

# BOOK OF ABSTRACTS IWPDF 2025

# 4<sup>th</sup> International Workshop on Plasticity, Damage and Fracture of Engineering Materials

24-26 September 2025 Istanbul, Türkiye

Edited by Tuncay YALÇINKAYA













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# **About**

# **IWPDF 2025**

These proceedings contain the abstracts presented at the 4th International Workshop on Plasticity, Damage, and Fracture of Engineering Materials, organized in a hybrid format by Middle East Technical University from 24 to 26 September 2025 in Istanbul, Türkiye. In addition to the in-person poster and oral presentations, which were broadcast live to online participants, pre-recorded virtual contributions were uploaded to a YouTube channel prior to the meeting. The subjects of the workshop focused mainly on the plasticity, damage, and fracture of engineering materials as the main topics. Both computational and experimental studies were presented, aiming to improve the understanding of how material microstructure, loading conditions, and environmental factors affect the deformation, degradation, and failure of engineering materials. In addition to the general scope of the meeting, this year's edition also spotlighted the following topics, featuring invited speakers and enriched by the support and contributions of various societies and institutions: Data-Driven Analysis, Materials Challenges in Nuclear Energy Systems, and Manufacturing and Material Forming. The organizers wish to thank all the invited plenary lecturers and technical session contributors who attended from around the world to discuss recent developments in the field. The papers from the workshop will be published in Procedia Structural Integrity (Open Access). The support of Middle East Technical University, REPKON Machine and Tool Industry and Trade Inc., Repkon USA, Norm Tooling, and ESIS (European Structural Integrity Society) is gratefully acknowledged.

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Okan Yılmaz - ArcelorMittal Global R&D Gent - OCAS NV (Belgium)

# **Plenary Lectures**

# Digital twins for accelerated materials innovation

### Surya R. Kalidindi\*

George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA, USA

**Keywords:** Machine Learning, Bayesian Framework, Multiscale mechanics, High-throughput Experiments, Digital twins

This presentation will expound the challenges involved in the generation of digital twins (DT) as valuable tools for supporting innovation and providing informed decision support for the optimization of material properties and/or performance of advanced heterogeneous material systems. This presentation will describe the foundational AI/ML (artificial intelligence/machine learning) concepts and frameworks needed to formulate and continuously update the DT of a selected material system. The central challenge comes from the need to establish reliable models for predicting the effective (macroscale) functional response of the heterogeneous material system, which is expected to exhibit highly complex, stochastic, nonlinear behavior. This task demands a rigorous statistical treatment (i.e., uncertainty reduction, quantification and propagation through a network of human-interpretable models) and fusion of insights extracted from inherently incomplete (i.e., limited available information), uncertain, and disparate (due to diverse sources of data gathered at different times and fidelities, such as physical experiments, numerical simulations, and domain expertise) data used in calibrating the multiscale material model. This presentation will illustrate with examples how a suitably designed Bayesian framework combined with emergent AI/ML toolsets can uniquely address this challenge.

<sup>\*</sup> surya.kalidindi@me.gatech.edu

# Predicting Mechanical Properties of Ti-Al Alloys Using Physics-Informed Neural Networks (PINNs) for Crystal Plasticity Modeling

### <u>Pinar Acar</u>\*, Mohamed Elleithy, Z. Ender Eger, Mahmudul Hasan

Department of Mechanical Engineering, Virginia Tech, Blacksburg VA 24060, USA

**Keywords:** Crystal Plasticity Modeling, Microstructure Evolution, Physics-Informed Neural Network

This study presents the development of Physics-Informed Neural Network (PINN) frameworks to predict the mechanical behavior of Ti-6Al-4V and Ti-7Al alloys under large plastic deformations. These Ti-Al alloys are widely used in aerospace systems due to their exceptional performance under complex thermo-mechanical loading.

The proposed approach integrates data-driven modeling with physics-informed constraints to enhance both prediction accuracy and interpretability in the context of crystal plasticity. The PINN frameworks are trained on data from crystal plasticity simulations, while also incorporating constraints related to the time evolution of microstructural texture.

The study focuses on two main applications, both aiming to predict the evolution of microstructural texture in Ti-6Al-4V and Ti-7Al alloys as a function of processing conditions and initial texture. The first involves solving an inverse design problem to identify the slip system parameters of Ti-7Al by aligning the PINN predictions with experimental texture data obtained after tensile testing. The second investigates the prediction of texture evolution in Ti-6Al-4V during deformation loading. Long Short-Term Memory (LSTM) and Transformer neural network architectures are employed to capture the time- and state-dependent nature of texture evolution during plastic deformation. Results demonstrate that the PINN models significantly outperform purely data-driven networks when compared with both experimental measurements and physics-based simulations.

<sup>\*</sup> pacar@vt.edu

# Achieving Alloys with Simultaneously High Strength and Ductility

### Evan Ma\*

Center for Alloy Innovation and Design (CAID), Xi'an Jiaotong University, Xi'an, China

Keywords: strength, ductility, strain hardening

To march into new territories in the strength-ductility space, we exploit additional strengthening and strain hardening mechanisms rendered possible by the widened scope of element selection and composition design in multi-principle-element alloys (MPEAs), which also help us to push towards extreme the known plasticity mechanisms including TWIP/TRIP. In particular, the unusually high chemical inhomogeneity in these highly concentrated alloys offer i) concentration fluctuation/undulation that can be intentionally enlarged [1]; ii) local chemical orders due to variable chemical affinity among the constituent species [2]; and iii) extraordinarily high number density and volume fraction of nanoscale (multi-phase) precipitates. All these roughen the atomic and energy landscape, elevating hardening via difficult nanoscale segment detrapping in the "nano-cocktail". The resultant stick-slip renders the dislocation motion sluggish, which then tend to stall, react, entangle and accumulate, sustaining the ability to work-harden on the fly with increasing tensile strain. In the meantime, the multi-component intermetallic precipitates can be tailored stronger (or more ductile) than normal, thanks to multi-component effects on anti-phase boundary energy. All these add new twists to dislocation mechanisms and dynamics to delocalize the plastic strain to prolong tensile elongation at GPa flow stresses [3]. In the absence of embrittling ceramic or brittle intermetallics with inherent dislocation starvation, effective means elevates strain hardening to keep up with the strength elevation, delaying plastic instability such as necking that instigates damage. New complex concentrated alloys with better and better strength-ductility synergy [3-5] are now at the verge of realizing yield strength up to  $\sim 1.8$ GPa, not far from the best bulk alloys (super steels), concurrently with uniform tensile elongation  $\sim$ 27% [5], similar to that of an elemental metal such as interstitial-fee Fe. Having it both ways towards the upper right corner, in the plot summarizing all the yield strength - tensile ductility combinations [5], can be likened to "having fish and bear's paw at the same time" (an old Chinese proverb).

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<sup>\*</sup> ema.matscieng@gmail.com

### Electro-chemo-hermo-mechanical Phase Field Modelling of Hydrogenassisted Fractures

### Emilio Martinez-Paneda\*

Department of Engineering Science, University of Oxford, Oxford, OX1 3PJ, UK

**Keywords:** Hydrogen embrittlement, Phase field fracture, Multi-physics modelling, Weld process modelling

Metallic materials experience a dramatic reduction in ductility, fracture toughness and fatigue resistance in the presence of hydrogen. This phenomenon, so-called hydrogen embrittlement, is pervasive across the transport, defence, energy and construction sectors, due to the ubiquitousness of hydrogen and the higher susceptibility of modern, high-strength alloys. Moreover, hydrogen embrittlement is one of the biggest threats to the future of hydrogen as a clean energy carrier. In this work, the speaker will overview recent efforts in his group aiming to predict hydrogen-assisted failures through the development of coupled, multi-physics models that explicitly resolve the underlying physical processes and exploit the potential of phase field approaches to deliver robust predictions across scales.

<sup>\*</sup> emilio.martinez-paneda@eng.ox.ac.uk

# Unsupervised learning of nanoindentation data of complex materials

### Ruth Schwaiger\*1, Chen Zhang2, Stefan Sandfeld2

**Keywords:** unsupervised learning, nanoindentation, heterogeneous materials

Nanoindentation has become an essential technique for characterizing the mechanical properties of materials at small length scales, providing key insights into hardness and elastic modulus with high spatial resolution. Traditional nanoindentation approaches often rely on a limited number of measurements, averaging the results to obtain representative values. However, this method may overlook variations in mechanical properties that arise from microstructural heterogeneity. To address this, statistical nanoindentation techniques have been increasingly employed to capture the full distribution of mechanical properties across a sample. Advancements in data acquisition and analysis methods, including machine learning techniques, have further enhanced the interpretation of nanoindentation datasets. In this study [1], we investigated Cu-Cr composites as model materials to explore fundamental methodological aspects of statistical nanoindentation. These composites provided an ideal system for examining the effectiveness of statistical nanoindentation in detecting variations in mechanical properties. Datasets, consisting of several hundred nanoindentation measurements of Young's modulus and hardness at varying indentation depths, were generated by performing arrays of indents across extensive sample areas. To analyze the data, we applied the Gaussian mixture model —an unsupervised learning technique—to deconvolute the mechanical property distributions and determine the number of distinct mechanical phases within the composite. A key challenge in statistical nanoindentation is determining the adequate amount of data required for reliable predictions. While machine learning techniques have been widely employed for data deconvolution and classification, there remains a critical question: How much data is necessary to ensure meaningful and reproducible results? To address this, we implemented a cross-validation approach to systematically assess the impact of data quantity on statistical reliability. By incrementally varying the dataset size and analyzing the convergence of mechanical property distributions, we were able to infer the minimum number of indentations needed to obtain robust predictions. By leveraging machine learning-based deconvolution methods, we provide a framework for more reliable mechanical characterization of multiphase materials. These results are not only relevant for Cu-Cr composites but also offer broader implications for the study of heterogeneous materials, including alloys, composites, and geological materials.

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<sup>&</sup>lt;sup>1</sup> Institute of Energy Materials and Devices – Structure and Function of Materials (IMD-1), Forschungszentrum Jülich, 52425 Jülich, Germany

<sup>&</sup>lt;sup>2</sup> Institute for Advanced Simulation – Materials Data Science and Informatics (IAS-9), Forschungszentrum Jülich, 52068 Aachen, Germany

<sup>\*</sup> r.schwaiger@fz-juelich.de

# From Specialist to Generalist Models for Microscopy and Simulation

### Stefan Sandfeld\*

Institute for Advanced Simulation – Materials Data Science and Informatics (IAS-9), Forschungszentrum Jülich, 52068 Aachen, Germany

Keywords: scientific machine learning, explainable AI, surrogate models, microscopy analysis

The shift from specialist to generalist models marks a pivotal transformation in scientific AI, redefining how we tackle complex challenges, e.g., in microscopy and in physics-based simulation. Traditionally, specialist models are crafted for narrowly focused tasks: microscopy for image interpretation, or simulation for solving specific PDEs, each relying on domain knowledge as well as on highly specialized and curated datasets to reach high accuracy. While excellent within their domains, such models tend to struggle with flexibility, cross-domain transfer, and robustness when facing out-of-distribution (OOD) conditions.

This presentation explores both sides: microscopy and simulation. In microscopy, we show how specialist models can reveal "invisible" information – for example, through in-situ TEM tracking of dislocation dynamics in high-entropy alloys, capturing jerky, avalanche-like motion with high precision [2]. Then we discuss generalist approaches: self-supervised and unsupervised learning over diverse microscopy datasets (such as HR-TEM of nanoparticles), emphasizing adaptability across imaging modalities and sample types [3].

On the simulation side, we focus on surrogate models for the evolution of partial differential equations: how to construct them so they generalize beyond the training regime, how to detect and handle OOD inputs, and how to build explainability (XAI) into the models (so we can interpret what the surrogate is doing, especially in novel scenarios).

Finally, we highlight ongoing efforts to bridge experiment and simulation through multimodal foundation models [1]. By combining data from microscopy, spectroscopy, and simulation, such models can integrate heterogeneous sources of information, interpolate across missing or sparse data, and reveal hidden structure in complex materials datasets. This convergence offers a pathway to truly generalist models that unify experiment and theory, accelerating discovery and design in materials science.

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<sup>\*</sup> s.sandfeld@fz-juelich.de

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# **Technical Sessions**

# Phase Field Modelling of Ductile Fracture with Discrete Cracks

### Iremnaz Yücel\*, Can Erdoğan, Tuncay Yalçinkaya

Department of Aerospace Engineering, Middle East Technical University, Ankara 06800, Türkiye

\* iremnaz.yucel@metu.edu.tr

Keywords: Ductile failure, Non-local modelling, Phase field fracture, Finite element method

Phase field (PF) model for fracture has recently become an attractive tool for analyzing a wide range of failure mechanisms. The model performs successfully in capturing the initiation and propagation of complex cracking patterns such as merging and branching. The extension of the method to ductile fracture has been studied in the literature, where plasticity is introduced to the governing equations [1]. The proposed PF framework in this study employs a critical plastic work threshold to model ductile failure [2,3]. This approach enables control of crack initiation. Additionally, the discrete cracks are simulated using an element deletion technique. This is possible by differentiating between failed and intact elements based on a limiting value of the phase field parameter such that once the value is exceeded, the failed elements are removed. The model's performance is assessed using multiple numerical examples that simulate ductile failure phenomena, including tearing-type fracture characterized by complex crack paths. The simulations are performed with Abaqus/Standard finite element solver via user subroutines. Furthermore, the finite element results are compared with experimental data to validate the model.

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# Modeling Failure in DP Steel Microstructures via Phase Field Fracture

### Can Erdogan\*, Berkehan Tatli, Tuncay Yalçinkaya

Department of Aerospace Engineering, Middle East Technical University, Ankara 06800, Türkiye

**Keywords:** Phase field fracture, Dual phase steels, Ductile fracture.

Dual-phase (DP) steels represent a key class of advanced high-strength steels, combining high ductility with good formability. Their microstructure, consisting of a ductile ferrite matrix and hard martensite regions, enables the tailoring of mechanical performance through microstructural control. Failure initiation in DP steels is closely linked to this two-phase architecture: depending on parameters such as martensite fraction and grain morphology etc. Cracks may initiate either at ferrite-martensite or ferrite-ferrite interfaces through decohesion, or within the martensite phase by fracture [1]. To better understand these competing mechanisms, it is essential to investigate the microstructure within a micromechanics-based framework. Numerical methods are effective tools to study these effects and identify the microstructural features that control performance. In this work, a phase-field fracture framework developed for ductile fracture is employed to model crack initiation and propagation in DP steels using the finite element method. Both ferrite and martensite are represented as von Mises plastic materials with isotropic hardening, while their different ductility is reflected through distinct toughness values in the phase-field model. Several microstructures are directly reconstructed from experimental microscope images of DP steels. Furthermore, numerous randomly generated artificial microstructures are analysed to assess the effect of martensite morphology on crack initiation. Simulations are conducted under both uniaxial and biaxial loading conditions, with varying martensite volume fractions. The results are then evaluated in relation to prior computational findings and experimental data.

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<sup>\*</sup> cane@metu.edu.tr

# Controlling Hot Cracking in WC-NiCrBSiFe Coatings Produced by Laser Surface Cladding: A Multiphase Field Approach for Enhancing Process Repeatability

### Roya Darabi\*, Ana Reis, Jose Cesar de Sa

Faculty of Engineering, University of Porto (FEUP), FEUP Campus, Rua Dr. Roberto Frias, 400, Porto, 4200-465, Portugal

Keywords: Additive Manufacturing, Hot Cracking, Phase Field

The rising demand for high-performance components in critical industries such as aerospace, medical devices, and micro-motors has accelerated the advancement of additive manufacturing (AM) techniques to fabricate and repair complex parts with superior material properties. Among these methods, laser cladding stands out as a leading AM technology capable of creating durable, high-quality coatings with customized properties tailored to specific operational needs. This research focuses on tungsten carbide (WC)-reinforced nickel-based metal-matrix composites (MMCs), known for their remarkable hardness, wear resistance, and thermal stability. However, challenges such as thermal cracking, porosity, and residual stresses—stemming from mismatched thermal expansion between WC particles and the Ni-based matrix—pose significant limitations, particularly for intricate structures. To mitigate these challenges, several approaches have been explored, including optimizing process parameters, modifying powder compositions, and employing advanced techniques like electromagnetic field application and ultrasonic vibration during cladding. Recent developments in computational modeling, specifically phase-field fracture models, have deepened our understanding of thermal cracking and defect formation in MMC coatings. These models enable detailed analysis of crack initiation, propagation, and the influence of process parameters on microstructure evolution and mechanical properties. This study integrates a fully coupled phase-field fracture model with thermomechanical analysis to investigate laser cladding of WC-NiCrBSiFe coatings. The analysis captures the thermal history, cladding morphology, and real-time crack behavior during solidification, offering insights into the interplay between WC content, hardness, toughness, and the risk of hot cracking. Findings reveal that optimal performance is achieved at approximately 30 wt% WC, where coatings exhibit excellent hardness and wear resistance with minimal defect formation. Beyond this threshold, the brittle nature of the carbide-reinforced matrix leads to reduced mechanical performance and increased residual stresses, elevating the risk of hot cracking. This research provides actionable guidance for minimizing defects and optimizing process parameters to enhance coating performance, facilitating the production of robust and reliable components for demanding applications. By advancing computational modeling techniques and delivering practical insights into the laser cladding process, this work contributes to the development of improved coating solutions for critical industries and promotes further innovation in additive manufacturing technologies.

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<sup>\*</sup> rdarabi@fe.up.pt

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### Deformation analysis in elastic half-space with a cylindrical cavity

### Anna Fesenko\*

Faculty of Mathematics, Physics and Information Technologies, Odesa I. I. Mechnikov National University, Odesa 65082, Ukraine

**Keywords:** elastic half-space, cylindrical defect, vector problem, matrix differential calculus, singular integral equation, orthogonal polynomials

The presence of structural imperfections such as inclusions, cavities, and cracks in elastic bodies leads to stress concentration, which significantly influences the overall stress distribution within constructions. A fundamental problem in this category is the axisymmetric elasticity analysis of a half-space containing a cylindrical defect, where various boundary conditions are imposed on both the defect's surface and the half-space's face. A half-space serves as a convenient model for analyzing deformations and stresses arising under various types of loads, as well as for testing new mathematical approaches. Its mathematical treatment allows for the comparison of stress-strain states with those obtained for plates and other structural elements, providing valuable insights into material behavior under different loading conditions. The construction of an explicit analytical solution requires satisfying ideal contact conditions. However, if the boundary conditions correspond to the first or second fundamental elasticity problem, the solution process involves solving an integral equation. G. Ya. Popov [1] previously addressed the elasticity problem for an infinite layer with a cylindrical cavity in a static formulation using matrix differential calculus, deriving an exact solution. In the same reference, this approach was later extended to the corresponding dynamic problem [2]. The wave field in an elastic half-space with a cylindrical cavity is analyzed under harmonic loading. The half-space's face is assumed to be rigidly fixed with a foundation, while a normal harmonic tensile load is applied to the surface of the cylindrical cavity. Unlike conventional methods that involve applying integral transforms to solutions expressed through harmonic and biharmonic functions, this study directly applies sine and cosine Fourier integral transforms to the axisymmetric equations of motion and boundary conditions. This transformation results in a one-dimensional inhomogeneous boundary value problem for the unknown transformed displacements. The problem is then solved using matrix differential calculus, and the initial displacement field is reconstructed via inverse integral transforms. n integral equation for the unknown displacement derivative is formulated. This equation is solved using the method of orthogonal polynomials, taking into account stress singularities occurring at the half-space. The study focuses on the case of steady-state oscillations, investigating deformation of the elastic half-space's face concerning types of acting load, the medium's material properties and natural oscillation frequencies. The possibility of separation zones forming at the interface between the half-space's face and the rigid foundation is also explored.

