is given to optimizing signal parameters to improve detection accuracy in conductive materials, such as aluminum. Results demonstrate that amplitude-modulated signals enhance the capability to detect subtle defects and material degradation. These findings contribute to advancing EMAT technology for industrial applications, particularly in damage assessment and long-term monitoring of critical structures.

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Optoacoustic Characterization of Three-Dimensional, Nanoscopic Interior Features of Microchips Using Ultrafast Laser

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Recent advances in micromanufacturing and material science are expanding the development of the next generation of semiconductor devices. Motivated by the demand to ensure the integrity of semiconductor devices through the micromanufacturing process, we develop a novel optoacoustic characterization approach, targeting *in situ* calibration and delineation of three-dimensional (3-D), nanoscopic interior features of microchips, which are inaccessible by conventional optical methods due to the opaque nature of microchips. In this approach, a femtosecond laser pump-probe set-up incorporated with an ultrafast Sagnac interferometer (**Fig. 1 (a)**) is configured to generate and acquire picosecond ultrasonic waves (PUWs) traversing through microchips, with a sampling rate up to 2 THz [1]. The interior features of the microchips induce the shifted phase of acquired PUW signals, which are further calibrated to compute the correlation of PUW signals between different acquiring positions, thereby delineating and imaging the interior features. Experimental validation is conducted via characterizing nanoscopic, invisible interior aurum (Au)-gratings with periodically varied depths in typical microchips. Results highlight that the 3-D nanoscopic features of microchips are revealed with a spatial resolution comparable with that of the atomic force microscope (AFM) (**Fig. 1 (b)**). This proposed approach has provided a fast, noninvasive route to “see” through an opaque microchip with a nanoscopic resolution.

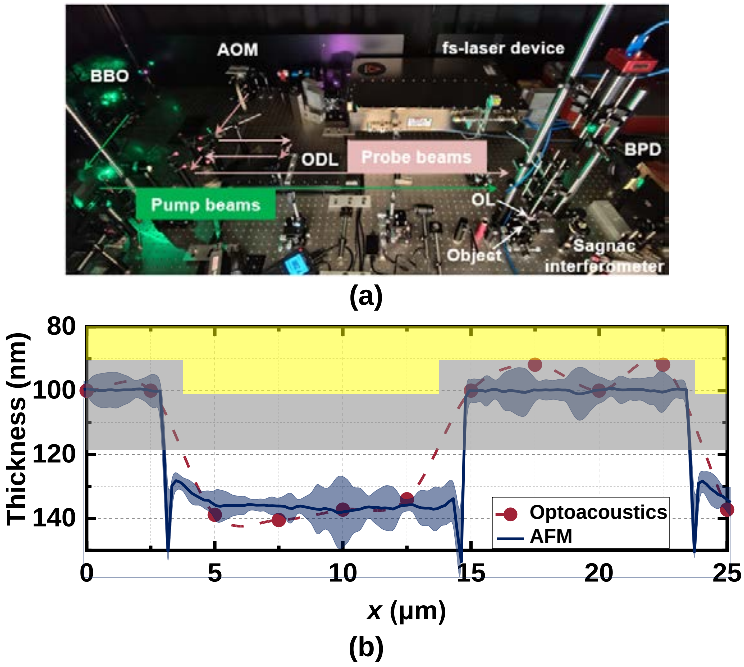

Fig. 1 (a) The configured femtosecond laser pump-probe set-up incorporated with an ultrafast Sagnac interferometer, and (b) the outlined profiles of Au-grating based on the correlation of phase-shifted PUW signals, with the spatial resolution competitive to that of AFM.

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Analysis of Crystal Defects by Electron Channeling Contrast Imaging (ECCI) for Advanced Failure Analysis

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Electron channelling contrast imaging (ECCI) is an SEM based technique for observation of extended crystal lattice defects like dislocations and stacking faults. It exploits the dependence of the backscatter electron intensity on crystal orientation and atomic order. For ECCI a crystalline sample is observed with the backscattered electron signal. The basic principle of contrast formation is that electrons channel into a crystal lattice when the incident beam hits the lattice along the Bragg angle of a set of crystal planes. In this case very few electrons are backscattered and the observed crystal appears dark. Under this condition, every defect that disturbs the order of the lattice planes leads to backscattering and are visible in the ECC image as bright features in a dark grain. Dislocations, for example, appear as bright lines, stacking faults as bright areas.