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<sup>\*</sup> fesenko@onu.edu.ua

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# Fatigue Crack Growth Of Turbine Disc Part Considering Combined Effect Of Overload And Hold Time Using Numerical Methods

### Adem Yılmaz\*, Şevket Ertekin

TUSAŞ Engine Industries, Inc., Eskişehir, Türkiye.

Keywords: Overload Mechanism, Time-dependent effect, Crack growth

Application of fracture mechanics is essential in understanding how cracks or defects in gas turbine components such as blades, disks or casings, can propagate and potentially lead to catastrophic failures. In gas turbine engines, disc components operate under high stresses and temperatures. Consequently, a number of variables may have a significant effect on component life. In this study, gas turbine mission profiles, including the interaction of overload effects due to high stresses and time-dependent effects, are considered. For the numerical calculation, a surface crack was chosen as the crack type. Yau's [1] weight function formulation was used to calculate stress intensity values with Newman-Raju [2] surface crack solution. An engine disc component life calculation was then made after time-dependent effects were included, using the linear superposition method to observe time-dependent effects. Using the linear super position method [3], time-dependent effects have significantly reduced the component life with long dwell times. Overload situations were also included in the numerical calculation in order to compensate for the life reduction caused by this effect. Overloading creates a large plastic zone at the crack tip. In this case, there is a slight decrease in the crack propagation rate until the crack exceeds this plastic zone. Modified Willenborg retardation model [4, 5] was used to calculate overloading effect. Consequently, adding overload effect led to an increase in engine disc life. In addition, overload and time-dependent effects were supported by literature data. Results are compared with numerical based crack growth commercial software and differences in results are highlighted. Applicability of numerical based crack growth method with overload and time-dependent effect is investigated. The role of the overload and time-dependent effect during crack growth is emphasized.

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<sup>\*</sup> adem.yilmaz@tei.com.tr

# A Prony Series-Informed Machine Learning Model for Canopy Bird-Strike Analysis

### Mert Güngör\*1, Hande Vural2, Seda Sürücü3, Tuncay Yalcinkaya2

- <sup>1</sup> Department Of Metallurgical And Materials Engineering, Middle East Technical University, Ankara 06800, Türkiye
- <sup>2</sup> Department of Aerospace Engineering, Middle East Technical University, Ankara 06800, Türkiye
- <sup>3</sup> Turkish Aerospace Industries, Ankara 06980, Türkiye

Keywords: Materials Acceleration Platform (MAP), Viscoelasticity, Machine Learning

Bird strikes pose a significant threat to flight safety, with nearly 20,000 incidents reported in 2023 alone and a continuous upward trend reported according to the Federal Aviation Administration (FAA). Aircraft canopies, often manufactured from polymethyl methacrylate (PMMA) due to its favorable optical and mechanical properties. However, accurately predicting the post-impact response of PMMA remains challenging due to its time-dependent, viscoelastic nature and the absence of dedicated failure models in commercial finite element software. Motivated by the need to enhance the predictive capabilities for canopy integrity under bird strike conditions, this study develops a computational-experimental framework augmented with machine learning to estimate the residual velocity of projectiles after impact. The viscoelastic behavior of PMMA is characterized through Prony series parameters derived from both stress relaxation [1] and dynamic mechanical analysis (DMA) [2], enabling the implementation of a generalized Maxwell model in Abaqus. A custom failure criterion based on the maximum stress theory is embedded via a user-defined subroutine (VUMAT) to model fracture, addressing the software's limitations in handling viscoelastic failure. To overcome the limitations of direct experimentation and reduce computational cost, a dataset of simulated scenarios spanning variations in impactor velocity, friction, and plate thickness is generated using a Python script. This dataset is used to train a Gradient Boosted Regression Trees (GBRT) model, which demonstrates exceptional performance  $(R^2 = 0.999, RMSE < 0.6 \text{ m/s})$  in predicting residual velocities across unseen conditions. This machine learning integration exemplifies key principles of a materials acceleration platform (MAP). Bird strike scenarios are simulated using Smooth Particle Hydrodynamics (SPH) to replicate the gelatin-based bird impactors, validated experimentally using strain gauge data [3]. Additional steel ball impact tests serve to benchmark residual velocity predictions [4].

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<sup>\*</sup> gungor.mert@metu.edu.tr

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# Nonlocal Crystal Plasticity for Multi-scale Modeling Through-Thickness Microstructure Gradients in TMCP Rolled X100 Steel

Maziar Toursangsaraki<sup>\*1</sup>, Pedram Parandavar<sup>1</sup>, Mahdi Karamabian<sup>1</sup>, Richard Barrett<sup>1</sup>, Mingming Tong<sup>1,2</sup>, Ruilin Tang<sup>3</sup>, Xu Zhang<sup>3</sup>, Seán B. Leen<sup>1,2,3,4</sup>

- <sup>1</sup> Mechanical Engineering, College of Science and Engineering, University of Galway, H91 HK31 Galway, Ireland
- <sup>2</sup> I-Form, the SFI Research Centre for Advanced Manufacturing, Ireland
- <sup>3</sup> Applied Mechanics and Structure Safety Key Laboratory of Sichuan Province, School of Mechanics and Aerospace Engineering, Southwest Jiao Tong University, Chengdu 610031, China
- <sup>4</sup> Ryan Institute for Environmental, Marine and Energy Research, NUI Galway, Ireland

**Keywords:** Dislocation-based nonlocal crystal plasticity fast Fourier, transform, Multi-scale modeling, Thermo-mechanical control rolling

Multi-scale modeling of deformation behaviour allows for optimising manufacturing processes by identifying the process-induced microstructural variations on the final material properties [1, 2]. This study developed multi-scale modeling of the thermo-mechanical control process (TMCP) rolling at 900 °C to quantify the microstructure-evolution gradients under strain variations through the thickness of X100 steel sheet. Firstly, the macroscale plane-strain rolling was simulated in ABAQUS based on the experimental stress-strain data from plane-strain compression of X100 at different rates. This model captured the variations in normal and shear strain and their rates through thickness. This data was then inserted into a nonlocal micro-scale crystal plasticity fast Fourier transform (CPFFT) representative volume element (RVE) with plane-strain compression for simulating rolling process. As for the CPFFT method, initial austenitic microstructure at 900 °C was synthesized to contain equiaxed grains with high-angle grain boundaries and constant mechanical properties through sheet thickness before rolling. The developed model then quantified the contributions of gradient in plastic deformation under different values of normal strain, shear strain, and their rates on the through-thickness evolutions in crystal morphologies, dislocation accumulation, and grain texture at different depths. Sheet regions nearer to the surface showed higher overall microstructure variations under more severe deformation trends. Normal strain had relatively higher lattice rotation and stronger {111}//loading direction (LD) than shear strain, both of which increased with increasing strain-rate.

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<sup>\*</sup> maziar.toursangsaraki@universityofgalway.ie

# A Machine Learning Model to Predict Residuals of Projectiles Against Kevlar 29/Epoxy Laminate

# Doruk Özyürek\*1,2, Tuncay Yalçinkaya<sup>2</sup>

- <sup>1</sup> ROKETSAN, Missile Industries Inc., Elmadağ, 06780 Ankara, Türkiye
- <sup>2</sup> Department of Aerospace Engineering, Middle East Technical University, Ankara 06800, Türkiye

Keywords: Ballistic impact, Composite Laminates, Machine Learning

Kevlar 29/Epoxy resin woven laminates could be manufactured with different fabric types such as plain, twill, satin etc. These laminates are significantly utilized as ballistic armors against various threads in the industry [1]. In the literature, the ballistic performance of Kevlar 29/Epoxy resin plain and satin woven laminates have been studied through numerical simulations and experimental studies for various impact scenarios [2], [3]. However, there is a lack of studies regarding the ballistic performance of Kevlar 29/Epoxy twill woven laminates. In this study, a series of ballistic impact simulations as well as experimental studies were conducted on Kevlar 29/Epoxy targets to obtain the residual velocity of the projectile. Experimental studies were conducted according to NATO AEP-55 STANAG 4569 standards. Moreover, Chang- Chang and Tsai-Wu composite failure criteria in LS-DYNA used to compare the modelling performances. Material model parameters were obtained via quasi-static uniaxial tension tests and from the literature [2], [3]. Numerical model results are used as the training data for Machine Learning algorithm. Experimental results are used as the validation data, hence the feasibility of the ML algorithm is validated. This study aims to obtain a ML database that could predict the residual velocity values of Kevlar 29/Epoxy twill woven materials for different target thicknesses and residual velocities.

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<sup>\*</sup> doruk.ozyurek@metu.edu.tr

# Experimental and Numerical Study on Ballistic Performance of Ti-6Al-4V Alloy

### Fatma Tasğın\*1,2, Tuncay Yalçinkaya<sup>1</sup>

Keywords: Ballistic impact, Metallic materials, Ductile failure

Ti-6Al-4V alloy is extensively utilized in aircraft structural applications due to its high strengthto-weight ratio, high corrosion resistance, and outstanding performance under extreme loading conditions [1]. Even though the aerospace industry continues to lead the demand for Ti-6Al-4V, these properties make it an excellent candidate for applications in defence industry, such as armour systems for vehicles, aircrafts, and personal protection. Hence, in this study, the ballistic performance of Ti-6Al-4V with various armour configurations was investigated through experimental testing and numerical simulations. Ballistic impact tests were performed on 5 mm thick plates using 7.62×51 mm armour-piercing (AP) projectiles. Target plates are arranged in three different configurations: monolithic, stacked double-layer, and double-layer with 20 mm gap. Experimental observations were complemented with numerical simulations conducted in LS-DYNA. Johnson-Cook (JC), Modified Johnson-Cook (MJC) and Gurson-Tveergard-Needleman (GTN) plasticity models are utilized from the LS-DYNA material library to simulate the material behaviour. Additionally, JC and Cockcraft-Latham (CL) damage models are employed for modelling ductile failure at the impact zone. Model parameters are taken from the literature [2], [3], [4]. Moreover, numerical observations were compared with the experimental findings. The results demonstrate that stacked double-layer targets exhibit better ballistic resistance as opposed to monolithic and spaced targets. The following work aims to investigate armour design optimization using Ti-6Al-4V alloy for ballistic impact scenarios and evaluate the perforation resistances of the targets using explicit finite element simulations.

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<sup>&</sup>lt;sup>1</sup> Department of Aerospace Engineering, Middle East Technical University, Ankara 06800, Türkiye

<sup>&</sup>lt;sup>2</sup> ROKETSAN, Missile Industries Inc., Elmadağ, 06780 Ankara, Türkiye

<sup>\*</sup> tasgin.fatma@metu.edu.tr

# On Stress State of Multilayered Hollow Poroelastic Cylinder

### Natalya Vaysfeld\*1, Zinaida Zhuravlova<sup>2</sup>

**Keywords:** poroelasticity, hollow cylinder, multilayered, integral transform, matrix differential calculation

Poroelastic materials, which couple fluid flow with mechanical deformation, play a critical role in many natural and engineered systems. Cylindrical structures composed of such materials are commonly found in applications like subsurface formations, biomedical devices, and civil infrastructure. When these cylinders are layered along the axial direction – due to geological stratification, material deposition processes, or functional design – the axial heterogeneity significantly influences their mechanical and hydraulic responses.

The poroelastic hollow axisymmetric cylinder (b < r < 1, 0 < z < H) is considered in terms of Biot's framework [1]. It consists of N layers  $h_i < z < h_{i+1}$ ,  $i = \overline{0, N-1}$ , where  $h_0 = 0$ ,  $h_N = H$ . The ideal contact conditions are fulfilled between the layers, which means the equality of boundary values of displacements, stress, pore pressure and normal flux at the surfaces  $z = h_i$ ,  $i = \overline{1, N-1}$ . The bottom edge of the cylinder is fixed, the top edge is under the external loading. The cylindrical surfaces are under the slide contact conditions. The poroelastic stress state of each layer of the hollow cylinder should be found.

The original problem is reduced to the one-dimensional boundary value problem with the help of Hankel transform applied regarding a variable r. The general solutions of the one-dimensional vector boundary problem for each layer is constructed with the help of matrix differential calculation apparatus [2] and the recurrent correspondence [3]. The analytical formulas are found for displacements, stress and pore pressure in each layer of the cylinder, and the numerical investigation was provided for two- and three-layered cylinders under different types of applied external load.

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<sup>&</sup>lt;sup>1</sup> King's college London, London WC2R 2LS, United Kingdom

<sup>&</sup>lt;sup>2</sup> Faculty of Mathematics, Physics and Informational Technologies, Odesa I.I. Mechnikov National University, Odesa 65082, Ukraine

<sup>\*</sup> natalya.vaysfeld@kcl.ac.uk

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# Changes of Paradigm in Nuclear Materials Science: the CONNECT-NM Co-funded European Partnership

#### Lorenzo Malerba\*

Energy Materials Division, CIEMAT, Madrid 28040, Spain

Keywords: Nuclear Materials, Paradigm Change, Accelerating Methodologies

Nuclear energy remains the EU's largest source of low-carbon electricity (22% in 2022). Its future depends on the industry's ability to become more competitive, by cutting costs and construction times, improving efficiency, managing waste, and ensuring safety. Achieving this requires three key paradigm shifts. First, a shift toward small modular reactors, both light-water and advanced designs, which can be built faster and more affordably than traditional large plants. Second, adopting fast reactors, which can extract over 90% of energy from nuclear fuel (compared to  $\sim 1\%$ in current reactors) while reducing waste volume and longevity. These reactors also allow for higher operating temperatures and efficiency. Both changes of paradigm, however, impose different needs and more severe constraints on materials than in current thermal light-water reactors. Modular reactors will require advanced manufacturing processes to be successful on the market, while there is a need to improve significantly their radiation-tolerance, their compatibility with heatcarrying fluids (different from water) and their stability at high temperature in the case of fast and high temperature reactors. Achieving this within the timeframe of about one decade requires a transformation in materials science, shifting from a traditional "observe and qualify" approach to a "design and control" strategy. This means designing materials to meet specific requirements from the outset, including sustainability and long-term safety. The corresponding nuclear materials research agenda [1,2] pursues acceleration in the development and qualification of materials, through tools like material acceleration platforms, test beds for accelerated qualification paths, advanced predictive models and structured knowledge organization systems, in combination with intelligent materials health monitoring and digital twins for the safe management of the lifetime of components. Such a drive towards innovation is the goal of the recently launched co-funded European partnership on nuclear materials, CONNECT-NM [3].

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<sup>\*</sup> lorenzo.malerba@ciemat.es

# On the Microstructural Evolution Under Irradiation in Reactor Pressure Vessel Steels and Its Effects on Hardening and Embrittlement

### Lorenzo Malerba\*1, Nicolas Castin<sup>2</sup>

- <sup>1</sup> Energy Materials Division, CIEMAT, 28040 Madrid, Spain
- <sup>2</sup> Nuclear Energy and Technology Institute, SCK CEN, 2400 Mol, Belgium

**Keywords:** RPV steels, embrittlement, microstructural evolution, modelling

Radiation-induced hardening and embrittlement of reactor pressure vessel (RPV) steels in current light water reactors has been extensively investigated for several decades, because of the irreplaceable and lifetime-limiting nature of this component. Over these decades, the main 'culprit' for embrittlement has shifted from copper precipitation to late blooming phases. Here we describe and discuss a microstructural evolution model that is proving seminal in terms of enabling reliable physically-based quantitative predictions of RPV steel microstructure evolution and subsequent hardening and embrittlement [1,2]. When applied to hundreds of cases, its assessment of embrittlement versus dose and other variables is better than with any available empirical correlation. However, in this model the connection between microstructural evolution and hardening/embrittlement remains semi-empirical. The need for microstructure-informed fracture toughness predictive models that reduce the uncertainty due to experimental calibration is briefly discussed.

One of the still open issues in connection with nuclear power plant extended operation (60-80 years) is the flux effect on RPV steel embrittlement [3]. This needs quantification, if reactor surveillance data and high-flux test reactor data are used to predict vessel embrittlement occurring at lower fluxes, especially in connection with extended operation (60-80 yrs). Unfortunately, usual correlations are unreliable. The above model is therefore used to explore this effect, in terms of microstructure mainly, in the case of low-copper RPV steels, which represent the wide majority of steels in use around the world and are the most likely to opt for extended operation.

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<sup>\*</sup> lorenzo.malerba@ciemat.es

### Progressive Collapse Analysis of Beirut Port North Block Silos'

### Sahar Ismail, Wassim Raphael\*

Department of Civil Engineering, the Higher School of Engineering ESIB, Saint Joseph University of Beirut, Beirut 17-5208, Lebanon

**Keywords:** Progressive collapse, concrete damage plasticity, finite-element model

The progressive failure of the Beirut port North block silos, initiated by the August 4 2020 ammonium nitrate explosion, is investigated through structural health monitoring and finite element analysis. Despite experiencing immediate damage, the North block silos remained standing for nearly two years, eventually collapsing in a multi-phase progression. High-resolution 3D laser scanning and real-time triaxial inclinometers were used to track the evolution of deformation, revealing a maximum permanent vertical inclination of up to 2 meters. A finite element model incorporating nonlinear material behavior was developed in Abaqus to simulate the blast-induced plasticity, foundation-soil interaction, and damage evolution over time. Results show that the increase in inclination rate following the fire event in July 2022, which was caused by fermenting grain, significantly reduced the concrete young's modulus, altering the stress redistribution and accelerating damage propagation within the structure. The study highlights the role of cumulative damage and time-dependent deformation in post-blast failure scenarios. This study recommends continuing monitoring of the remaining South block silos to assess their resilience to future seismic or environmental loading conditions.

<sup>\*</sup> wassim.raphael@usj.edu.lb

# Fracture Behavior in Neutron-irradiated Low-alloy Steel: A Microstructure-based Approach

### Dong-Hyeon Choi\*1, Do Yeon Lee1, Yoon-Suk Chang2

- <sup>1</sup> Graduate School, Kyung Hee University, Yongin 17104, Republic of Korea
- <sup>2</sup> Department of Nuclear Engineering, Kyung Hee University, Yongin 17104, Republic of Korea

**Keywords:** Low-alloy steel, Microstructure-based approach, Neutron irradiation

Neutron irradiation induces progressive microstructural changes in low-alloy steels [1], leading to the formation of defects such as dislocation loops, voids and eventually cracks. This degradation reduces ductility, increases strength and lowers fracture resistance. While the effects of irradiation and crack configuration have been examined independently [2], microstructure-based evaluations remain relatively underexplored.

This study investigates the fracture behavior of SA-508 Gr.3 steel by simulating irradiation-induced effects through variations in crack geometry. Numerical analyses compare unirradiated and irradiated conditions, considering differences in crack shapes (circular and elliptical) and locations (surface and corner). Fracture energy is employed as a key parameter in damage initiation and evolution modeling. The results provide insights into how the material degradation and defect characteristics collectively influence the structural integrity of reactor vessels.

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<sup>\*</sup> choi960809@khu.ac.kr

# Numerical Analysis of Single Crystal CMSX-4 Turbine Blades Under Operating Conditions

### Orhun Bulut\*1, Umud Esat Öztürk2, Tuncay Yalçinkaya1

- <sup>1</sup> Department of Aerospace Engineering, Middle East Technical University, 06800 Ankara, Türkiye
- <sup>2</sup> TUSAŞ Engine Industries, Inc., Istanbul, Türkiye

Keywords: Single Crystal Superalloy, Turbine Blade, Crystal Plasticity

Nickel-based superalloys are widely used in single crystal turbine blades in aircraft engines because of their strength and creep resistance at high-temperature service [1]. This study presents a comparison on mechanical response to operating conditions by three material models: orthotropic elasticity, isotropic plasticity, and crystal plasticity where the first two are commonly used in the industry. Isotropic plasticity and crystal plasticity hardening parameters are calibrated by fitting them to experimental data reported in the literature [2]. The crystal plasticity parameters are optimized to cover the response at different loading rates. Turbine blade finite element analyses under cyclic centrifugal loading are performed to demonstrate the strengths and weaknesses of each framework. The aim is to assess how these models differ in their representation of stress distribution, deformation, and fatigue-relevant behavior at service conditions. Although elastic models offer simple solutions in linear analysis, these are incapable of modeling irreversible deformation, strain accumulation, or hardening effects—importantly so in cyclic and high-stress operation conditions. The shortcoming is addressed by plasticity-based formulations in terms of modeling of permanent deformation and load history. However, isotropic plasticity is limited in modeling plastic behavior by assuming identical behavior in all directions and neglecting anisotropic features. The rate and orientation dependent nature of crystal plasticity model is considered to give more realistic response especially around the contact and stress concentration regions. The other frameworks either over or under predict the stress values. The present results by blade analyses indicate that choice in material modeling considerably affects the predicted mechanical behavior and must be carefully examined in the structural analysis and life estimation of turbine parts.

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<sup>\*</sup> orhun.bulut@metu.edu.tr

# **Dynamic Flow and Fragmentation of Artificial Gelatin Birds**

### Chunyang Zhang\*, Jiacheng Sheng, Jun Liu

School of Aeronautics, Northwestern Polytechnical University, Xi'an 710072, China

Keywords: artificial gelatin birds, dynamic behavior, equation of state

The development of artificial gelatin birds plays an important role in evaluating the bird strike resistance of aircraft structures, and provides a more consistent substitute for real birds. But the dynamic behavior of gelatin remains insufficiently characterized. Current approaches primarily rely on combining experimental data with numerical simulations to infer material parameters [1, 2]. high-velocity gelatin bird impacts are commonly approximated as fluid-like without strength [3], it is still necessary to establish the relationship between pressure and volumetric deformation through an equation of state (EOS).

When subjected to axial plate impact, gelatin specimens exhibit four stages: initial impact, pressure release, steady-state flow and impact termination. Radial release waves generated at the edge of the specimen weakens the initial shock pressure, and after multiple internal reflections, a stable steady-state flow is established. These radial release waves are also the primary cause of fragmentation in gelatin. The process was further duplicated through a combination of experiments and numerical simulations.

An EOS was developed by analyzing the propagation of shock waves, capturing the dynamic response of gelatin while neglecting its shear strength. Simulations using different constitutive models revealed that while deformation varied, the impact loads were largely insensitive to material strength. Experimental validation through flexible target impact tests confirmed the accuracy and applicability of the EOS, which was subsequently employed in engineering simulations.

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<sup>\*</sup> zhangchunyang@mail.nwpu.edu.cn

# Modeling Crack Propagation in Rock Salt: A Numerical Study of Intergranular and Intragranular Damage

### Nour Habib\*, Saber El Arem, Amine Ammar

LAMPA Arts et Metiers Institute of Technology, 2 boulevard du Ronceray, BP 93525, 49035 Angers cedex 01, France

**Keywords:** Viscoplasticity, rock salt, cohesive zone model, rate dependent traction separation law, phase field fracture

The global energy landscape is undergoing a significant transformation driven by the urgent need to mitigate climate change and reduce carbon emissions. Hydrogen stands out as a highly promising alternative among the various energy storage methods under investigation, offering the potential to decarbonize multiple sectors—ranging from transportation to industrial processes—and acting as a versatile fuel for energy systems. However, one of the major hurdles for the widespread deployment of hydrogen-based systems is the challenge of storing hydrogen safely and efficiently. One of the most prominent solutions is the use of rock salt as a geological storage rock. The primary objective of this research is to advance the numerical modeling of rock salt's viscoplastic behavior, focusing specifically on its application in hydrogen storage. Previous studies have explored the viscoplastic properties of rock salt, highlighting the importance of crystal slip plasticity observed at the level of individual grains. However, there is a need to go beyond conventional models by incorporating additional deformation mechanisms—namely, inter- and intra-granular cracking. Experimental evidence has shown that the opening and sliding of grain boundaries occur concomitantly with the viscoplastic deformation observed by formation of glide planes on the grain surfaces [1]. These phenomena, often overlooked in traditional models, are significant because grain boundary sliding and opening can account for up to half of the total strain experienced by the rock salt, depending on the size of the grain aggregate. Although crystal slip plasticity remains the dominant deformation mechanism, accurately modeling the behavior of grain boundaries and the cracking inside the grain bulk is essential for predicting the overall mechanical response of rock salt. To this end, we use a cohesive zone model to simulate intergranular fracture, focusing on the traction-separation relationship governing the opening and sliding of grain boundaries. The model accounts for rate-dependent behavior critical to rock salt's long-term response. Complementarily, intragranular cracking is modeled using a phase field approach for ductile fracture, allowing for a smooth transition from intact to fully broken states within the grains, governed by crystal plasticity. This dual approach enables a more comprehensive and thermodynamically consistent representation of damage evolution in rock salt. By coupling these mechanisms, the model improves the predictive capability of rock salt performance under complex loading scenarios, contributing to safer and more reliable hydrogen storage systems.

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<sup>\*</sup> nour.habib@ensam.eu

# Rate-dependent Fracture in Elastomers: A Phase-field Model based on Polymer Chain Micro-Mechanics

### Giovanni Lancioni\*1, Jacopo Ciambella<sup>2</sup>

- <sup>1</sup> Polytechnic University of Marche
- <sup>2</sup> Sapienza University of Rome

Keywords: Rubber fracture, finite viscoelasticity, rate-dependent failure

The proposed presentation introduces a phase-field model for rate-dependent fracture in rubbery materials, formulated within finite viscoelasticity. The model's constitutive choices are directly inspired by the micro-mechanical behavior of polymer chains during stretching and rupture. At small deformations, polymer chains undergo entropic stretching driven by time-dependent disentanglement, while at large deformations, they experience enthalpic bond stretching. The proposed model, extending the formulation in [1], captures rate-dependent disentanglement through a shearthinning viscosity and models the recovery of stiffness at high stretches via a non-Gaussian strain energy function. Bond scission at extreme stretches is modeled using a smeared phase-field fracture approach. A discussion of the energy dissipation mechanisms, including viscous strain and fracture opening, informs the constitutive hypotheses that couple the various energy contributions. The model is formulated in a thermodynamically consistent framework and subsequently implemented in a finite element code. Numerical results demonstrate the model's predictive capability.

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<sup>\*</sup> g.lancioni@univpm.it

# Toughness-Oriented Design of Two-Phase Particulate Metal Matrix Composites Using Microstructure-Free Finite Element Modeling

### Sebak Oli\*, Yunhua Luo

Department of Mechanical Engineering, University of Manitoba, 66 Chancellors Circle, Winnipeg, MB, R3T 2N2, Canada

Keywords: Metal matrix composites, Microstructure-free, Plasticity, Damage, Toughness

Toughness, typically associated with the nonlinear deformation regime, is a critical property that defines a material's ability to absorb energy and resist catastrophic failure, making it essential for applications where safety, impact resistance, or crack tolerance is paramount. In metal matrix composites (MMCs), once the constituent phases are selected, their volume fractions become a key factor in balancing strength and toughness, alongside other factors such as matrix-particle interface strength, defects, and residual stresses. Traditional design approaches for composites often rely on detailed knowledge of particle shape, size, distribution, and orientation, making the analysis of their nonlinear behavior highly complex and computationally intensive. In this work, the recently developed microstructure-free finite element modeling (MF-FEM) approach [1] is extended to investigate how phase volume fraction affects the toughness of two-phase particulate MMCs. In MF-FEM, the representative volume element (RVE) is assumed to be significantly larger than the size of the reinforcement particles and employs uniformly meshed cubic elements, with material phases assigned randomly based on the desired volume fractions. The model incorporates matrix plasticity with ductile damage and particle brittle failure to capture nonlinear behavior, and validation against experimental data [2] demonstrates good agreement in capturing both strength and ductility trends [3]. The results reveal an inverse relationship between toughness and particle volume fraction, reflecting the trade-off between particle-induced strengthening and matrix-provided ductility. Overall, MF-FEM offers an efficient and cost-effective tool for early-stage, toughness-oriented design of particulate composites, reducing the need for extensive experimental testing.

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<sup>\*</sup> olis1@myumanitoba.ca

### 3D hybrid numerical model of TiN thin films fracture based on cohesive elements and XFEM methods

### Konrad Perzynski\*1, Grzegorz Cios2, Piotr Bała2, Lukasz Madej1

Keywords: TiN thin film, cohesive zones, XFEM

Thin layers of titanium nitride (TiN) are widely used in a variety of applications due to their unique properties, including high hardness and wear resistance. These characteristics of TiN are suitable for many applications such as hard and decorative coatings, as well as crucial diffusion barriers in semiconductor technologies [1]. Such material systems display a distinctive combination of properties, exhibiting both metallic-like electrical conductivity and characteristics typically associated with insulating materials, such as covalent bonds, high hardness and elevated melting points. Despite these advantages, TiN films are sensitive to brittle cracking and low fracture toughness, which limits their applicability in specific demanding environments [2]. Therefore, a thorough understanding and accurate modeling of fracture behavior in TiN thin films are important for enhancing their reliability and expanding their potential applications in areas like microelectronics, protective coatings, and biomedical devices [3], [4]. Therefore, in this work, we provide a comprehensive method for modeling fractures in thin film TiN by considering 3D thin film morphology explicitly. A methodology for generating 3D statistically representative digital models and incorporating them into the finite element simulations to evaluate the initiation and propagation of fractures in thin films is discussed. The proposed approach is based on a hybrid cohesive and XFEM fracture models operating within such a digital material model. The numerical analysis is focused on the evaluation of fracture mechanisms observed in films subjected to complex deformation states during nanoindentation tests.

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<sup>&</sup>lt;sup>1</sup> Faculty of Metals Engineering and Industrial Computer Science, AGH University of Krakow, Krakow, Poland

<sup>&</sup>lt;sup>2</sup> Academic Centre for Materials and Nanotechnology, AGH University of Krakow, Krakow, Poland

<sup>\*</sup> kperzyns@agh.edu.pl

### Dynamic behavior testing and application of aircraft wing materials

### Jiacheng Sheng\*, Chunyang Zhang, Jun Liu

School of Aeronautics, Northwestern Polytechnical University, Xi'an 710072, China

Keywords: dynamic behavior, material damage, aircraft wing

With the increasing prevalence of UAVs, their interference with aircraft flights has become more frequent, posing a significant threat to both aircraft and passenger safety [1]. Consequently, understanding the dynamic behavior resulting from UAV impacts on aircraft structures is critical. This study investigates the material properties of various materials commonly used in aircraft wings and UAVs, including composite woven materials, metals, and honeycomb structures. To validate the material parameters and numerical models, both tests and numerical simulations were conducted [2]. Detailed models of the UAV and the wing's leading-edge structure were developed, incorporating experimental design, mesh generation, and numerical simulations. The collision between the UAV and the wing's leading edge was simulated using the explicit finite element software PAM-CRASH. A comparison of the dynamic responses and damage results from both the tests and simulations demonstrated strong agreement in the trends observed. Furthermore, the study explored the effects of different UAV postures and impact velocities on the wing structures. The findings offer valuable insights for risk assessment and the design of wing structures subjected to UAV impacts.

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<sup>\*</sup> shengjiacheng@mail.nwpu.edu.cn

# Study on the Evolution of Mechanical Properties of 42CrMo Steel under Ultrasonic Rolling

### Haojie Wang\*1,2, Ramón Jerez Mesa<sup>2</sup>, Eric Velázquez-Corral<sup>2</sup>, Xiaoqiang Wang<sup>1</sup>

- <sup>1</sup> School of Mechatronics Engineering, Henan University of Science and Technology, Luoyang 471003. China
- <sup>2</sup> Department of Mechanical Engineering, Universitat Politècnica de Catalunya, Barcelona 08019, Spain
- \* 1330767311@gg.com

Keywords: Single-factor test, Hardness, Residual stress

To further investigate the influence of ultrasonic rolling on the surface mechanical properties of 42CrMo steel, a series of single-factor ultrasonic rolling experiments were designed. The distributions of residual stress and hardness under different process parameters during ultrasonic strengthening were obtained. The results show that ultrasonic rolling forms a residual compressive stress layer with a certain depth on the surface of 42CrMo steel. With increasing depth, the residual compressive stress first increases, then decreases, and eventually approaches zero, transitioning into residual tensile stress. Meanwhile, the ultrasonic rolling process induces severe plastic deformation at the surface, leading to the formation of a work-hardened layer and a significant increase in surface hardness [1]. The combined effect of improved residual compressive stress and enhanced hardness significantly boosts the surface mechanical properties of 42CrMo steel [2], thereby extending its service life and improving its fatigue resistance [3].

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### Characterising Entropy Generation in Fatigue of Additively Manufactured AlSi10Mg with Artificial Neural Networks

Muhammad Muaz Mubasyir<sup>1</sup>, <u>Shahrum Abdullah</u>\*<sup>1</sup>, Salvinder Singh Karam Singh<sup>1</sup>, Mohd Khairul Faidzi<sup>2</sup>, Chuin Hao Chin<sup>2</sup>, Zaliha Wahid<sup>1</sup>, M. F. Abdullah<sup>2</sup>

**Keywords:** Acoustic Emission, AlSi10Mg Alloy, Entropy, Fatigue Crack, Machine Learning

Additively manufacturing (AM) is widely used in making structural parts, especially in aerospace and automotive industries. Despite their advantages, components fabricated through selective laser melting (SLM) are prone to fatigue failures due to inherent microstructural defects such as pores and lack-of-fusion zones [1]. Traditional fatigue life prediction methods struggle to account for the complex behaviours exhibited under cyclic loading [2]. This study addresses these challenges by integrating entropy analysis, acoustic emission (AE) monitoring, and artificial neural networks (ANN) to evaluate and predict fatigue failure in additively manufactured AlSi10Mg. Compact tension (CT) specimens were prepared according to ASTM E647 standards and under constant amplitude loading, high-low and low-high block spectrum loading under stress ratios, R = 0.1. AE sensors captured transient signals associated with crack initiation and propagation, while infrared thermography monitored surface temperature changes to compute entropy generation [3,4]. The extracted AE features and entropy metrics were used as input parameters to train an ANN model for predicting fatigue crack growth behaviour. Results demonstrated a strong correlation between entropy generation, AE activity, and crack growth rates. The ANN model achieved high predictive accuracy with  $R^2$  values exceeding 0.92. Furthermore, the study revealed that entropy generation increases nonlinearly with crack propagation, and AE event density intensifies as damage progresses, providing early warning indicators for fatigue failure. The proposed hybrid framework significantly improves fatigue life assessment, offering a non-destructive, datadriven approach suitable for real-time structural health monitoring in AM components [5].

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<sup>&</sup>lt;sup>1</sup> Department of Mechanical and Manufacturing Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia

<sup>&</sup>lt;sup>2</sup> Department of Mechanical Engineering, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, Kem Perdana Sg. Besi, 57000 W.P Kuala Lumpur, Malaysia.

<sup>\*</sup> shahrum@ukm.edu.my

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### Thermal Diffusivity and Heat Transfer Behavior of Rubber Composites Filled with SiO<sub>2</sub> Nanoparticles

### Jelena Lubura Stošić\*, Oskar Bera

University of Novi Sad, Faculty of Technology Novi Sad, Bulevar cara Lazara 1, 21000 Novi Sad, Serbia

\* jelenalubura@uns.ac.rs

Keywords: thermal diffusivity, rubber composites, nanosilica, heat transfer, temperature profile

Understanding the thermal properties of rubber composites is crucial for their application in temperature-sensitive environments. This study investigates how the addition of nanosilica ( $SiO_2$ ) affects thermal diffusivity and heat transfer characteristics of rubber materials. The experimental procedure involved monitoring the temperature at the center of rubber spheres immersed in a thermal fluid maintained at  $70^{\circ}$ C, as well as at varied surrounding fluid temperatures ( $40^{\circ}$ C- $70^{\circ}$ C). Thermal responses were analyzed over a 2-hour period. The experimental temperature profiles were fitted using a heat conduction model with high statistical accuracy, where  $R^2$  was higher than 0.999 and MAPE was lower than 0.832%. The fitted model enabled the calculation of thermal diffusivity values across different sample formulations. Results showed an increasing trend of thermal diffusivity values with higher  $SiO_2$  content. Additionally, it was observed a relationship between ambient fluid temperature and thermal diffusivity, as the fluid temperature increased, thermal diffusivity decreased. These results suggest that nanosilica has a moderate but measurable effect on the heat transfer behavior of rubber materials. The findings contribute to a deeper understanding of the thermal design considerations needed when using nanosilica-modified rubber composites in industrial or high-temperature applications.

## Fatigue-Life Prediction of R260 Rail Steel under Rolling Contact from Lower to Higher Speed Ranges

### Ananthu Jayakumar\*, Ajith Ramesh

Department of Mechanical Engineering, Amrita School of Engineering, Coimbatore, Amrita Vishwa Vidyapeetham, India

Keywords: Rolling Contact Fatigue, R260 Rail Steel, Finite Element Analysis

The service life of railway infrastructure is significantly affected by rolling contact fatigue (RCF), which results from repeated interactions between the wheel and the rail, causing both surface and subsurface damage. Accurately predicting the fatigue-life of rail components under realistic loading conditions is essential for developing effective maintenance strategies, minimizing costs, and ensuring operational safety. Although RCF has been widely studied, the specific influence of varying train speeds on fatigue behavior remains relatively underexplored. Earlier studies have primarily concentrated on characterizing the fatigue properties of R260 rail steel through uniaxial fatigue testing [1], providing valuable baseline material data. However, there is limited understanding of how R260 performs under actual rail—wheel rolling contact, especially at higher operational speeds. To address this gap, this study investigates the fatigue performance of R260 rail steel under dynamic rail—wheel interactions.

A detailed three-dimensional rail—wheel contact model was developed in ABAQUS/Explicit, featuring a UIC-60 rail profile and a UC-515 wheel profile, supported by a 2-meter rail segment with three sleepers. High-strength concrete C50/60 was used as sleeper material. The substructure, including ballast, sub-ballast, and subgrade layers, was modeled using the Mohr–Coulomb plasticity model, accounting for elastic–perfectly plastic behavior. The rail material, R260 steel, was modeled with a Chaboche-type elastic–plastic constitutive law to capture cyclic plasticity behavior [2]. Dynamic simulations were carried out for a range of speeds between 50 km/h and 300 km/h. The resulting stress–strain histories were then used for fatigue life prediction in FE-SAFE, employing the Brown–Miller multiaxial fatigue criterion with mean stress correction to reflect the behavior of ductile materials [3].

The results show a gradual decrease in fatigue life as the train speed is increased from lower to moderate ranges. This decline was attributed to shorter contact durations leading to higher frequencies of stick-slip phenomena and hence, to higher stress frequencies at elevated speeds. Beyond 200 km/h, however, dynamic amplification effects such as wheel-rail separation, impact forces, and vibration-induced loads became more significant, causing a marked acceleration in fatigue damage. A sharp reduction in fatigue life was observed beyond this critical speed, emphasizing the transition from beneficial dynamic effects at moderate speeds to high-frequency damaging dynamics at very high speeds. These insights highlight the need for careful management of train speeds to reduce the risk of rolling contact fatigue and to extend the service life of railway infrastructure.