The technique can be used very similar to transmission electron microscopy (TEM), however with the serious advantage that a bulk sample can be analysed with true sample representivity compared to that in TEM which can probe an extremely smaller volume in comparison. This enables observation of much larger samples, simplifies sample preparation, and it facilitates in-situ experiments like deformation, heating, or gas reaction observations. For ECCI to be operated on an SEM, a few important conditions have to be met. Most importantly, the need for high resolution and conditions where small beam convergence and high beam current prevail. Additionally, a highly sensitive backscatter detector and a high precision versatile stage (at best 6-axis) are crucial and facilitate the imaging by providing the means of precisely tilting and rotating the sample to meet the two-beam condition at which the dislocations produce the most contrast.

In this work we will present the working principles of the technique and demonstrate its capability and advantages through a number of examples of observations on a variety of materials ranging from superalloys, high strength steels and ceramics.

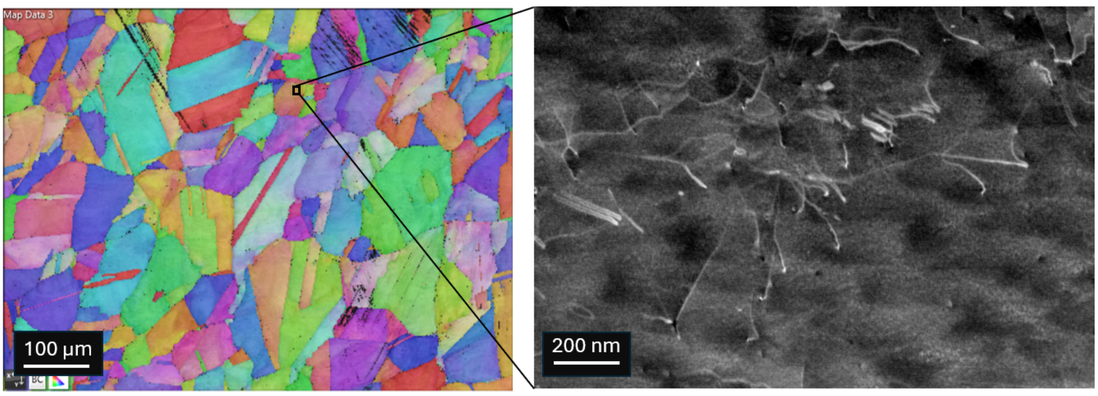

Figure 1: Electron backscatter diffraction image of a Nickel superalloy showing the overview of grains with random crystallographic orientations (left). Channeling contrast imaging of dislocation network in the same sample. The sample is imaged at 30 kV electron beam energy. Dislocation networks along grain boundaries in a strained grain at high magnification under the ECCI condition (right).

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Exploring Hybrid Conductive Composite for Flexible Sensors

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Abstract

Flexible sensors have gained significant attention due to their ability to conform to complex surfaces, making them ideal for applications in wearable technology, soft robotics, and health monitoring systems. These sensors can seamlessly integrate with the human body or dynamic environments, expanding the scope of traditional rigid sensors, which often struggle in such contexts. Flexible hybrid conductive composites, which combine multiple types of fillers, show great promise in advancing sensor performance by offering superior sensitivity and detection range compared to single-filler composites. Typically, these composites detect strain through resistance changes during deformation, with conductivity decreasing as the conductive fillers separate when stretched. This negative piezoconductive behaviour limits their use in highly stretchable electronics. However, the incorporation of both soft (e.g., liquid metals) and rigid (e.g., iron, nickel, and silver) fillers into the matrix is a novel approach that can impart unique electromechanical properties. For example, composites incorporating liquid metals and iron microparticles exhibit positive piezoconductivity, a rare and beneficial property for flexible sensors [1]. Furthermore, applying an external magnetic field to align the magnetic particles (e.g., iron, nickel) can induce anisotropic behaviour, enhancing the sensor's functionality [2]. By introducing new structural designs, the composites offer unparallelled mechanical attributes as well as sensing applications [3]. This talk will explore the advantages and unique properties of flexible hybrid conductive composites, demonstrating how the strategic use of hybrid fillers can lead to the development of superior sensing materials for diverse applications in fields ranging from healthcare to smart electronics.