<sup>\*</sup> j ananthu@cb.amrita.edu

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# Investigation of Mechanical Properties in the Heat-Affected Zone of MIG-Welded 6082 Aluminum Alloy Using Simulated Thermal Histories

<u>Amir Khodabakhshi</u>\*<sup>1</sup>, Samar Keshavarz<sup>1</sup>, Shahriar Afkhami<sup>1</sup>, Juho Havia<sup>2</sup>, Hamidreza Rohani Raftar<sup>2</sup>, Juha. Uusitalo<sup>3</sup>, Antti Kaijalainen<sup>3</sup>, Tuomas Skriko<sup>1</sup>

**Keywords:** Welding, Aluminum, Microstructure, Thermo-mechanical simulation

Welding of precipitation-hardening aluminum alloys often leads to degradation of mechanical properties in the heat-affected zone (HAZ), and accurately characterizing these localized changes remains a significant challenge. Gleeble thermo-mechanical simulators is a valuable tool for investigating these effects under controlled conditions. While localized simulations have been conducted in various aluminum alloys, few studies focus on alloy 6082. This study examines the mechanical behavior of the HAZ in MIG-welded 6082 aluminum alloy utilizing local thermal cycle simulation. Welding simulation was conducted using Simufact welding software to evaluate the thermal cycles at various locations. The simulation was experimentally validated by recording real-time temperature data during welding using several thermocouples attached at different distances from the weld seam. Thermal cycles acquired from validated welding simulation were used to reproduce three HAZ regions via a Gleeble machine, each representing a specific subzone. The microstructure of the samples were investigated by optical and scanning electron microscopy (SEM). Mechanical characterization, including Vickers hardness and tensile testing equipped with Digital Image Correlation (DIC) were conducted for each HAZ subsection. Results indicated that the region exposed to a peak temperature of approximately 450°C exhibits the lowest yield strength, tensile strength, and hardness. This degradation is attributed to thermal over-aging and microstructural changes caused by temperature exposure. However, the elongation percentage values indicate that this sample exhibits a high degree of strain, indicating this sample is more ductile than others.

<sup>&</sup>lt;sup>1</sup> Laboratory of Welding Technology, School of Energy Systems, LUT University, Lappeenranta, Finland

<sup>&</sup>lt;sup>2</sup> Steel Structures, School of Energy Systems, LUT University, Lappeenranta, Finland

<sup>&</sup>lt;sup>3</sup> Materials and Mechanical Engineering, University of Oulu, Oulu, Finland

<sup>\*</sup> amir.khodabakhshi@lut.fi

### Modeling of Microplastic Deformation Influence on the Behavior of Vibration Protection Device with Shape Memory Alloy Parts

### Maria S. Starodubova\*, Fedor S. Belyaev, Margarita E. Evard, Aleksandr E. Volkov

Faculty of Mathematics and Mechanics, St Petersburg University, Saint Petersburg 199034, Russia

Keywords: shape memory alloys, modeling, vibrations

Shape memory alloys (SMAs) are smart materials whose mechanical properties change in response to external factors, such as temperature and applied stress. These materials can be effectively used for vibration protection due to their high damping capacity in both high-temperature austenitic and low-temperature martensitic states. An experimental and theoretical study of the oscillations of a torsion pendulum with a SMA element was previously conducted [1, 2]. However, in those works irreversible deformation in the SMA was not taken into account during modeling. In this paper, forced oscillations of a torsion pendulum were calculated for different amplitudes and frequencies of the forced oscillations. In order to quantify how vibrations are transmitted through the system, the frequency-dependent acceleration transfer coefficient was determined. Elements of artificial intelligence were used to predict the resonance frequency for different material states. Microplastic deformation of the SMA element at different temperatures corresponding to the austenitic, two-phase and martensitic states was studied. Based on the results, it was concluded that microplastic deformation in the calculations significantly affects the behavior of the device during the first few periods of oscillation. The most pronounced effect was observed in martensitic state at frequencies near resonance. Accounting for microplastic deformation leads to a reduction in the acceleration transfer coefficient at critical frequencies within the resonance range. The results obtained using the model may be of interest in designing vibration protection devices based on shape memory alloys.

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<sup>\*</sup> st063188@student.spbu.ru

### Inverse Stress Evaluation from Full-Field Strain: Uniqueness Conditions and Characteristic Analysis

### Benjamin C. Cameron\*

Department of Mechanical Engineering, Southampton University, Southampton SO17 1BJ, United Kingdom

Keywords: Digital image correlation, Partial differential equations, Inverse problem

Measuring the true stress-strain relationship of materials is impeded by plastic flow instabilities, material heterogeneities, and the complexity of the relationship itself. Digital image correlation allows full two-dimensional strain fields to be measured even in these complex cases, however the stress field is also required to obtain properties. This motivates the inverse problem: obtaining the stress field from the strain field, when material properties are unknown.

One promising approach is to utilise a system of partial differential equations (PDEs) previously developed [1,2]. Stable numerical solvers exist, and the approach has been extended to finite-deformation non-linear elasto-plasticity [3]. Accurate solutions have been obtained for several non-trivial problems, however, there are also cases where the PDEs admit no unique solution. This prevents potential users from being able to applying the approach with confidence.

Here, we investigate the characteristic structure of the PDEs, which governs uniqueness, in the case of continuous and differentiable strain fields. It happens that points in the domain with repeating strain eigenvalues are critically important, which we analyse this using degenerate matrix perturbation theory. This leads to understanding exactly when the PDEs admit solutions. Specifically, the equations admit unique solutions whenever there are no points in the domain that both: (1) have repeating strain eigenvalues and (2) has spatial derivatives of the strain with repeating eigenvalues. Furthermore, the analysis gives insights into new numerical solution strategies applicable to different conditions.

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<sup>\*</sup> b.c.cameron@soton.ac.uk

## Crystal plasticity modelling for cyclic elastoplastic behavior of additively manufactured 316L steel with sub-grain cellular structure

### Marco Pelegatti\*<sup>1</sup>, Enrico Salvati<sup>1</sup>, Francesco De Bona<sup>1</sup>, Nicolò Grilli<sup>2</sup>

- <sup>1</sup> Polytechnic Department of Engineering and Architecture, University of Udine, Udine 33100, Italy
- <sup>2</sup> School of Electrical, Electronic and Mechanical Engineering, University of Bristol Bristol, BS8 1TR, United Kingdom

Keywords: crystal plasticity, cyclic elastoplastic response, additive manufacturing

The 316L stainless steel is an easy-to-process metal by AM techniques, such as laser-powder bed fusion (L-PBF), that has been widely studied in recent years because of its relevance in industrial applications. The most outstanding microstructural features of the L-PBF 316L steel is the cellular structure generated during the AM process at the sub-grain level. This feature has been widely described in several works and was related to the exceptional balance between strength and ductility. Despite this consensus, only a few works attempted to include the AM cellular structure in constitutive models [1,2]. They all focused on monotonic behavior, whereas their models have never been applied to the cyclic elastoplastic response. Therefore, the present study proposes a cyclic plasticity model to simulate the behavior of L-PBF 316L steel using the crystal plasticity finite element method (CP-FEM). The model includes the pre-existing AM cellular structure by considering it a dislocation structure which induces back stresses at the subgrain level. Furthermore, the cyclic softening observed in the experiment is physically related to the development of persistent slip bands (PSBs), which are also consistently implemented in the model. Once the model had been developed, the parameters were calibrated based on microstructural investigations and literature. The model was finally validated by comparing the simulations with the experimental data for the cyclic response of the L-PBF 316L steel loaded at 0.4% strain amplitude. The cellular structure morphology and its associated high dislocation density are discussed to elucidate their role in mechanical behavior. The proposed constitutive model and approach stand as an effective tool for understanding the microstructure-property relationship of AM metal and accurately modeling cyclic performance.

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<sup>\*</sup> marco.pelegatti@uniud.it

## Preliminary Approach to Tool Wear Behavior on C45 Steel in Ultrasonic Vibration-Assisted Turning

#### Murat Sarp Koçak\*, Ramón Jerez Mesa, Eric Velázquez Corral

Department of Mechanical Engineering, Universitat Politècnica de Catalunya, Barcelona 08019, Spain

**Keywords:** Ultrasonic Vibration Assisted Turning, Tool Wear Mechanisms, Cutting Tool Degradation

This study investigates the influence of ultrasonic vibration-assisted turning (UVAT) on tool wear behavior in comparison to conventional turning. In this work, systematic turning experiments were conducted on C45 steel using TiN coated cemented carbide inserts, both under conventional and ultrasonic-assisted conditions. The evolution of tool wear will be monitored over controlled machining lengths, and wear patterns were characterized through optical microscopy. Key wear mechanisms such as abrasion, adhesion, micro-chipping, and crater wear were identified and analyzed. The results reveal that while ultrasonic vibration reduces initial cutting loads and can delay the onset of severe wear, it may also introduce new failure modes due to high-frequency cyclic stresses at the tool—workpiece interface. This study aims to provide a better understanding of tool damage and degradation mechanisms under ultrasonic excitation, offering insights for optimizing machining strategies and extending tool life in advanced manufacturing applications.

<sup>\*</sup> murat.sarp.kocak@upc.edu

# Fracture Toughness Assessment of FFF-processed Poly(hydroxybutyrate-co-3-hexanoate) (PHBH) Biopolymer

Lorenzo De Noni, Sara West, Hung-Jue Sue, Albert Patterson\*

Texas A&M University, College Station, Texas 77843, USA

**Keywords:** Additive manufacturing, Polymer processing, Fracture toughness

The fracture behavior of additively manufactured (AM) thermoplastic materials is a major topic of interest in design and manufacturing process development, particularly for biomaterials. Of the available major biomaterials that can be processed using fused filament fabrication (FFF), poly(hydroxybutyrate-co-3-hexanoate) (PHBH) offers great promise as a bio-based and bio-degradable, ocean-friendly engineering material. It is known to be more sensitive to processing conditions due to its high level of crystallinity, shrinkage, and tendency to degrade, so knowledge of the impacts of these conditions is vital. To better understand these effects on the fracture toughness of PHBH samples fabricated using FFF, a set of experiments were performed using ASTM D5045 with compact tension samples. The factors were bead width (0.4mm and 0.8mm) and printing temperature (190°C and 230°C), with three replications of each. These experiments were repeated for three sample sizes (10mm, 20mm, and 30mm) for a total of 36 tests. A statistical analysis (validated 2-way ANOVA) of the final data was done to identify statistically significant factors and interactions, with the results used to drive design and processing recommendations for FFF-processed PHBH.

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<sup>\*</sup> aepatterson5@tamu.edu

### Compaction, Consolidation and Sintering of UHMW-polyethylene

### Sergey V. Kotomin\*1, Dmitry V. Dudka<sup>2</sup>

**Keywords:** compaction, sintering, UHMW-polyethylene

Ultrahigh molecular weight polyethylene is widely used for the manufacture of prostheses, mainly by polymer powder compression molding [1]. The high viscosity of that polymer makes it difficult to process the material by injection molding and using well known additive technologies, for example, widespread 3D printers FDM and SLS type. The conditions of UHMWPE powder compaction and sintering are related to the molecular weight of the polymer powder and the size of its particles [2]. The thermomechanical properties and relaxation behavior of UHMWPE under these conditions have not been sufficiently studied but are very important for new approaches to that polymer processing [3]. The compaction, sintering and thermomechanical properties of UHMWPE powder of the brands GUR – 4150, GUR 4120 manufactured by Celanese and UTEC 6540 manufactured by BRASKEM were studied on a capillary viscometer as a press equipped with a precision dilatometric device. The retardation of the powder after removal of the load has been studied as well.

The kinetics of compaction and sintering of UHMWPE powders under compression at various temperatures, as well as melt retardation after sintering, have been studied in isothermal conditions. It is revealed that the sintering of the powder occurs unevenly over the volume of the sample, which is associated with the pressure gradient due to the friction of the powder on the surface of the cylinder in which sintering occurs. The thermomechanical curves during powder heating correspond to continuous compaction of the material up to 150 C, and the heat resistance of the material in block during indenter testing is 140 C. The difference in the molecular weight and particle size of the polymer powder affects both the kinetics of compaction and sintering, as well as the retardation of the melt.

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<sup>&</sup>lt;sup>1</sup> Department of Chemistry, Bauman State Technical University, Moscow 105005, Russia

<sup>&</sup>lt;sup>2</sup> reseacher, Institute of Petrochemical Synthesis? Russian Academy of Scienses, Moscow

<sup>\*</sup> servk@bmstu.ru

### Reverse-notch Fracture Energy Assessment for FFF-processed Polyamide and Polycarbonate with Chopped Carbon Fibers

### Jackson Rahm, Albert E. Patterson\*

Texas A&M University, College Station, Texas 77843, USA

**Keywords:** Polymer additive manufacturing, Fracture energy, Composite material failure

The focus of this study was the fracture energy assessment of additively manufactured thermoplastic matrix composites with chopped carbon fiber reinforcement under reversed-notch (notch-in-compression) impact loading. This type of loading is common in structures and products where a stress concentration (corners, holes, pre-existing cracks) may be in compression during use [1-2]. The setup was done according to ASTM D256 with a Type E configuration. The matrix materials used were polyamide and polycarbonate with approximately 15% fiber loadings by weight. The specimens were printing using a standard raster orientation and 100% target density. The parameters varied were the nozzle size (0.6, 0.8, and 1mm), layer thickness (0.1, 0.25, and 0.5mm), printing temperature (260, 270, and 275°C), and notching method (0.1mm V notch, 0.25mm V notch, and 2mm U notch). An L9 Taguchi design was used with three replications of each test, for a total of 56 tests. The samples were testing using the IZOD method with a 20J impact testing machine. Statistical and fracture analyses were done on the collected data, showing that the processing parameters had a noticeable impact on the fracture behavior. This was used to drive some design recommendations for product manufacturing using these materials.

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<sup>\*</sup> aepatterson5@tamu.edu

# Assessment of Volute Damage in Centrifugal Pump Under Harsh Operating Conditions

### Mohaned Djedidi\*, Mariem Ben Hassen, Hatem Mrad

DIFIA Laboratory, University of Québec in Abitibi-Témiscamingue, Rouyn-Noranda J9X 5E4, Canada

Keywords: Finite element method, Low-cycle fatigue, Crack growth, Damage

Multistage submerged pumps work in harsh conditions in dewatering operations in the mining sector [1]. Pumped water is always heavily loaded with slugs and full of solid particles [2]. These conditions lead to premature failures [3], mainly crack initiation and fatigue [4] on components at the discharge stage where pressure reaches extreme values.

This study is divided into two parts, the first is based on a coupled fluid-structure interaction (FSI) to simulate the real functioning condition of the pump in steady and transient domains to assess stress distributions and deformation behaviors. The second part investigates the root causes of damage and predicts the crack growth path, based on the stress intensity factors calculated with the M-integral method. In addition, the fatigue life cycle is predicted using NASGRO law.

The results indicate that dynamic fluid forces significantly contribute to stress concentrations and lead to plastic deformations, resulting in low-cycle fatigue (LCF) and premature cracking of the last-stage volute. The FSI model was validated using the experimental performance curve of the pump. A comparison between the numerically predicted crack path and the experimental data shared by our industrial partner is conducted, resulting in a high accuracy validation. Other findings indicate that the component's initial design exhibits highly vulnerable zones, which, combined with elevated bolt torque, significantly accelerate the failure process. Finally, this work is concluded by proposing an economic solution with enhanced design.

This study offers a robust framework for anticipating component lifespans and guiding design improvements to enhance reliability in multistage submerged pumps operating under harsh conditions.

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<sup>\*</sup> djem04@ugat.ca

Engineering Failure Analysis, vol. 60, pp. 1-8.

# Accurate Crack Path Co-simulation in Cruciform Aluminum Joints Under Biaxial Loading

### Mariem Ben Hassen\*, Seyyed Mojtaba Fakhkhari, Ahmed Nsir, Hatem Mrad

DIFIA Laboratory, University of Quebec in Abitibi-Témiscamingue, Rouyn-Noranda, QC J9X 5E4, Canada

Keywords: Crack growth, Co-Simulation approach, XFEM, Biaxial loads

Abstract: Crack initiation and propagation in industrial equipment often result from a combination of critical factors such as cyclic loading, continuous vibrations, design irregularities, and material or manufacturing defects. These interacting factors accelerate damage accumulation, leading to a progressive loss of structural integrity. To mitigate such risks, several methods have been developed to simulate fatigue crack propagation, including the classical Finite Element Method (FEM) [1], Extended Finite Element Method (XFEM) [2], and modified XFEM [3]. However, these methods may face limitations when dealing with complex loading scenarios involving multiple and combined solicitations, such as biaxial or dynamic loads. Thus, more refined and robust modeling techniques are essential to precisely predict the crack growth path.

This work focuses on a developed FRANC3D and ABAQUS Co-Simulation approach [1] that was used to assess the crack path growth of an aluminum alloy cruciform joint under biaxial load. A sensitivity analysis was conducted to quantify the effect of several parameters, such as the crack's size, shape, and location, on the crack growth rate and stress intensity factors. In addition, the crack growth paths are calculated respectively under biaxial tension, biaxial tension-in-plane bending, and biaxial in-plane bending according to different biaxial stress range ratios r = 0.1, 0.3, 0.5, and 0.7. The numerical results in this paper are compared with the modified extended finite element method (XFEM) and results in the literature [2, 3].

For the loading scenarios and under different stress ratios, the crack growth paths predicted using the proposed method achieved a mean squared error (MSE) below  $10^{-2}$  when compared to results from the literature, demonstrating its high accuracy and reliability in predicting complex crack growth behavior. In addition, the calculation results show that the crack growth paths are significantly dependent on the stress ratio.

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<sup>\*</sup> mariem.benhassen@ugat.ca

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## Topology Optimization of Axial Mining Fan Hubs using the Solid Isotropic Material with Penalization (SIMP) Method

#### Ahmed Nsir\*, Mariem Ben Hassen, Seyyed Mojtaba Fakhkhari, Hatem Mrad

DIFIA Laboratory, University of Quebec in Abitibi-Témiscamingue, Rouyn-Noranda, QC J9X 5E4, Canada

\* Ahmed.Nsir@uqat.ca

Keywords: Mining fan, Topology optimization, SIMP, Co-simulation, MTS, Fatigue life

At the core of the ventilation system, the hub plays a critical role in transmitting rotational forces under extreme conditions [1]. However, in mining industrials, weight optimization has become an essential strategy for improving equipment performance, energy efficiency, and fatigue life cycle [2, 3]. To address this challenge, this study was carried out as part of the topological optimisation of real axial fan hubs used in mining operations. The primary objective is to minimise their mass while maintaining or enhancing the mechanical performance. Two approaches were explored: a manual optimisation based on the creation of pocket milling and a more advanced numerical optimisation, implemented by the Solid Isotropic Material with Penalization (SIMP) method, with various penalty factors (1,3,5) and topology rates (12, 20, 30). In addition to the optimized geometry developed and validated through structural, modal analyses, a fatigue life prediction using a co-simulation approach proposed in [4] was used. Based on the Maximum Tensile Stress criteria (MTS) and using a semi-elliptical crack inserted in the maximum stress concentration zone. A comparison between the life cycle of the optimized and original models revealed a significant improvement in the predicted fatigue life using the Pris-low. The results proved particularly effective, reducing weight by 20% while improving the safety coefficient by 3.5%, without compromising the system's rigidity or vibration stability. Overall, this project demonstrates the relevance of topological optimisation applied to critical mining ventilation components, leading the way to lighter, more efficient, and resistant designs that are adapted to industrial realities.

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## A Comparative Study of Nonlocal Frameworks for Ductile Fracture Modeling

#### <u>Izzet Erkin Unsal</u>\*, Can Erdogan, Tuncay Yalçınkaya

Department of Aerospace Engineering, Middle East Technical University, Ankara 06800, Türkiye

Keywords: Nonlocal damage models, Ductile damage, Mesh-dependency

Hydrogen embrittlement is a critical degradation mechanism in metallic materials, where absorbed hydrogen atoms significantly reduce ductility, fracture toughness, and fatigue resistance [1]. This phenomenon compromises the structural integrity of components across a wide range of engineering applications. Although hydrogen-assisted cracking has been well studied at the macroscopic scale, the effects of microstructural features at the mesoscale are yet to be fully understood. When analyzing hydrogen redistribution at this scale, the role of grain boundary constraints in hydrogen transport should be considered, as strain gradient hardening is known to play an important role in fracture [2]. Regardless of specimen size, the plastic zone ahead of a crack tip is very small and develops sharp spatial gradients of deformation, which create plastic strain gradients and geometrically necessary dislocations (GNDs). In these regions, hydrostatic stress gradients become strongly localized and significantly affect the redistribution of hydrogen at the grain scale. Driven by these considerations, and to investigate the influence of grain size as a key microstructural feature, this study employs a strain gradient crystal plasticity framework coupled with a hydrogen diffusion model and a potential-based mixed-mode cohesive zone model to simulate crack initiation and propagation in polycrystalline microstructures. The model captures the effects of strain gradients on hydrogen transport through GND-induced diffusion paths and on the hydrogen-enhanced decohesion mechanism by amplifying stress concentrations [3]. Simulations are performed on microstructures with varying grain sizes to evaluate the influence of grain morphology. The findings are compared with existing literature, and the influence of grain size are re-examined alongside the contributions of non-local strain gradient effects.

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<sup>\*</sup> eunsal@metu.edu.tr

### Predictive Approaches to Enhance the Fatigue Assessment of Ni-Ti Biomedical Devices

Alma Brambilla\*1, Francesca Berti<sup>2</sup>, Luca Patriarca<sup>3</sup>, Laura De Lorenzis<sup>4</sup>, Lorenza Petrini<sup>1</sup>

- <sup>1</sup> Department of Civil and Environmental Engineering, Politecnico di Milano, Milan, Italy
- <sup>2</sup> Department of Chemistry, Materials and Chemical Engineering, Politecnico di Milano, Milan, Italy
- <sup>3</sup> Department of Mechanical Engineering, Politecnico di Milano, Milan, Italy
- <sup>4</sup> Department of Mechanical and Process Engineering, ETH Zurich, Zurich, Switzerland

**Keywords:** Shape memory alloys, Fracture mechanics, Phase-field modeling, Cardiovascular devices, Cyclic behavior

Nickel-Titanium (Ni-Ti) shape memory alloys (SMAs) are the top choice for designing self-expanding cardiovascular devices for minimally invasive surgeries, thanks to their superelastic behavior related to stress-induced phase transformation. The long-term reliability of these devices remains a critical issue, especially for peripheral stents and heart valves subjected to millions of load cycles due to body movements. Current practices combine in vitro tests on surrogate samples with computational simulations to assess device safety [1]. However, simplistic fatigue indicators that overlook material complexities are typically adopted without accounting for material defects or addressing the effect of crack tip phase transformation on damage. This work investigates complementary predictive approaches to enhance the fatigue assessment of Ni-Ti biomedical devices, considering surrogate multi-wire samples. Uniaxial fatigue tests were carried out to evaluate the fatigue life at several mean and alternate strains, followed by fracture surface analysis, providing a statistical distribution of material defects.

A fracture mechanics-based predictive approach was first implemented, assuming crack propagation from defects up to fracture. Fatigue crack growth tests on Ni-Ti notched samples were conducted, adopting the energetic cyclic J-integral parameter as driving force to calibrate a proper crack growth law [2]. Conservative fatigue life predictions matching the experimental trend were obtained for multi-wire samples, neglecting the crack nucleation phase.

A more sophisticated phase-field model of fracture was developed by coupling a SMA constitutive model [3] with a gradient damage model [4], following a variational approach. After model calibration, multi-wire fatigue tests were simulated, exploiting the inherent structure of the model accounting for fatigue effects, analyzing both the homogeneous and the localized response. Promising life predictions were obtained, capturing the experimental outcomes and gaining insights into the peculiar material behavior in the damage zone. Future efforts will allow to establish an integrated predictive tool to enhance SMA device reliability.

<sup>\*</sup> alma.brambilla@polimi.it

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# Data-Driven Time Integration in Spectral Boundary Integral Methods for Fracture Modelling

### Joshua McNeely\*, Luis Espath, Gabriele Albertini

- <sup>1</sup> Faculty of Engineering, University of Nottingham, Nottingham, NG7 2RD, United Kingdom
- $^{2}$  School of Mathematical Sciences, University of Nottingham, Nottingham, NG7 2RD, United Kingdom

Keywords: Fracture Mechanics, Data-Driven Modelling, Mathematical Simulations

Material failure is induced by fracture propagation. Modelling this process is complex due to the non-linear behaviour of fractures and the involvement of multiple length and time scales. A systematic approach that utilises data to unravel the complexity of fracture modelling is currently lacking. In response, we propose a novel data-driven time-integrator approach, coupled with a Spectral Boundary Integral Method (SBIM) in a predictor-corrector framework, to solve elastodynamic responses of fracture propagation. Sparse displacement measurements collected from the crack surface are used to inform the time integrator. This work builds upon an existing SBIM framework [1] to solve the elastodynamic response of two half-spaces coupled through a cohesive law that models the fracture process. Simulations are conducted using the open-source Uguca software [2]. We strategically employ sporadic data measurements to mimic the incomplete observations typically encountered in real-world fracture systems, with the view to use this data to refine previous general assumptions about the boundary and initial conditions of the crack front. Our method derives the explicit time integrator by minimising a combined physics-data loss function for displacement. We benchmark the method against a ground truth solution generated by a high-fidelity forward simulation, assessing the new method's capability to maintain reliability with real data. This advancement may lead to the quantification of previous uncertainties regarding fracture behaviour and enable solutions to be provided across the entire domain, even with incomplete data. Our method serves as a precursor to the goal of using data to infer quantities and relations that are not directly measurable, such as constitutive laws and material property interactions, representing an essential step towards practical and robust mathematical fracture modelling applicable to real-world problems.

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<sup>\*</sup> joshua.mcneely@nottingham.ac.uk

### Numerical Simulation of Crack Kinking with Cohesive Zone Extensions

### Danylo M. Selivanov\*

S.P. Timoshenko Institute of Mechanics, National Academy of Sciences of Ukraine, Kyiv 03057, Ukraine

Keywords: piecewise linear crack, cohesive zone model, crack kinking

A bilinear fracture configuration is studied, where a traction-free crack transitions into a kinked cohesive interface. This setup serves as a reduced model for the onset of a curved crack path in quasi-brittle materials, with the cohesive segment representing the initial increment of crack growth. The interface behavior is governed by a mixed-mode cohesive zone model (CZM) with a potential-based traction-separation law (TSL) defined in a local coordinate system. Mode mixity is controlled via a scalar parameter representing the ratio of normal to tangential cohesive strength, enabling a unified formulation of cohesive response in different loading modes, as employed in branching and fragmentation studies [1,2]. The numerical formulation introduces tangential and normal cohesive tractions as additional degrees of freedom and solves a stabilized nonlinear system to simultaneously enforce equilibrium and the TSL at each cohesive node. The Jacobian matrix is constructed analytically to improve convergence, extending methods from mixed-mode delamination modeling [3]. For Mode I conditions, symmetry is imposed. In the mixed-mode case, an adaptive meshing strategy—developed in MATLAB—is used to surround a piecewise-linear kinked crack path with paired cohesive nodes, inspired by topology-based approaches to cohesive element insertion [4]. Unlike models that prescribe the crack trajectory, the kink direction in this work is determined by minimizing the total cohesive energy under a limit-state condition defined by maximum normal separation at the crack tip. Numerical results highlight the impact of mesh resolution, cohesive parameters, and stabilization strategy on the stress distribution and crack deflection angle. Simulations show good agreement with previous cohesive damage models used in quasi-brittle fracture [5].

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<sup>\*</sup> dselivanov29@gmail.com

## EBSD-Based Analysis of Microstructural Evolution in 7075 Aluminum Alloy processed by Biaxial Alternating Forging

Tae-Yeong So\*1,2, Seong-Ho Ha<sup>1</sup>, Young-Chul Shin<sup>1</sup>, Dong-Earn Kim<sup>1</sup>, Byoung-Ho Choi<sup>2</sup>

**Keywords:** 7075 aluminum alloy, Severe plastic deformation, Biaxial alternating forging, Electron backscatter diffraction

In conventional metal forming processes such as rolling, forging, and extrusion, the imposed plastic strain typically does not exceed 2.0. To achieve substantially higher strains without significant shape changes, severe plastic deformation (SPD) techniques have been developed. Biaxial alternating forging (BAF) has been proposed as a promising SPD method, capable of continuously accumulating large plastic strains through multi-directional forging cycles [1]. In this study, the microstructural evolution of a 7075 aluminum alloy subjected to BAF at different strain levels and forging temperatures was systematically investigated. The BAF process was performed by repeatedly forging the workpieces with a 90-degree rotation around their longitudinal axes, maintaining the workpiece's cross-sectional shape even after multiple cycles.

Electron backscatter diffraction (EBSD) was employed to investigate the impact of second-phase particles on the development of severely deformed microstructures during processing. The results revealed that although cold BAF induced limited microstructural changes, primarily the formation of twins and increased dislocation density, higher processing temperatures significantly promoted dynamic recovery and recrystallization during BAF. These findings demonstrate the effectiveness of BAF combined with temperature control in tailoring the microstructure of high-strength aluminum alloys for potential performance enhancements.

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<sup>&</sup>lt;sup>1</sup> Korea Institute of Industrial Technology, Incheon 21999, South Korea

<sup>&</sup>lt;sup>2</sup> Shool of Mechanical Engineering, College of Engineering, Korea University, Seoul 02841, South Korea

<sup>\*</sup> re-soty1013@kitech.re.kr

## **Enhancing Strength and Controlling Crack Growth in Low Carbon Steel Using CNT Nanofluid Quenching Medium**

### Abdullah Helmi Isahak<sup>1</sup>, Mohamad Faizal Abdullah<sup>\*1,2</sup>, Shahrum Abdullah<sup>3</sup>

- <sup>1</sup> Department of Mechanical Engineering, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, Kem Perdana Sg. Besi, 57000 W.P Kuala Lumpur, Malaysia
- <sup>2</sup> Centre for Tropicalization, Defence Research Institute, Universiti Pertahanan Nasional Malaysia, Kem Sungai Besi 57000 Kuala Lumpur, Malaysia
- <sup>3</sup> Department of Mechanical and Manufacturing Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia

Keywords: Nanofluid quenching, Crack growth, Low carbon steel

This study presents the crack growth behaviour of low carbon steel guenched by carbon nanotube (CNT) nanofluid quenching media. Quenching is a critical heat-treatment process for improving the mechanical properties of low-carbon steel, especially hardness and strength [1]. Conventional quenching such as water and oil often face challenges, including inconsistent cooling rates, undesirable residual stress, microstructural inconsistencies, and distortion or cracking [1]. CNT nanofluids, with high thermal conductivity and excellent heat transfer properties, have emerged as a promising alternative quenchant [2]. However, a comprehensive understanding of how fluids based used in CNT nanofluids affect particularly in the context of mechanical performance and crack growth behaviour of quenched steels, while elucidating microstructural mechanisms governing crack growth remain underexplored. The experimental methodology involved heating the low carbon steel specimens to an austenitizing temperature of 900 °C, followed by rapidly cool into two types of CNT based nanofluids consisting of water based and oil based aimed to compare the strength performance and resistance of the steel to cyclic loading. The mechanical properties were evaluated using tensile testing, while crack growth behaviour was experimentally assessed through compact tension specimens subjected to constant amplitude loading. Microstructural changes were observed using optical microscopy to analyse phase transformation and fracture surface morphology. The results demonstrate that quenching with water-based CNT nanofluid leads to a 33% enhancement in tensile strength and a fourfold improvement in fatigue life. These gains are attributed to the combined effects of high thermal conductivity, refined martensitic microstructure, and uniform nanoparticle distribution. Additionally, the relationship between crack growth rate and stress intensity factor range was analysed within the Paris regime for both waterbased and oil-based CNT nanofluids. The study concludes that water-based CNT nanofluid significantly suppresses crack propagation.

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<sup>\*</sup> m.faizal@upnm.edu.my

# Finite Element Analysis and Experimental Investigation of Damage Evolution During Shape Rolling of Compressor Blades

Seyyed Mojtaba Fakhkhari\*<sup>1</sup>, Vali Alimirzaloo<sup>2</sup>, Taher Azdast<sup>2</sup>, Hossein Gheshlaghi Ghadim<sup>2</sup>, Kourosh Karami<sup>3</sup>, Hatem Mrad<sup>1</sup>

- <sup>1</sup> DIFIA Laboratory, University of Quebec in Abitibi-Témiscamingue, Rouyn-Noranda, QC J9X 5E4, Canada
- <sup>2</sup> Mechanical Engineering Department, Faculty of Engineering, Urmia University, Urmia, Iran
- <sup>3</sup> Mechanical Engineering Department, Science Research Branch of Islamic Azad University, Tehran, Iran
- \* SeyyedMojtaba.Fakhkhari@uqat.ca

**Keywords:** Cold Rolling, Damage Prediction, Finite Element Simulation

The manufacturing of gas turbine blades through the shape rolling process often faces challenges related to surface damage, particularly cracking, wrinkling and tearing [1], which arise from the complex geometrical changes during the cold rolling process [2]. Cold rolling process parameters affect significantly the quality of the final products. Several works have addressed the relationship between process parameters such as rolling force, reduction ratio, and number of passes on the surface integrity and dimensional accuracy of the formed blades using finite element method and experimental validations [3]. Further verification is necessary to investigate the damage and crack initiation of the cold formed blades.

This study aims to predict damage evolution during the shape rolling of compressor blades made from 17-7 PH stainless steel, utilizing finite element simulations that are validated by experimental observations. The simulation was conducted, assuming rigid rollers and a deformable preform with refined mesh tetrahedral elements, as confirmed through mesh sensitivity analysis. In order to study the plastic deformation of the blade, material properties were derived from standard tensile tests. Damage prediction was conducted based on the Cockroft-Latham criterion, where the damage criteria was computed and mapped across the blade surface [1] and compared with the experimental test results based on different process parameters.

Strain distribution analysis revealed that increasing the number of rolling stages resulted in more uniform strain fields and a reduced risk of surface damage. Experimentally, blades processed with a higher number of rolling stages exhibited no visible cracks, while those rolled with fewer stages displayed severe surface cracking at the edges and center. The numerical results based on Cockroft-Latham damage predictions and experimental findings demonstrate the effectiveness of multi-stage rolling in mitigating surface defects and validate the predictive accuracy of finite element simulations industrial applications.

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# Fatigue-Driven Multi Objective Optimization of a Parametric Fan Hub Using Bayesian Algorithms and Coupled Fluid-Structure Simulations

#### Seyyed Mojtaba Fakhkhari\*, Ahmed Nsir, Mariem Ben Hassen, Hatem Mrad

DIFIA Laboratory, University of Quebec in Abitibi-Témiscamingue, Rouyn-Noranda, QC J9X 5E4, Canada

\* SeyyedMojtaba.Fakhkhari@uqat.ca

Keywords: Bayesian optimization, Structural integrity, Fatigue

Ventilation systems used in underground environments rely heavily on the mechanical integrity of rotating components such as axial fan hubs, which are subjected to complex cyclic loading from both aerodynamic and centrifugal forces [1]. Over time, these components are vulnerable to fatigue failure, particularly when manufactured from cast alloys with limited life cycle [2]. In the absence of optimized geometry, the risk of premature failure is high, leading to costly maintenance, downtime, and safety concerns. Thus, there is a critical need for robust design approaches that can accurately predict fatigue behavior and enable the development of lighter, longer-lasting components without compromising structural reliability. This study presents a fatigue-critical, multi-objective optimization strategy for the redesign of a 21-inch axial fan hub used in mining industry. The original hub, manufactured from cast aluminum 713, was analyzed under combined centrifugal and aerodynamic loads based on fluid-structure coupling approach [3]. Stress-life approach coupled with modal analysis is used for fatigue life assessment [1]. Fatigue crack growth behavior and propagation paths were preliminarily evaluated using Paris' law [4] in ANSYS Mechanical, providing insights to stress intensity factors and mixed-mode fatigue life for both baseline and optimized geometries [2].

The natural frequencies for the first three mode shapes were found to be at least 15 times greater than the rotational frequency, indicating stability and no resonance risk for the original hub design. Structural analysis showed a static safety factor of 1.4, and a fatigue safety factor of 0.8, failing to meet the target design life of 500 million cycles. To address these limitations, a Bayesian-based optimization algorithm was implemented, targeting mass reduction while maximizing natural frequency and fatigue safety factor. The fan hub was parameterized through key geometric variables such as thickness, length, and radii subject to manufacturing and assembly constraints. Coupled CFD, structural, and modal simulations were used for fitness evaluations. The optimized design achieved a 5% mass reduction, a 3.5% increase in natural frequency, and a fatigue safety factor exceeding 1.0, confirming its structural viability. This study highlights the potential of integrating data-efficient Bayesian optimization with high-fidelity simulations to improve the fatigue resistance of rotating components.

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### Hybrid Acoustic-Emission and Machine Learning-Based Classification Approach for Non-Destructive Characterization of Damage Evolution in Cross-Ply Composites

### <u>Mariem Ben Hassen</u>\*<sup>1</sup>, Sahbi Tamboura<sup>2</sup>, Joseph Fitoussi<sup>3</sup>, Mohaned Djedidi<sup>1</sup>, Hatem Mrad<sup>1</sup>

- <sup>1</sup> DIFIA Laboratory, University of Quebec in Abitibi-Témiscamingue, Rouyn-Noranda, QC J9X 5E4, Canada
- <sup>2</sup> École Nationale d'Ingénieurs de Sousse, LMS, Pôle Technologique, Route de Ceinture,4054 Sousse, Tunisie
- <sup>3</sup> Arts et Métiers ParisTech (ENSAM), PIMM, 151 Boulevard de l'Hôpital, 75013 Paris, France

Keywords: Cross-ply composites, Acoustic emission, Machine learning, Damage mechanisms

Acoustic emission (AE) is a widely used technique to monitor damage in composite structures, as the emitted signals change with damage progression [1]. Under mechanical loading, different types of damage can occur. These damage mechanisms arise at various stages and locations and may appear simultaneously [2]. In cross-ply laminates, mechanical loading typically generates a sequence of damage events, including matrix microcracking, delamination, and eventual fiber breakage that together define the material's acoustic emission signature [3]. In this study, an experimental investigation is conducted to identify the damage mechanisms in laminated cross-ply carbon/epoxy composites. Five types of crossed-ply specimens were tested under static tensile tests, labelled ±15°, ±30°, ±45°, ±86°, and multi-layers (±84°, ±35°, ±45°, ±85°). Acoustic emission (AE) was used to monitor all experiments to identify the growth and development of the main damage mechanisms. Based on a temporal characteristic such as the amplitude range, the cumulative number of hits, and the acoustic energy, the AE recorded events were classified using an unsupervised machine learning (ML) clustering technique k-means algorithm. The clustering method based on five temporal parameters was used to identify damage mechanisms in the tested composites and to track their evolution over time. After classification, the results were reported by plotting the amplitude and number of hits as a function of time for different configurations. Results revealed only three classes are identified for ±30°, ±45°, and ±86° in the following order: Fiber/matrix debonding, matrix cracking, and delamination, which appear and evolve differently from one fiber orientation to another. For the three orientations, we notice that the dominant mechanism that accompanies the test until the total fracture is fiber/matrix debonding. While in the case of  $\pm 15^{\circ}$  and multi-layer samples, four classes were captured in the following order: Fiber/matrix debonding, matrix cracking, pseudodelamination, and fiber breakage.