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Biomechanical Assessment of fixation Plate used for Mandibular Reconstruction

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Large bone loss and defects caused by trauma, tumor or osteoradionecrosis signify a common issue in the maxillofacial clinic. The reconstruction plate plays an important role in maintaining stability and load-sharing while a grafted fibula bone unites with adjacent bone in the course of healing and bone remodeling. Clinical experience and specialized literature show that titanium reconstruction plates used for mandibular defects are often subjected to excessive mechanical stress, conceivably leading to fatigue fracture [1]. The study on fatigue characteristics for the design of medical devices is of fundamental importance, particularly for load-bearing prosthetic devices. However, failure of these devices due to fatigue under cyclic loading has been recognized as a primary concern on therapeutic longevity. In this study, we develop a computational approach for modelling fatigue process in the reconstruction plate based upon the eXtended Finite Element Method (XFEM). The mechanical stresses introduced by plate pre-bending and screw tightening were first modeled computationally and the residual stress data induced by the surgical procedure was incorporated to the deformed reconstruction plate for the subsequent biomechanical evaluation. The finding is of important clinical implications for surgeons who are commonly involved in selecting and preparing different forms of fixation plates for mandibular reconstruction. The simulation results demonstrate that the pre-stresses induced by screw tightening are more substantial than that from plate bending during the surgical procedure. This study helps elucidate the key factors contributing to the failure of reconstruction plates and guide the development of more robust and durable mandibular reconstruction systems.

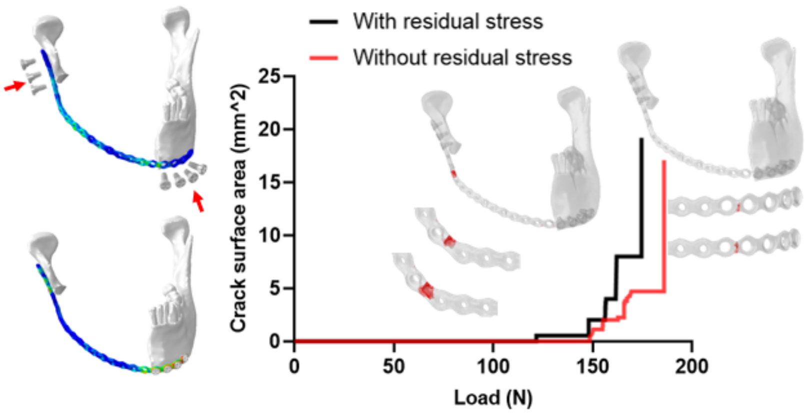

Fig. 1: Simulation of the screw tightening pre-stress. Crack propagation in the reconstruction plate and representative fracture patterns.

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Coalescence of many fractures or non-planar growth of a single fracture?

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Traces of fractures/cracks observed on the surfaces or in cross-sections of material samples are not straight; they have interruptions and overlappings. These morphological features are often interpreted as a result of coalescence of small often pre-existing fractures into a large one. However, these observed fractures are only 2D traces of real fractures. For the real 3D fractures to coalesce they must be coplanar across the sample, which is an unlikely occurrence owing to the additional degree of freedom in the fracture orientation.

This paper proposes another interpretation: the fracture traces seen on the surfaces or cross-sections are morphological features of a single large fracture whose growth is affected by heterogeneities and microscopic defects (e.g., pores or microcracks). When the fracture is bypassing these heterogeneities, it exhibits local bounded interruptions of the fracture surface and deviations leading to overlappings. It is these features that when looked at in a cross-section create impression of coalescence of small fractures.

Interruptions and overlappings leave local zones of the fractured material intact; they act as bridges distributed all over the fracture surface (outside the fracture process zone) constricting the fracture opening. Thus, a new type of fracture emerges – the fracture with constricted opening. The collective behaviour of the bridges can be modelled by an effective (possibly non-uniform) Winkler layer situated between the opposite surfaces of the fracture. The paper presents a model of such fractures based on asymptotics of small and large fractures and interpolation between them to determine the SIFs and volume of fracture opening. The model is currently being used for modelling hydraulic fractures.

Reliability-based analysis and design of steel-reinforced timber columns

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Contemporary building methodologies have led to the development of novel timber-based structural elements, including components reinforced with materials such as steel or Fibre-Reinforced Polymers (FRPs). Recent studies have demonstrated their effectiveness in reducing cross-sectional areas to accommodate greater loads [1-2]. Nonetheless, the existing Australian standard (AS1720.1-2010) does not account for composite timber structures. Thus, the present study conducts a structural reliability analysis to determine suitable capacity reduction factors (ϕ). In recent decades, structural reliability approaches have been employed to address practical engineering challenges and guide decisions in design and assessment [3-4]. In this work, the reliability analysis considers the variability of material and geometric properties, loads, and model accuracy linked to their probability density functions (PDFs). These distributions formulate the construction of limit state functions that define failure conditions, enabling the estimation of failure probabilities. A target reliability index (β_T), inferred from the literature, is adopted and validated, as the current standard does not specify a relevant reliability index for the three defined categories based on the element's importance and affected failure areas. To illustrate the approach, MGP10 (Australian Radiata pine) combined with N500 steel bars is referred to validate the associated reliability index for both unreinforced and reinforced specimens. From these investigations, capacity reduction factors (ϕ) are derived for axial loadings. Preliminary results indicate that the derived capacity reduction factors for unreinforced columns are reasonably consistent with values suggested in the Australian Standard. Furthermore, this study demonstrates the application of the proposed reliability analysis framework to benchmark examples and compares the findings with results from the available literature.

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Simultaneous Identification of Bridge Properties and Road Roughness from Drive-By Inspection by Integrating Kalman Filter and Optimization Approach

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In recent decades, researchers have investigated various methodologies for identifying bridge properties through drive-by bridge inspection. However, road roughness has been identified as a crucial component in introducing significant noise into vehicle bridge interaction systems. This work proposes a hybrid methodology for numerically identifying both physical properties of the bridge and road roughness profiles based on the response collected from a sensing vehicle. The vehicle-bridge interaction system is modelled as a simply supported Euler-Bernoulli beam traversed by a quarter-car with two degrees of freedom. The proposed approach integrates the Joint-Input-State Kalman Filter with the Particle Swarm Optimization to achieve a simultaneous identification of both road roughness and bridge properties. Additionally, the study examines the sensitivity of the identification process to factors such as vehicle configuration, driving speed, and road roughness level. The result demonstrates the effectiveness of the mentioned approach in accurately estimating bridge properties and road roughness.

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Integrating Physics-Informed Neural Networks with Phase-Field Modelling for Thermoelastic Fracture

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Fracture modelling is essential for understanding material failure mechanisms under complex thermomechanical loading conditions. The interaction between thermal effects and mechanical deformation becomes significantly more intricate when fracture occurs, introducing material discontinuities. The phase-field method provides a continuous description of fracture, addressing the fundamental difficulty caused by discontinuity in traditional approaches by transforming sharp crack interfaces into diffuse transition zones. This method effectively captures the diffuse nature of phase boundaries and the intricate evolution of crack propagation. Our approach, based on the Deep Energy Method (DEM) [1], integrates Physics-Informed Neural Networks (PINNs) with the phase-field method by directly embedding physical laws into the learning process, ensuring numerical solutions closely follow underlying principles. This study explores the application of PINNs in conjunction with the phase-field method for modelling fracture in thermoelastic systems, using the system's total energy as the loss function. The proposed methodology enables a fully coupled solution that captures the complex interaction between heat transfer, mechanical stress, and crack development. An adaptive refinement strategy is also employed which allows effective management of complex geometries and boundary conditions, addressing the challenges of multiphysics modelling. The deep energy method provides a novel framework for minimizing the physical inconsistency typically encountered in traditional numerical approaches, offering a more robust and physically consistent solution strategy. Several benchmark problems will be presented to demonstrate the effectiveness and accuracy of the proposed methodology in modelling thermoelastic interactions with fracture using the phase-field method and PINNs.

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Enhancing Self-Healing in Concrete Using Natural Fibers as Bacterial Carriers

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Self-healing bacterial-based concrete offers a sustainable solution to extend the lifespan of structures by enabling autonomous crack repairing through microbial-induced calcium carbonate precipitation (MICP). This study evaluates the performance of natural fibers (jute and flax) and expanded perlite aggregate (EPA) as bacterial carriers in self-healing concrete applications. The results of the study show that natural fibres outperform EPA because they better promote biopolymer formation. Biopolymer, which were layers observed on the surfaces of jute and flax fibres, act as scaffolds to significantly enhance bacterial colonisation and calcite growth (Fig 1).

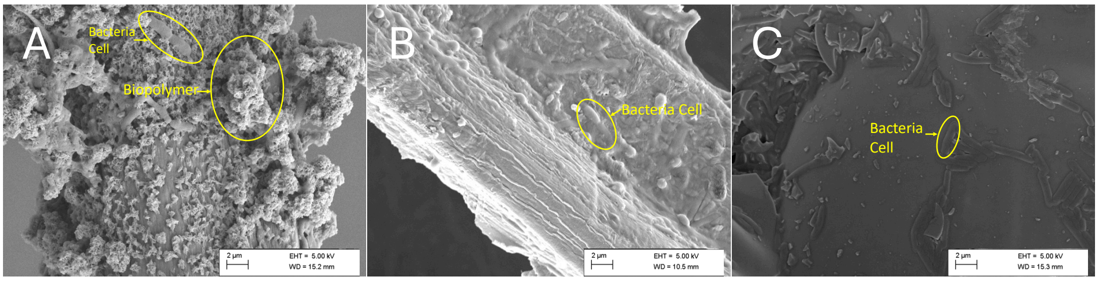

Fig.1: Growth of bacteria on carriers: (A) Jute; (B) Flax; and (C) EPA.