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## Enhancement of Lightweight Sandwich Panel under Static and Cyclic Loading Condition using Systematic Data Analysis

### Mohd Khairul Faidzi\*1, Shahrum Abdullah², Salvinder Singh Karam Singh², Abdul Hadi Azman²

**Keywords:** Core design, Hybrid data analysis, Lightweight, Qualitative, Quantitative

The use of lightweight sandwich panels, particularly those made from aluminium and magnesium alloys, is increasingly vital in heavy industries such as defense due to their light weight, ease of handling, and structural toughness [1]. Under severe conditions like cyclic loading, these panels are prone to issues such as delamination and debonding between layers— often leading to catastrophic failures including core crushing and severe face sheet deformation [2]. Hence, an enhancement is vital to improve the performance of sandwich panels, specifically on their core structure to promote better life cycle and maintain their structural integrity [3]. This study addresses these challenges by promoting a systematic framework of data analysis to determine the best core design configuration for sandwich panels. The results of finite element analysis were used and integrated into the hybrid data analysis of decision making (AHP & TOPSIS), with element of fuzzy to justify and helps to determine the high precision result of the best core design configuration [4]. These analysis process involved the several criteria such as stress analysis, deformation, life cycle and damage under static and cyclic loadings. All results of hybrid data analysis were validated using experimental procedure and statistical analysis. Results demonstrated that an average size of dimple on core surface layer tend to improve life cycle by 38% better than normal core, with highest closeness coefficient value of 1.00. Under 95% of confidence interval analysis, it showed that all the data points from hybrid data analysis and experimental analysis were within the boundaries, indicated strong correlation and high accuracy between them. This study demonstrates a robust approach combining quantitative simulations and qualitative decision-making tools to optimise sandwich panel design-offering an opening for advanced machine learning analysis and a reliable path to enhance structural integrity and service life in critical applications.

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<sup>&</sup>lt;sup>1</sup> Department of Mechanical Engineering, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, Kem Perdana Sg. Besi, 57000 Kuala Lumpur

<sup>&</sup>lt;sup>2</sup> Department of Mechanical and Manufacturing Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43000 UKM Bangi, Selangor

<sup>\*</sup> khairulfaidzi@upnm.edu.my

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### Characterization of Surface Degradation and Changes in Mechanical Properties of HDPE Exposed to Chlorine Dioxide

Jeonug Kang\*1, II-Hyun Kim1, Min-Seok Choi1,2, Suleyman Deveci3, Byoung-Ho Choi1

**Keywords:** High Density Polyethylene, Chlorine Dioxide, Degradation, Mechanical Properties, Failure Mechanism

Chlorine dioxide (CIO<sub>2</sub>) is widely used as a disinfectant in water pipe systems; however, its chemical interaction with HDPE pipes leads to material degradation. Previous research primarily focused on mechanical property changes in thick HDPE specimens, typically several millimeters in thickness, without fully characterizing the thin degraded layer formed at the surface due to diffusion-limited oxidation (DLO). As a result, the specific contribution of this surface-degraded layer to overall mechanical properties and failure mechanisms of HDPE pipes has not been systematically analyzed. To complement this gap, this study focused on mechanical property changes within the surface-degraded layer. HDPE micro-tensile specimens (ASTM D1708) of 2mm and 50m thickness were subjected to accelerated chemical aging in water containing CIO<sub>2</sub> (1.5ppm, pH7.0) at 60°C. Mechanical property changes were evaluated at various aging times through tensile testing, while chemical and morphological changes were characterized using Fourier-transform infrared spectroscopy (ATR-FTIR), Gel Permeation Chromatography (GPC), and optical microscopy. In the 2mm specimens, tensile testing showed an initial reduction in elongation at break between 12 and 24 hours of aging. As degradation progressed, elongation at break continued to decline, and after approximately 84 hours, specimens exhibited immediate brittle fracture under tensile loading. Interestingly, due to the DLO effect, the degraded surface layer growth was limited to approximately  $50\mu m$ , and the removal of this layer reset the mechanical properties of the 2mm specimens to levels comparable to undegraded specimens. After 384 hours of aging, the elongation at break decreased to 9.8% of the initial value but reached 94% after degraded layer removal, and ATR-FTIR analysis confirmed that no carbonyl peak was detected, verifying that degradation was confined to the surface layer. To better explain this phenomenon, additional tests were conducted using  $50\mu m$  film specimens, which have the same thickness as the surface-degraded layer observed in the 2 mm specimens. After 12 hours of exposure to CIO2, the weight-average molecular weight decreased to approximately onethird of its initial value, and the ultimate tensile strength dropped by 17%, indicating extensive chain scission. Continuous interval sampling revealed a steady decline in both tensile strength and elongation at break, and after 72 hours, the films exhibited immediate brittle fracture. These mechanical property changes in the films helped explain the reduction in elongation at break observed in the 2 mm bulk specimens, as a brittle fracture readily initiated in the thin degraded surface layer during tensile loading, followed by

<sup>&</sup>lt;sup>1</sup> School of Mechanical Engineering, College of Engineering, Korea University, 5-ga Anam-dong, Sungbuk-gu, Seoul, 136-701, South Korea

<sup>&</sup>lt;sup>2</sup> Hyundai Mobis Fundamental Technology Materials Team, 17-2, Mabuk-ro 240beon-gil, Giheung-gu, Yonginsi, Gyeonggi-do, Republic of Korea

<sup>&</sup>lt;sup>3</sup> Borogue Pte.Ltd, sheikh Khalifa Energy complex, Corniche Road, PO Box 6951, Abu Dhabi, UAE

<sup>\*</sup> rkdwjsdnr9@korea.ac.kr

crack propagation into the undegraded inner region, ultimately leading to failure. These findings clearly demonstrate that even in thick HDPE structures, mechanical property degradation and premature failure are primarily governed by the formation and growth of a thin surface-degraded layer, enhancing the understanding of how surface degradation leads to structural failure in piping systems.

#### New Insights into Hydrogen-Assisted Fracture of Alloys

#### Livia Cupertino-Malheiros\*

Department of Civil and Environmental Engineering, Imperial College London, London, UK

Keywords: Hydrogen embrittlement, Fracture mechanics, Engineering alloys

A wide range of commonly used metals and alloys are susceptible to hydrogen embrittlement (HE), which imposes significant limitations on the design of structures across many industrial sectors, particularly in energy and transportation. HE is strongly linked to the interactions between hydrogen and the metal's lattice structure, including its crystallographic defects - such as interfaces, dislocations, second-phase particles, and vacancies - as well as local mechanical states (hydrostatic stress and/or plastic strain). Consequently, understanding the underlying mechanisms of hydrogen-assisted fracture requires testing methodologies specifically designed to capture the unique fracture behaviours of each alloy-hydrogen system [1-2]. This work presents recent developments in fracture testing for hydrogen-assisted intergranular cracking in nickel and hydrogen-assisted fracture in pipeline steels and welds. The findings provide new insights into the threshold conditions that govern HE fracture modes and the preferred crack propagation paths, as a function of hydrogen concentration, depending on the hydrogen-containing environment to which the alloys are exposed.

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<sup>\*</sup> I.cupertino-malheiros@imperial.ac.uk

#### Forgeability and Microstructural Evolution of Al-Based Alloys via Biaxial Alternate Forging

Seong-Ho Ha\*, Young-Chul Shin, Bong-Hwan Kim, Young-Ok Yoon, Hyun-Kyu Lim, Shae K. Kim

Korea Institute of Industrial Technology, Incheon 21999, Republic of Korea

\* shha@kitech.re.kr

**Keywords:** Aluminum alloys, Biaxial alternate forging, Microstructure

This study investigates the forgeability and microstructural evolution of two types of aluminum alloys—non-heat-treatable Al-6 wt%Mg and age-hardened 2014-T6—processed through biaxial alternate forging (BAF) at room temperature. Using specially designed octagonal dies, repeated compressive deformation was applied up to 6 passes, and the effects of accumulated strain on cracking behavior, tensile properties, and internal structure were analyzed. For the Al-6 wt%Mg alloy, finite element simulations and experimental observations confirmed that strain concentrated in the core region, forming X-shaped shear bands. Cracks initiated at both ends after the 5 passes. The 2014-T6 alloy withstood up to 4 forging passes, reaching a maximum effective strain of 356%, with significant microstructural changes such as high-density dislocations and band-shaped dislocation clustering observed by transmission electron microscopy. Both alloys demonstrated enhanced tensile strength with increasing forging passes, while elongation decreased. Additionally, TEM analysis of the 2014-T6 alloy revealed the evolution of precipitates ( $\theta$ ' and Q' phases) and dislocation structures under severe plastic deformation. This integrated study highlights the potential of BAF as a unified method for evaluating both forgeability and mechanical performance of aluminum alloys.

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### Investigation of Impact Behavior of Hybrid Composites Obtained by Two Different Methods

#### Serdar Kaveloglu\*, Cem Guzelbulut

Department of Mechanical Engineering, Kahramanmaras Istiklal University, Kahramanmaras 46100, Turkey

**Keywords:** Hybrid composite, Impact, Wire mesh

In this study, the impact behaviors of laminate and sandwich hybrid composites produced with two different methods were investigated. First, four different types of experimental samples were produced using metal wire mesh and carbon fiber reinforced polymer (CFRP) composite: samples without wire mesh, with 0.5 mm thick wire mesh, with 1 mm thick wire mesh and both. Then, low-speed impact tests were applied to all samples at energy levels of 30 and 90 J. According to the experimental data obtained, the samples were not punctured but damaged at the energy level of 30J. Composites having 0.5 mm and 1 mm metal wire mesh made a positive contribution to CFRP composites, but the use of both together was more effective in stiffening the material. At the 90 J energy level, samples with 1 mm and 0.5mm&1mm wire mesh were not punctured, while the others were punctured. The highest contact force was obtained in 0.5mm&1mm sandwich samples at the 90J energy level. Due to the adhesive and bonding gaps, 40laminated composite with the same arrangement.

<sup>\*</sup> serdar.kaveloglu@istiklal.edu.tr

#### Shear Band Patterns by Boundary Integral Equations

#### Davide Bigoni<sup>1</sup>, Domenico Capuani\*<sup>2</sup>

<sup>1</sup> DICAM, University of Trento, via Mesiano 77, I-38123 Trento, Italy

Keywords: shear bands, pre-stress, nonlinear elasticity

Large strain effects are important in a number of engineering problems, and they can influence the behaviour of microelectromechanical systems, geological formations, biological tissues, and structural elements, such as seismic insulators and rubber bearings. High levels of pre-stress may induce shear bands in materials like metals, polymers, granular solids.

Here, boundary integral equations are presented to analyse perturbations in terms of small elastic deformations superimposed upon an arbitrary, homogeneous strain. Plane strain deformations of an incompressible elastic solid are considered, within the elliptic range, assuming the Biot constitutive framework [1]. The integral equations are the means to analyse strain localization as a special case of instability which is induced by perturbations and is found to occur within the elliptic range.

The boundary integral equations are based on Green's functions developed by the Authors for nonlinear incremental elastic deformations [2], [3].

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<sup>&</sup>lt;sup>2</sup> DA, University of Ferrara, via Quartieri 8, I-44121 Ferrara, Italy

<sup>\*</sup> domenico.capuani@unife.it

#### Multimaterial PLA/TPU Structures for Fail-Safe 4D Printed Energy-Dissipative Systems

Rahaf Homssi<sup>1</sup>, Manuel J. Carvajal Loaiza<sup>1</sup>, Maria I. Vallejo Ciro<sup>1</sup>, Albert E. Patterson<sup>2</sup>, Vanessa Restrepo\*<sup>1</sup>

Keywords: Shape Memory Polymer, 4D Printing, Architected Structure

Four-dimensional (4D) printing is an emerging fabrication strategy that integrates the geometric freedom of three-dimensional (3D) printing with time-dependent shape transformations activated by external stimuli. Polylactic acid (PLA) is a widely used 4Dprintable shape memory polymer; however, its brittleness and limited shape recovery following deformation impede its use in durable adaptive structures. To address this limitation, a multimaterial 4D-printed composite combining PLA with thermoplastic polyurethane (TPU) was developed to improve mechanical durability and shape recovery capabilities of PLA. Composite specimens with alternating layers of PLA and TPU were fabricated via dualmaterial fused filament fabrication and subjected to bending and uniaxial tensile tests to evaluate their performance. These laminates were designed to undergo plastic deformation when loaded and to recover their original shape upon heating above PLA's glass transition temperature, thereby activating the shape memory effect. The arrangement of PLA and TPU layers was designed to mitigate crack propagation and enable structural recovery even if some PLA layers fractured, imparting a degree of self-healing behavior. Results showed that increasing the TPU content in the layered architecture yielded more than a threefold improvement in fracture toughness relative to PLA, and that the composites retained full shape recovery after failure. This combination of high toughness and recoverable deformation endows the PLA/TPU 4D-printed structures with robust energy-dissipative, fail-safe characteristics, underscoring their potential for advanced structural applications requiring high damage tolerance and shape adaptability.

<sup>&</sup>lt;sup>1</sup> Department of Mechanical Engineering, Texas A&M University, College Station, Texas

<sup>&</sup>lt;sup>2</sup> Department of Engineering Technology & Industrial Distribution, Texas A&M University, College Station, Texas

<sup>\*</sup> vrestrepo@tamu.edu

### Mechanism and Correction Methods for ANCG in Elastic-Plastic Fracture Toughness Evaluation

#### Jun Suzuki\*, Tomoya Kawabata

Department of Systems Innovation, Graduate School of Engineering, The University of Tokyo, Tokyo 1138656, Japan

**Keywords:** Apparent negative crack growth, *J-R* curve, ductile crack initiation

The investigation of Apparent Negative Crack Growth (ANCG) [1] in cryogenic Reurve testing is a critical endeavor to enhance the accuracy of elastic-plastic fracture toughness evaluations, particularly for materials used in liquid hydrogen storage tanks. ANCG is an unrealistic phenomenon observed during the initial stages of fracture toughness testing, notably when employing the unloading compliance method with Compact Tension (CT) specimens. It manifests as an apparent decrease in crack length, leading to significant overestimation of fracture toughness parameters, such as  $J_{IC}$ . This study aims to elucidate the mechanisms driving ANCG and establish robust correction methods to improve the reliability of fracture toughness assessments for materials like SUS310S and SUS316L, which are vital for cryogenic applications. The research employs a multifaceted approach, combining experimental CT tests and Finite Element Method (FEM) simulations to confirm ANCG's occurrence and investigate its properties. Experimental tests utilize 1TCT specimens with pre-cracks to replicate cryogenic conditions, while FEM calculations model crack behavior and stress distributions. The study hypothesizes that ANCG originates from plastic deformation near the crack tip, influenced by material properties such as work hardening in Face-Centered Cubic (FCC) materials like austenitic stainless steels. Validation of this hypothesis involves comparing rear crack displacement under identical loading conditions and analyzing the correlation between the plastic zone size  $(\omega_{0.1})$  and the displacement difference  $(\Delta V_x)$  at the same load. These analyses reveal that plastic deformation and experimental factors, such as specimenfixture interactions and residual stresses, significantly contribute to ANCG. The study proposes correction methods for ANCG using Swift's equation,  $\sigma = a(1 + \bar{\varepsilon}_p/\alpha)^n$  with parameters a, n, and  $\alpha$  calculated to quantify ANCG magnitude. Tests on SUS310S and SUS316L confirm improved J-R curve accuracy. Specimen thickness and notch shape influence ANCG severity, and corrected  $J_{IC}$  values prevent overestimation critical for cryogenic material selection. Future work includes testing DENT specimens and SUS316L, refining ANCG formulations with varied geometries, and FEM-based ANCG comparisons.

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<sup>\*</sup> suzuki-jun303@g.ecc.u-tokyo.ac.jp

### The Potential Role of Disc Herniation in Wedge Angle Development: A Finite Element Investigation

#### Serhat Onur Çakmak\*1,2, Ercan Gürses<sup>1</sup>

**Keywords:** Functional Spinal Unit (FSU), Adolescent Idiopathic Scoliosis (AIS), Decomposition Based Finite Growth

The etiology of Adolescent Idiopathic Scoliosis (AIS) remains largely unclear, with recent studies suggesting a potential contribution of intervertebral disc abnormalities to spinal curvature development [1]. In this study, we investigate the possible role of intervertebral disc herniation in the formation of vertebral wedge angle, which may contribute to the progression of AIS, by evaluating its mechanical implications within a finite element framework. A mechanobiological growth model based on the stress-dependent Hueter-Volkmann law [2] is implemented within a decomposition-based growth formulation [3], developed within a large deformation framework. Finite element simulations are conducted using an idealized, healthy Functional Spinal Unit (FSU) geometry, which is then compared with a modified version exhibiting disc herniation. The objective is to determine whether disc herniation can induce asymmetrical growth, thereby contributing to the development of a wedge angle characteristic of scoliosis. The results of this comparative modeling approach aim to shed light on the mechanobiological pathways through which disc pathologies may influence asymmetric vertebral body growth contributing to scoliosis in adolescents.

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<sup>&</sup>lt;sup>1</sup> Department of Aerospace Engineering, Middle East Technical University, Ankara 06800, Turkey

<sup>&</sup>lt;sup>2</sup> Department of Aerospace Engineering, Adana Alparslan Türkeş Science and Technology University, Adana 01250, Turkey

<sup>\*</sup> cakmak.onur@metu.edu.tr

### Peridynamic Modeling of Damage Propagation in a Composite Laminate Under Impact Loading

#### Reza Alebrahim\*, Riccardo Panciroli

Università degli studi Niccolò Cusano, Engineering Faculty, Rome, Italy.

**Keywords:** Composite laminates, Impact loading, Peridynamic theory, Crack propagation

The non-local theory of peridynamics (PD) was initially introduced by Silling [1, 2] to overcome the limitations that exist in conventional methods when tackling discontinuous regions. Accurately modeling crack growth in composite structures is critically important in many industries, such as automotive, aerospace, and aviation. The impact phenomenon in aerospace structures is particularly important, as they are susceptible to strikes by objects like flying birds. The non-local theory of PD has provided efficient numerical results over the last decade for modeling composite structures. In this study, the peridynamic modeling of crack propagation in 3-D composite plate structures under both low and high-velocity impact loading is investigated (see Fig. 1). Here, we consider a circular plate structure with clamped boundary conditions, influenced by a solid spherical ball moving downward before the strike occurs. The composite plate is composed of several glass-fiber epoxy layers with varying fiber angles. The force-displacement diagram and damage in the composite plate are thoroughly studied.

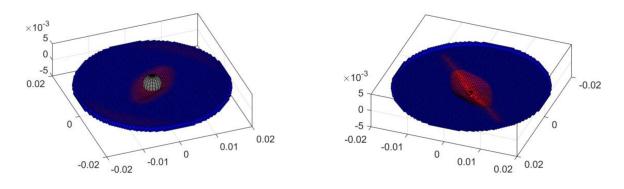


Figure 1: Top (left) and bottom views (right) of a composite beam under impact loading.

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<sup>\*</sup> reza.alebrahim@unicusano.it

### Benefits of Synergistic Effects on Fatigue Strength of Laminated Composites

#### João Parente\*1, Abílio Silva1, Paulo Reis2

- <sup>1</sup> Centre for Mechanical and Aerospace Science and Technologies (C-MAST), Universidade da Beira Interior, Rua Marquês d' ´Avila e Bolama, 6201-001 Covilhâ, Portugal
- <sup>2</sup> University of Coimbra, CEMMPRE, ARISE, Department of Mechanical Engineering, 3030-788 Coimbra, Portugal

**Keywords:** Hybridization, Nano-reinforcement, Fatigue strength, Laminated composite materials

Hybridization of different nano-reinforcements and fiber types in laminated composite materials can be a highly effective strategy to increase fatigue strength and structural durability [1]. This approach takes advantage of the distinct mechanical and morphological characteristics of nanoand macro-scale reinforcements to produce synergistic effects that significantly exceed the performance of conventional composite systems [2, 3] Therefore, to compare these two strategies, this study evaluated the fatigue response of a laminate produced with carbon fibers and an epoxy matrix reinforced with graphene nanoplatelets (GNP) and carbon nanotubes (CNTs) with the results obtained with the same type of resin reinforced with a hybridization of glass and carbon fibers. It was found that the hybridization of nano-reinforcements in the polymer matrix improves load transfer at the fibre-matrix interface, which promotes fatigue life by delaying the initiation of microcracks and increase resistance to crack propagation. On the other hand, the use of hybrid fibers promoted a better mechanical response of the composite, because the contrasting failure modes and stiffness characteristics of the fibers resulted in more uniform stress distribution and delayed the catastrophic failure. Therefore, the hybridization of nano-reinforcements or fibers provides a multiscale reinforcement structure that significantly improves fatigue strength and structural integrity. This methodology represents a promising direction for the design and development of nextgeneration high-performance composite materials.

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<sup>\*</sup> joao.miguel.parente@ubi.pt

### Test and Numerical Simulation on Dynamic Response of Aircraft Structure Impacted by Bird

#### Jun Liu\*, Jiacheng Sheng, Chunyang Zhang

School of Aeronautics, Northwestern Polytechnical University, Xi'an 710072, China

Keywords: FME, dynamic response, bird-strike, material damage

This study systematically investigates aircraft structural design methodologies for bird-strike resistance and ground-based air cannon simulation test methods, with a comprehensive summary of inverse characterization methods and processes for avian constitutive model parameters. The research details three representative engineering cases in aircraft anti-bird-strike design: (1) Experimental and numerical simulation studies on birdstrike resistance of typical aerospace structural materials; (2) Bird-strike testing and numerical modeling of an aircraft panel structure; (3) Weight reduction optimization design for a horizontal tail configuration under bird-strike constraints. Furthermore, the report extends to emerging challenges in drone impacts on aircraft structures and ground-based high-value targets. Through integrated approaches encompassing computational mechanics, experimental validation, and parametric optimization, this work establishes a multidisciplinary framework for enhancing aviation structural safety. The developed methodologies provide critical insights into impact dynamics, material failure mechanisms, and energy dissipation strategies, offering practical references for aerospace engineering applications and regulatory compliance. The key Innovations Highlighted in present report including Hybrid experimentalnumerical protocol combining SPH (Smoothed Particle Hydrodynamics) and FEM (Finite Element Method), Inverse parameter identification algorithm for avian tissue modeling (RMSE < 8.7%), Multiobjective optimization framework balancing structural integrity and weight efficiency, Novel risk assessment matrix for UAV-aircraft collision scenarios.

<sup>\*</sup> liujun top@nwpu.edu.cn

### Finite Element Analyses of Damage Propagation in Filled-Hole Compression Tests of CFRP Laminates

A. Kondo\*1, W. Mikami<sup>2</sup>, Y. Iwahori<sup>2</sup>, E. Hara<sup>3</sup>, H. Katoh<sup>3</sup>

**Keywords:** Compressive Failure, CFRP, Finite element analysis (FEA)

Extensive studies on the strength of CFRP laminates containing holes under compressive loading have been conducted because it depends not only on existence of the hole but also inclusions in the hole [1]. Because the damage mechanisms that govern the difference in strength between the open- and filled-hole specimens have not been completely understood, the factors affecting the strength have been experimentally studied [2]. The previous study revealed that contact conditions between holes and inclusions such as its clearances significantly affect the compressive failure process. In the present study, further investigation by numerical analyses with consideration of the contact conditions were conducted to explain the failure process observed in the experiments. In the previous experiments, quasi-isotropic specimens with stacking sequence of [45/0/-45/90]<sub>25</sub> made with prepreg sheets consisting of T800S-24K Fibers and #3900-2B epoxy resin (Toray Inc.) were used. A hole with diameter D=16.0 mm was drilled in the center of the specimens, and a pin made with tool steel SKH51 with various diameters from 15.6 to 16.0 mm were inserted to the hole. Compression tests were conducted with JIS K7093 fixture. The results demonstrated a clear trend that the failure load increased as the clearance decreased. Finite element analyses were conducted in the present study to model the experiments by using a finite element code Marc (MSC software Inc.). Each ply of the laminated specimens was modeled with different sets of elements and the coordinate system of orthotropic material. When the specimen ultimately failed in the experiments, the damage started at the horizontal edge of the hole and propagated instantly in the transverse direction of the specimens. To numerically analyze this phenomenon, a numerical method considering unstable propagation of the damage was developed. Various analysis cases with different clearances between the hole and pin were calculated. From detailed investigation of the stress distribution around the contact area in the analyses, it was found that the smaller the clearance was, the larger the compressive load was carried through the pin, and hence the load distributed to the specimen decreased. The results demonstrated that the strength of the specimen decreased as the clearance increased, which is the same as the trend observed in the previous experiments.

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<sup>&</sup>lt;sup>1</sup> Department of Mechanical Engineering, Nippon Institute of Technology, Saitama, Japan

<sup>&</sup>lt;sup>2</sup> Department of Mechanical Engineering, Meiji University, Kanagawa, Japan

<sup>&</sup>lt;sup>3</sup> Aviation Technology Directorate, Japan Aerospace Exploration Agency, Tokyo, Japan

<sup>\*</sup> kondo.atsushi@nit.ac.jp

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## Evolution Mechanism of Interfacial Multi-layer Intermetallic Compounds and Failure Behavior of the Al-Au Wire Bonding during Thermal Fatigue

#### Kengfeng Xu\*, Jiao Luo

School of Materials Science and Engineering, Northwestern Polytechnical University, Xi'an 710072, China

Keywords: Heterogeneous bonding, Intermetallic compound, Thermal stress, Thermal fatigue

Al-Au wire bonding is widely used in the electronic chips of space satellite for its excellent conductivity and reliable connection. However, large temperature variations in space cause thermal fatigue and failure in Al-Au wire bonding. To uncover the reason of thermal fatigue in Al-Au wire bonding, thermal storage and thermal cycling are employed to respectively simulate high-temperature and temperature variation conditions in space, and the evolution mechanism of interfacial multi-layer intermetallic compounds (IMCs) and their effects on the failure behavior of Al-Au wire bonding are investigated in this work.

Microstructural analysis shows that multi-layer IMCs form between the Al wire and barrier layer. After thermal storage and thermal cycle process, the Au<sub>8</sub>Al<sub>3</sub> layer transforms into AuAl<sub>2</sub>, and Au pad transforms to a thicker layer containing Au<sub>2</sub>Al and AuAl. Thermodynamic analysis indicates that Au<sub>8</sub>Al<sub>3</sub>, Au<sub>2</sub>Al, AuAl, and AuAl<sub>2</sub> have increasing stability. Small-size, equiaxed AuAl<sub>2</sub> grains form due to high stored energy, while large-size, columnar Au<sub>2</sub>Al and AuAl grains result from slower reaction rate and limited recrystallization. The stack-like formation of AuAl<sub>2</sub> grains is attributed to the balance between driving force and interfacial energy resistance. During thermal storage, thicker IMC layers cause cracking between IMC layers and Au pad, and micro voids form near the IMC layers/barrier layer interface due to Kirkendall effect. Thermal stress results show that plastic deformation of the Al layer slightly affects the thermal stress in other layers during the thermal cycle process. The cyclic stress at the interface with initial cracks ranges from -157 MPa to 114 MPa, facilitating crack propagation. Additionally, micro void grows under cyclic thermal input, weakening interface adhesion. Therefore, bond strength decreases and frequency of bonding lift-off with cracking along the IMC layers/barrier layer interface increases after thermal storage and thermal cycle process. These results provide the guidance for regulating the interfacial IMCs, predicting the thermal stress and improving the thermal fatigue resistance in Al-Au wire bonding.

<sup>\*</sup> kf.xu@mail.nwpu.edu.cn

#### A Generalized Plasticity Framework Capturing Tension—Compression Asymmetry and Shear Anisotropy of Lightweight Sheet Metals

#### Yong Hou\*1, Yannis Korkolis1, Myoung-Gyu Lee2

Keywords: Plastic anisotropy, Sheet metal forming, Yield criterion

Complex loading conditions in lightweight sheet metal forming significantly amplify the challenges of modeling plastic anisotropy [1-2]. In this study, a generalized plasticity framework is introduced to accurately reproduce plastic anisotropy and tensioncompression asymmetry under diverse loading scenarios [3]. This framework incorporates the stress triaxiality dependence of internal state variables and builds upon existing plasticity theories to ensure both computational efficiency and broad applicability. It is compatible with a wide range of yield criteria, including associative models such as Hill48, Yld2000-2d, and Poly6, as well as non-associative models like Stoughton-Yoon2009. Notably, the framework allows adaptive selection of yield functions depending on tensile, compressive or shear loadings, enhancing the accuracy of anisotropic modeling across stress states. Importantly, under non-shear deformation conditions, the yield function, anisotropic parameters, and their optimized or analytical determination remain unchanged [4]. When integrated with simple anisotropic yield functions (e.g., Hill48 with one or two parameters), the framework accurately captures both yield strength and plastic flow behavior in shear-dominated deformation directions. The validity of the proposed framework is thoroughly demonstrated through its predictive capability across metals with different crystal structures, accounting for evolving yield surface asymmetry with respect to strain, temperature, and strain rate. Lastly, the identification process is discussed, highlighting the analytical determination of model parameters using experimental or generic material data from various loading modes, including uniaxial tension, compression, plane strain, and pure shear.

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<sup>&</sup>lt;sup>1</sup> Institute of Forming Technology and Lightweight Components (IUL), TU Dortmund University, Dortmund 44227, Germany

<sup>&</sup>lt;sup>2</sup> Department of Materials Science and Engineering and RIAM, Seoul National University, Seoul 08826, South Korea

<sup>\*</sup> yong.hou@iul.tu-dortmund.de

#### Hardness Enhancement and Deformation Mechanisms in the Surface Layer of TB6 Alloy Hole Treated by Laser Shock Peening

#### Zihui Luo\*, Kengfeng Xu, Jiao Luo

School of Materials Science and Engineering, Northwestern Polytechnical University, Xi'an 710072, China

\* luozihui@mail.nwpu.edu.cn

Keywords: Laser shock peening, TB6 alloy, Hardness, Deformation microstructure

Laser shock peening (LSP) treated TB6 alloy is a promising candidate for bearing mounting holes in helicopter rotor hubs, owing to its high strength and excellent fatigue resistance. It is essential to understand the deformation mechanisms of TB6 alloy induced by LSP for tailoring microstructures with enhanced fatigue performance. In this work, the surface hardness and underlying microstructural mechanisms of LSP-treated TB6 alloy hole are investigated.

Microhardness measurements show that at 200% coverage, increasing the laser energy density from 7.22 GW·cm $^{-2}$  to 8.84 GW·cm $^{-2}$  and 10.83 GW·cm $^{-2}$  leads to corresponding surface microhardness increments of 23.58 HV, 28.74 HV and 32.82 HV, respectively. Microstructural analysis reveals that in LSP-treated TB6 alloy hole, the primary  $\alpha$  grains are refined, and dislocation pileups occur on the  $\beta$  side of the  $\beta/\alpha$  phase boundary, with the dislocations in the  $\beta$  phase identified as edge dislocations on the  $\bar{1}10<11\bar{1}>$  slip system. Besides, needle-like  $\alpha'$  martensite forms within the  $\beta$  matrix, with  $\alpha'$  martensite exhibiting  $10\bar{1}1<10\bar{1}\bar{2}>$  twinning. Crystallographic calculations indicate that under shock loading, the  $\bar{1}10<11\bar{1}>$  slip system with the highest Schmid factor in the  $\beta$  phase is activated first. Furthermore, the activated  $\bar{1}10<11\bar{1}>$  slip system of the  $\beta$  phase competes with the  $\bar{1}10<110>$  shear required for the  $\beta->\alpha'$  transformation, thereby promoting the formation of  $\alpha'$  martensite in the  $\beta$  matrix. Interface strengthening due to refined primary  $\alpha$  phase,  $\alpha'$  martensite,  $\alpha'$  twin boundaries, as well as dislocation strengthening lead to enhanced surface hardness. These findings offer insights for the precise tailoring of surface microstructures in LSP-treated TB6 alloy holes

### Crystal Plasticity Modeling of Dwell Fatigue in Dual-phase Ti-6Al-4V Microstructures

#### Sadik S. Acar\*, Mehmet Y. Yamak, Tuncay Yalçinkaya

Department of Aerospace Engineering, Middle East Technical University, Ankara 06800, Türkiye

Keywords: Dwell fatigue, Crystal plasticity, Ti-6Al-4V

This study examines the dwell fatigue behavior of dual-phase titanium alloys through a crystal plasticity modeling approach, with emphasis on the roles of microstructural features and loading conditions. Titanium alloys are widely used in the cold sections of gas turbine engines, where components experience loading histories that include constant-stress dwell periods. The reduction in fatigue life caused by such stress holds, known as dwell sensitivity, is mainly attributed to microstructural properties and the applied loading history. In this study, representative volume elements (RVEs) with varying  $\beta$  phase volume fractions are constructed to simulate grain scale mechanical response. A phenomenological crystal plasticity model is employed in numerical simulations of stress-controlled cyclic loading within the DAMASK framework [1]. Simulations reveal that, under stress-controlled cyclic loading, RVEs with higher  $\beta$  phase content exhibit less strain accumulation over successive cycles. Introducing dwell periods has an amplifying effect on cyclic strain accumulation and local stress concentrations, particularly in microstructures with low eta phase content. Dwell holds are shown to alter homogenized and local slip system activities on various slip families. Number of cycles to failure is estimated for each microstructure, using the Basquin-Coffin-Manson relation combined with the Palmgren-Miner cumulative damage rule. This modeling framework contributes to the understanding of material behavior under dwell fatigue loading and supports the design of titanium alloys with improved resistance to the severe conditions encountered in gas turbine applications.

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<sup>\*</sup> sadik.acar@metu.edu.tr

### Coupled Thermal—metallurgical—mechanical Simulation of TMCP for Uniform Grain Structure in Wind Turbine Steel Plates

- <sup>1</sup> Mechanical Engineering, School of Engineering, College of Science and Engineering, University of Galway
- <sup>2</sup> Ryan Institute for Environmental, Marine and Energy Research, University of Galway
- <sup>3</sup> I-Form Advanced Manufacturing Research Centre, Ireland

**Keywords:** Thermo-mechanical control process (TMCP), Finite element (FE), Materials modelling

Addressing the increasing demand for renewable energy remains a major engineering challenge, particularly in the pursuit of reducing fossil fuel consumption and mitigating environmental impacts such as air pollution. The offshore wind energy sector—both fixed-bottom and floating systems—is expanding rapidly. A critical barrier to this growth is the need to scale up structural components, including towers and monopiles, to support the larger loads associated with next-generation turbine nacelles. One of the key limitations in this upscaling effort is the size-dependent mechanical performance of rolled steel plates, particularly under welded conditions. Thermo-mechanical controlled processing (TMCP) offers a promising solution, as it enables the enhancement of mechanical properties and microstructural control during the hot rolling of steel, making it a widely adopted technique in the production of high-performance structural steels.

This paper presents the development of a finite element thermal—metallurgical model that serves as a key input to a coupled thermal—mechanical framework for investigating the mechanical response and metallurgical evolution of steel plates subjected to multi-pass thermomechanical controlled processing (TMCP). Particular attention is given to incorporate critical metallurgical mechanisms that occur during TMCP to enable accurate prediction of mechanical behaviour both during and after processing. A unified, physically-based viscoplastic constitutive model is employed to capture the thermo-mechanical response of the material. The formulation integrates key process variables—such as cooling rates and rolling pass temperatures—into the metallurgical mechanisms, including static and dynamic recovery, dislocation density evolution, static recrystallization, and grain structure evolution, to predict the mechanical behaviour during and after TMCP. The influence of these parameters on mechanical performance is systematically studied to evaluate their role in achieving uniform grain size across varying plate thicknesses. Additionally, this work provides representative TMCP stress—strain histories to support the design of TMCP-specific Gleeble simulation experiments aimed at understanding microstructure distribution.

<sup>\*</sup> pedram.parandavar@universityofgalway.ie

### A Framework for Computational Homogenization of Porous Shape Memory Polymers

#### Alperen Demirtaș\*1, Cagri Ayranci<sup>2</sup>, Ercan Gürses<sup>1</sup>

**Keywords:** porous shape memory polymers, computational homogenization, constitutive modeling

Shape memory polymers (SMP) are part of the smart materials family. SMPs can be shaped to store a temporary shape and the original shape can be recalled upon application of external stimuli, such as electric and magnetic fields, humidity, temperature, and light [1]. They are used in several industries, such as medical, aerospace, robotics, and textile, in the form of composites, foams, and 3D-printed parts. The shape recovery and fixity behavior arise from variations in the thermomechanical properties of hard and soft segments of the SMP above and below the glass transition temperature. In the constitutive modeling of SMPs, the standard linear viscoelastic (SLV) model has been widely used. However, the SLV model fails to accurately capture material behavior, particularly due to its neglect of internal friction. To address this limitation, slip mechanisms have been introduced in recent models [2]. These improved constitutive models show better agreements with the experimental results of up to 20 percent applied strain. Despite the availability of experimental studies, there are relatively few efforts to extend such modeling approaches to porous SMPs and SMP composites. In this study, a computational homogenization framework for porous SMPs is proposed to determine the homogenized material properties of the constitutive model developed in [3]. The numerical results obtained using the proposed homogenization framework will be compared with the experiments

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<sup>&</sup>lt;sup>1</sup> Department of Aerospace Engineering, Middle East Technical University, Ankara 06800, Turkey

<sup>&</sup>lt;sup>2</sup> Mechanical Engineering Department, University of Alberta, Alberta, Canada

<sup>\*</sup> alperen@metu.edu.tr

### Thermo-Mechanical Fatigue Life Prediction for the Critical Features of a Turbine Blade and a Nozzle Guide Vane

#### Umud Esat Öztürk\*1, Abdurrahim Kubat<sup>2</sup>, Thomas Seifert<sup>3</sup>

- <sup>1</sup> TUSAŞ Engine Industries, Inc., Istanbul, Turkey
- <sup>2</sup> TUSAŞ Engine Industries, Inc., Eskisehir, Turkey
- <sup>3</sup> Offenburg University of Applied Science, Offenburg, Germany

**Keywords:** Cyclic Plasticity, Viscoplasticity, Thermo-Mechanical Fatigue (TMF)

In a gas turbine engine, nozzle guide vanes direct the hot air flow onto the turbine blades and increase the speed of the air. Turbine blades extract the energy from the high temperature, high pressure gas and convert to mechanical energy. Nozzle guide vanes are stationary and mainly subjected to thermal expansion and aerodynamic forces, whereas the dominant loading mode for rotating turbine blade is the centrifugal force in addition to the thermal expansion and aerodynamic forces. Hence, critical features of the nozzle guide vanes are dominantly under displacement-controlled cyclic loading, while force-controlled cyclic loading is more valid for turbine blades.

This paper presents a parametric comparison of different constitutive modelling approaches for cyclic thermo-mechanical loading. Linear elastic modelling and Chaboche type viscoplastic modelling approaches employed for cyclic plastic deformation and stress-strain prediction. Results of stress-based low-cycle fatigue (LCF) and creep approaches and thermomechanical damage models are compared for both displacement- and force-controlled loading conditions at two temperatures for the Mar-M247 nickel-based alloy.

<sup>\*</sup> Abdurrahim.Kubat@tei.com.tr

### Evaluation of the Accuracy of Various Forming Limit Curve Models for Thick Hot Rolled High-Strength Low-Alloy S700MC Steel

#### Mehmet Okan Görtan\*1, Melih Tuyan<sup>2</sup>

- <sup>1</sup> Department of Mechanical Engineering, Hacettepe University, Ankara 06800, Turkey
- <sup>2</sup> Teknorot Steering and Suspenison Parts, Düzce 81060, Turkey

**Keywords:** Forming limit curve, Hot rolled steel, Fracture modelling Reducing vehicle weight has emerged as a key driving force in the evolution of the automotive industry over the past two decades. As a result, the use of high-strength steels in the structural parts of automobiles has increased rapidly. While newly developed advanced high-strength steel (AHSS) grades are preferred in applications where thinner sheets can be utilized, conventional hot-rolled high-strength low-alloy (HSLA) steels are still commonly chosen for components exposed to fatigue loading, such as suspension elements. In HSLA steels, an increase in mechanical strength typically leads to a reduction in ductility, which causes cracking in the sheet material to occur at relatively low strain levels during forming operations.