Jute, at 1% of the total mortar mix by volume, exhibited the most effective healing by sealing cracks. This improvement was attributed to the formation of multilayered biopolymer structures, which facilitated uniform calcite deposition and enhanced bacterial activity. Flax fibers, with thinner biopolymer layers, showed moderate healing efficiency for cracks. In contrast, EPA exhibited limited healing for relatively wide cracks. This research shows the critical role of biopolymers in improving self-healing efficiency and highlights the potential of natural fibers, particularly jute, for developing durable and sustainable concrete solutions.

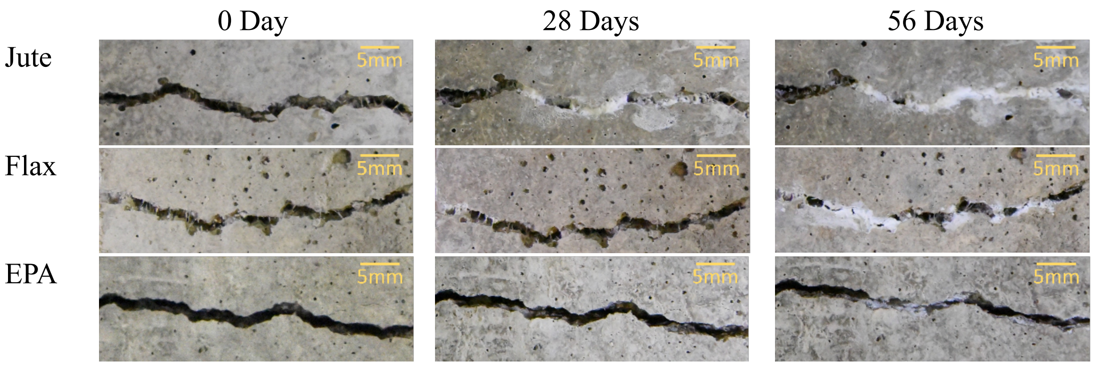

Fig.2: Crack-healing process of mortar specimens.

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Simultaneous Energy Harvesting and Bearing Fault Detection using Piezoelectric Energy Harvesters

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Bearings are critical components in industrial machinery, but they are prone to failure, leading to significant mechanical breakdowns. Traditional fault detection methods often rely on vibration data processed through cloud computing, which is energy-intensive due to the sensing process and data collection/transmission. This study proposes replacing accelerometers with piezoelectric energy harvesters (PEHs) [1] tuned to specific fault frequencies. This approach allows the simultaneous use of harvested energy for power supply and as an indicator feature for fault detection. The harvested energy, as a feature, can be directly estimated on-site, avoiding the energy costs associated with analog-to-digital conversion and wireless transmission of high-frequency samples. The study investigates the performance of various PEH designs with different natural frequencies, utilising a numerical model of PEHs [2] and acceleration data from publicly available datasets [3, 4]. Some factors, including the classification algorithm, the number of devices, and the duration of time windows, are analysed. The results demonstrate that energy generated by PEHs can effectively classify bearing faults under different conditions and severities, establishing the feasibility of using PEH-generated energy as a dual-purpose solution. This contributes to advancements in smart machinery and sustainable technology.

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Mechanism of rock spallation

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Spallation is a type of rock failure whereby thin rock fragments (spalls) get detached from a rock surface as a consequence of applying high compression parallel to the surface. At small scales spallation is sometimes observed at uniaxial compressive loading of rock (and concrete) samples as well as in the process of thermal spallation. At larger scale spallation is a mechanism of strain rockburst. In all these cases the mechanism of spallation is based on the extensive crack/fracture growth parallel to the free surface. It is initiated by the compressive stress acting in the planes normal to the surface; it produces wing cracks from the largest pre-existing defects, cracks or pores. The compressive stress is caused by sample loading or it is a result of compressive thermal stress caused by surface heating or it is the result of stress concentration at the wall of excavation. In the presence of intermediate principal stress (8% of the major principal stress is sufficient) the wing crack is able to grow into a large crack of a size greater than the distance to the free surface. Interaction with the free surface considerably accelerates the crack growth to the stage when it separates a layer sufficiently large to buckle. It is the buckling that is seen as spallation. After buckling a new surface is created and the process can repeat itself. We developed a model of spallation based on asymptotics of cracks situated very close to a free surface and parallel to it. The results will provide tools for optimising thermal spallation and developing methods of rock burst prevention.