In the present study, investigations were carried out on the forming behavior of hot-rolled HSLA S700MC steel with a thickness of 4.0 mm. For this purpose, the mechanical properties of the material were determined through standardized tensile tests. The obtained mechanical data were then used in empirical equations commonly applied to estimate forming limit diagrams (FLDs) under multiaxial strain conditions, particularly for thin steel and aluminum sheets. The FLDs derived from different empirical models were integrated into the AutoForm software. Using this program, a finite element analysis (FEA) of the forming process of a sheet suspension arm component produced via stamping was conducted. Subsequently, forming tests were performed using a die manufactured for the same component, and the accuracy of the different forming limit curves in predicting the formability limits of hot-rolled HSLA S700MC steel was evaluated.

<sup>\*</sup> okangortan@hacettepe.edu.tr

### Numerical Analysis on Shear Band Formation in High Purity Niobium during ECAE based on Material Flow

Hiromasa Yoshizumi\*, Yusei Watanabe, Takaaki Ikeda, Motohiro Yuasa, Hiroyuki Miyamoto

Faculty of science and engineering, Doshisha University, 1-3 Miyakodani, Tatara, Kyotanabe, Kyoto, 610-0394, Japan

Keywords: Niobium, equal-channel-angular extrusion, Shear band

Pure niobium (Nb) is an attractive material for use in superconducting cavities. High hydro formability is demanded to fabricate cavities. Grain size refinement is an effective method to enhance formability in metallic materials. However, the body-centered cubic (bcc) structure and the high stacking fault energy (SFE) of Nb suppress the recrystallization (RX) and grain size refinement. A previous study has reported that shear band introduction using severe plastic deformation (SPD) facilitates RX [1] since a shear band is a preferential site for nucleation. Nevertheless, the shear band formation has been studied mainly in the rolling, while the formation mechanism in other processes remains unrevealed. Thus, this study investigates the shear band formation during equal-channel-angular extrusion (ECAE). A high-purity Nb was subjected to ECAE at room temperature. The microstructure was observed by electron backscattering diffraction (EBSD). The deformation during ECAE was numerically analyzed by a material flow model [2]. The shear bands with a crystallographic orientation rotated 50 ° from the matrix were observed. Numerical analysis shows that the matrix orientation changes by rigid body rotation and slip activity, whereas shear band formation is not obtained from them. This result suggests that the shear band is caused by the localized inhomogeneous deformation

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<sup>\*</sup> cyjk1504@mail4.doshisha.ac.jp

### Microstructural Evolution of EBM-Manufactured Ti6Al4V Under Incremental Tensile Loading: A Combined EBSD-XRM Approach

<u>Roberto Perrone</u>\*1, Mirko Sgambetterra<sup>1</sup>, Flavio Cognigni<sup>2</sup>, Matteo Trombettoni<sup>2</sup>, Daniele Mirabile Gattia<sup>3</sup>, Angelo Tatì<sup>3</sup>, Marco Rossi<sup>4,5</sup>

**Keywords:** Ti6Al4V, Additive Manufacturing, Electron Beam Melting, EBSD, XRM, Plastic Deformation, MOS

The titanium alloy Ti6Al4V is widely used in the aerospace industry due to its high strength, low density, high fracture toughness and excellent corrosion resistance [1]. Electron Beam Melting (EBM), an additive manufacturing technique offering near-net-shape capabilities and tailored microstructures, has become an increasingly attractive method for producing Ti6Al4V components [2]. In this study, dog-bone tensile specimens were manufactured using a GE Arcam A2X EBM system. The aim is to investigate the microstructural response of the alloy to plastic deformation using a combination of ex-situ Electron Backscatter Diffraction (EBSD) and X-ray Microscopy (XRM). Tensile tests were carried out with intermediate interruption points at different strain to capture the evolution of the microstructure during plastic deformation. At each step, EBSD maps were acquired to analyze grain deformation, misorientation distributions, and the evolution of the mean orientation spread (MOS). Furthermore, XRM was carried out to explore possible subsurface damage initiation, necking and porosity evolution. This approach provides complementary insight to surface-sensitive EBSD, potentially revealing mechanisms such as strain accumulation or the activation of specific slip systems. These results contribute to a deeper understanding of the deformation behavior of Ti6Al4V produced by EBM, supporting the optimization of process parameters and post-processing methods for critical load-bearing applications

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<sup>&</sup>lt;sup>1</sup> Italian Air Force - Aeronautical and Space Test Division, via Pratica di Mare, 00071 Pomezia (RM), Italy

<sup>&</sup>lt;sup>2</sup> Carl Zeiss S.p.A, via Varesina 162, 20156 Milan, Italy

<sup>&</sup>lt;sup>3</sup> Laboratory for technologies and materials for additive manufacturing, SSPT-TIMAS-MADD, Department for Sustainability, ENEA Casaccia Research Center, via Anguillarese 301, 00123 Rome, Italy

<sup>&</sup>lt;sup>4</sup> Department of Basic and Applied Sciences for Engineering (SBAI), Sapienza University of Rome, via Antonio Scarpa 14, 00161 Rome, Italy

<sup>&</sup>lt;sup>5</sup> Research Center on Nanotechnologies Applied to Engineering (CNIS), Sapienza University of Rome, Piazzale Aldo Moro 5, 00185 Rome, Italy

<sup>\*</sup> robi.perrone@gmail.com

### Transferability of Fracture Resistance from Sub-sized to Standard Specimens in Eurofer97

#### I. Umay Aydiner\*1, Can Erdogan1, Dmitry Terentyev2, Tuncay Yalçinkaya1

Keywords: nuclear material, mini-DCT, J-integral, size correction, fracture resistance

Fusion energy is considered a promising source for future clean energy. Ensuring the structural integrity of nuclear reactor materials is critical, as they are typically subjected to extreme conditions such as irradiation and high temperatures. EUROFER97 steel has been identified as a candidate material for the tritium breeder blankets in fusion reactors due to its favorable mechanical properties. Because of space constraints, sub-sized specimens are often used to measure fracture resistance. However, these experiments yield results that deviate from those obtained with standard geometries, as defined in ASTM E1820 [1], primarily due to differences in constraint conditions. Therefore, establishing reliable methods to derive standardized resistance curves from miniaturized specimen tests is both cost-effective and essential for safety.

In this study, size-correction methods based on numerical simulations and empirical relations between standard and sub-sized specimens are applied. Both sub-sized and standard specimen tests [2] are analyzed numerically. After reproducing experimental resistance curves via finite element analysis, the results from sub-sized specimens are corrected to match those of standard specimens using empirical correction relations. Two different constraint parameters—the R-parameter and stress triaxiality—are investigated for size correction. Their effectiveness is investigated by comparing corrected results with experiments, as well as by evaluating their ability to capture both in-plane and out-of-plane constraint effects.

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Department of Aerospace Engineering, Middle East Technical University, Ankara 06800, Turkey
 Structural Materials Group, Institute of Nuclear Materials Science, SCK CEN, 2400 Mol, Bel-

<sup>\*</sup> umay.aydiner@metu.edu.tr

### Self-Magnetic Flux Leakage Assessment Technique for Early Fatigue Detection in ASTM A36 Steel

#### Azli Arifin\*, Shahrum Abdullah, Ahmad Kamal Ariffin, Salvinder Singh Karam Singh

Department of Mechanical and Manufacturing Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM Bangi, Selangor, Malaysia

**Keywords:** magnetic flux leakage, fatigue, stress concentration zone

Early detection of fatigue damage in various structural materials is essential for ensuring the safety and reliability of engineering components. Conventional non-destructive evaluation techniques, such as acoustic emission and ultrasonic testing methods, have been widely applied but often exhibit limitations, including sensitivity to surface conditions and limited ability to detect subsurface changes during initial fatigue stages [1]. This study investigates the use of the self-magnetic flux leakage (SMLF) technique as a more accessible and sensitive method for identifying stress concentration and early fatigue detection [2,3]. Cyclic fatigue tests were conducted on ferromagnetic steel, ASTM A36, at 10 Hz with stress ratios of 0.1, 0.4 and 0.6. Magnetic field signal components, Hp(x) and Hp(y), were measured every 5,000 cycles using SMLF, alongside detailed visual inspections to identify permanent deformation. Results revealed distinct and noticeable changes in Hp(x) and Hp(y) signals between 65,000 and 110,000 cycles across the stress ratios, well before any visible damage was observed. The findings clearly demonstrate that SMLF can identify magnetic anomalies associated with early microstructural fatigue failure. Thus, the method shows potential as a non-destructive tool for early-stage fatigue detection in ferromagnetic steels.

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<sup>\*</sup> azli@ukm.edu.my

#### Influence of Plasticization and Crack Formation in the Beam Crosssection at the Column Face on the Shear Force in the Beam-column Connection - Part I, Symmetrical Cross-section

#### Albena Doicheva\*

Department of Technical Mechanics, University of Architecture, Civil Engineering and Geodesy, Sofia 1046, Bulgaria

\* doicheva fhe@uacg.bg

**Keywords:** shear force in a symmetrical cross section, analytical simulation, uniformly distributed load occupying various possible positions, larges deformations, crack on the face of the column.

During seismic events, the connection between the beam and the column is a particularly vulnerable element in frame structures. In recent years, the shear force in the connection has continued to be cited as a cause of damage and destruction in frame structures. Research over the past six decades has not led to the establishment of a uniform procedure for analytically determining the shear force and shear strength in the connection. One of the reasons is the difficulty in calculating the forces transmitted from the beams to the columns [1]. In the current Eurocode 2, the shear force is determined capacitively. This article discusses a mathematical model of the beam that allows all dimensions of the beam in height to be taken into account, as well as the characteristics of the material from which the beam is made [2-6]. This study considers a cantilever beam with a symmetrical cross-section, loaded with a linearly distributed load, occupying various possible positions. The solution is performed using Menabrea's theorem, and the reactions of the beam supports along the height of the side and edge are determined. The results for a selected beam are shown. The shear force is calculated using the exact forces determined by the newly derived formulas. To confirm the results, a comparison is made between the new shear force and that determined by the approximate method recommended in the literature. The difference is up to 15%. A comparison is also made with the shear force determined according to Eurocode 2. The difference varies from -50% to +60%.

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#### Influence of Plasticization and Crack Formation in the Beam Crosssection at the Column Face on the Shear Force in the Beam-column Connection - Part II, Asymmetrical Cross-section

#### Albena Doicheva\*

Department of Technical Mechanics, University of Architecture, Civil Engineering and Geodesy, Sofia 1046, Bulgaria

\* doicheva fhe@uacg.bg

**Keywords:** shear force in an asymmetrical cross section, analytical simulation, uniformly distributed load occupying various possible positions, larges deformations, crack on the face of the column.

The connection between the beam and the column is often "responsible" for damage and destruction in frame structures. The reason is the shear force, which still cannot be determined analytically, making it difficult to analytically determine the shear strength in the beam-column connection [1]. In the current Eurocode 2, the shear force is determined capacitively, which does not allow its specific value to be determined under a specific load. This article discusses a mathematical model of the beam that allows all dimensions of the beam in height to be taken into account, as well as the characteristics of the material from which the beam is made [2-5]. This study considers a cantilever beam with an asymmetrical cross-section, loaded with a linearly distributed load, occupying various possible positions. The solution is performed using Menabrea's theorem, and the reactions of the beam supports along the height of the side and edge are determined. The results for a specific, selected beam are shown. The shear force is calculated using the exact forces determined by the newly derived formulas. To confirm the results, a comparison is made between the new shear force and that determined by the approximate method recommended in the literature. The difference is up to 15%. A comparison is also made with the shear force determined according to Eurocode 2. The difference varies from -60% to +70%.

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#### **Dynamic Behavior of Copper Using Modified RMI Test**

Mirko Sgambetterra\*<sup>1</sup>, Roberto Perrone<sup>1</sup>, Andrea Ceccacci<sup>2</sup>, Sara Ricci<sup>2</sup>, Gianluca Iannitti<sup>2</sup>, Gabriel Testa<sup>2</sup>

Keywords: RMI, SEM, metal strength

In metal literature, an upturn in strength has been generally observed at strain rates in the range of  $10^3$ - $10^5$  s<sup>-1</sup>, but there's not universal agreement on the underlying reasons for this phenomenon. The discrepancies observed are thought to stem from the various techniques employed to cover this strain rate range, including plate impact experiments. [1] Indeed, the effects of high-pressure experiments on material strength are still a major concern. The "relatively" low pressure obtained by Richtmyer-Meshkov instability (RMI) experiments, used to measure strength, caused this technique to receive considerable attention in recent years. In RMI experiments, it has been both theoretically and experimentally proved that strain rate for a given shock is inversely proportional to the length scale of the sine wave perturbations if the amplitude to wavelength ratio is held fixed. Typically, in a gas-gun driven experiment, strain rate over 10<sup>7</sup> s<sup>-1</sup> could be achieved with a perturbation of a hundred microns length [2]. With the aim to achieve a lower pression while slightly compromising on strain rate, and obtain also larger fragments easier to be measured by means of Photon Doppler velocimetry, in this study we explored the application of RMI experiments to investigate the mechanical response of annealed copper with larger perturbation. Numerical simulations indicated that material points along the longitudinal axis represent various stages of a shared temperature-compensated deformation history. The fragments were recovered and both fracture surface and microstructure were analyzed.

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<sup>&</sup>lt;sup>1</sup> Italian Air Force - Aeronautical and Space Test Division, Rome, Italy

<sup>&</sup>lt;sup>2</sup> University of Cassino and Southern Lazio

<sup>\*</sup> mirko.sgambetterra@gmail.com

### Effect of Flow Forming on the Aging Behavior and Mechanical Properties of Inconel 718

#### Mehmet Mutlu\*1,2, Aptullah Karakaş1,2, Murat Baydoğan1

**Keywords:** Flow forming, Inconel 718, Aging behavior

Flow forming, also known as roll flo or flow turning, is an advanced metalworking process that enables the production of seamless, dimensionally precise, and rotationally symmetric components by plastically deforming preforms on a rotating mandrel [1]. This process offers numerous advantages, including enhanced mechanical properties, high surface quality, monolithic designs with integral features, and significant reductions in welding requirements, weight, and material waste, making it highly suitable for manufacturing aerospace-grade Inconel 718 components. In this study, Inconel 718 material in its conventional AMS 5662 condition was flow-formed as a cylindrical tubular preform to reduce its wall thickness from 4 mm to 2.65 mm. To investigate the effect of cold deformation on the alloy's aging response and mechanical properties, aging heat treatment, tensile testing, and microstructural analysis were performed. The findings revealed that the strength of the flowformed material before aging was similar to that of the conventionally aged preform material, with both showing an ultimate tensile strength (UTS) of approximately 1400 MPa. However, while the aged preform exhibited an elongation of about 12%, the flowformed material showed significantly lower ductility, with elongation reduced to around 6%. Cold forming combined with subsequent aging resulted in a UTS of 1800 MPa, while elongation was further reduced to 4%, indicating a substantial loss in ductility. Post-flow forming recrystallization treatment at 870°C successfully mitigated the adverse effects on ductility, restoring it to 12-14% while achieving AMS 5663-standard strength and elongation values. These findings demonstrate that flow forming can effectively optimize the strength-ductility balance in Inconel 718 alloys and enable achieving the target mechanical properties after final heat treatment

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<sup>&</sup>lt;sup>1</sup> Department of Metallurgical and Materials Engineering, Istanbul Technical University, Istanbul 34469, Türkiye

<sup>&</sup>lt;sup>2</sup> Repkon Machine and Tool Industry, Istanbul 34980, Türkiye

<sup>\*</sup> mehmet.mutlu@repkon.com.tr

### A Three Dimensional Multi-Physics Model of Grain Microstructure Evolution with Dislocation Induced Spontaneous Grain Nucleation

#### Izzet Tarik Tandogan\*1, Michael Budnitzki1, Stefan Sandfeld1,2

Keywords: Nucleation, Recrystallization, Cosserat Crystal Plasticity

The grain microstructure of metals evolves significantly during thermo-mechanical treatment as a result of inhomogeneous viscoplastic deformation and recrystallization. Severe plastic deformation causes texture formation, fragmentation of grains into sub-grains and bands of localized deformation. The highly non-uniform deformed state determines the evolution of microstructure throughout subsequent heat treatment, where grain boundaries migrate at elevated temperatures. In addition, new dislocation-free grains nucleate and grow forming a recrystallized microstructure, with defects such as triple-junctions and secondphase particles being preferred nucleation sites. This challenging multi-physics problem is usually tackled by employing specialized numerical models in a staggered scheme. A common approach is to use crystal plasticity for mechanical deformation and phase field models for recrystallization. However, the nucleation has to be handled as another separate step, where dislocation-free seeds are planted in an ad-hoc manner based on trigger criteria such as critical dislocation density, stress or strain. In this work, we show that a unified monolithic thermo-mechanical framework [1], is naturally capable simulating dislocation induced spontaneous nucleation at grain boundaries. It couples Cosserat crystal plasticity with a Henry-Mellenthin-Plapp orientation phase field [2], which captures both curvature and deformation driven grain boundary motion, and can account for inclination-dependent grain boundary energies. The model is implemented in 3D for small deformations, and its capabilities are illustrated based on numerical examples of single crystals as well as periodic bi- and polycrystals. Advanced mechanisms such as strain-induced boundary migration, subgrain coarsening and coalescence are replicated.

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<sup>&</sup>lt;sup>1</sup> Institute for Advanced Simulations – Materials Data Science and Informatics (IAS-9), Forschungszentrum Jülich GmbH, 52425 Jülich, Germany

<sup>&</sup>lt;sup>2</sup> Chair of Materials Data Science and Materials Informatics, Faculty 5 – Georesources and Materials Engineering, RWTH Aachen University, 52056 Aachen, Germany

<sup>\*</sup> t.tandogan@fz-juelich.de

# Impact of the Formation and Growth of Crack in the Beam, on the Face of the Column, to the Shear Force in the Joint for Two Linearly Distributed Loads Occupying Different Possible Positions - Part I, Symmetrical Cross-section

#### Albena Doicheva\*

Department of Technical Mechanics, University of Architecture, Civil Engineering and Geodesy, Sofia 1046, Bulgaria

\* doicheva fhe@uacq.bg

**Keywords:** shear force in a symmetrical cross section, analytical simulation, two linearly distributed load occupying various possible, positions, large deformations, crack on the face of the column

Earthquakes actions often lead to damage in frame structures caused by shear stresses in the beam-column connection [1]. The determination of shear stresses requires the exact knowledge of the shear forces. In the current Eurocode 2, this shear force is determined capacitively, which means that we cannot calculate it exactly as a result of the applied load. This paper introduces a mathematical model of the beam, which takes into account the dimensions of the beam on the height, as well as the material properties of the materials used [2-6]. This study considers a frame beam with a symmetrical cross-section. The loading is with two linearly distributed loads, symmetrically located on the beam. The derivations of the formulas are carried out using the Menabrea's theorem. The support reactions between the beam and the column, along the lateral edge of the beam, are determined. The results for a specific beam are shown. The shear force is calculated using the exact forces determined by the newly derived formulas. To confirm the results, a comparison is made between the new shear force and that determined by the approximate method recommended in the literature. The difference is up to 15%. A comparison is also made with the shear force determined according to Eurocode 2. The difference varies from -20% to +25%.

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# Impact of the Formation and Growth of Crack in the Beam, on the Face of the Column, to the Shear Force in the Joint for Two Linearly Distributed Loads Occupying Different Possible Positions - Part II, Asymmetrical Cross-section

### Albena Doicheva\*

Department of Technical Mechanics, University of Architecture, Civil Engineering and Geodesy, Sofia 1046, Bulgaria

\* doicheva\_fhe@uacg.bg

**Keywords:** shear force in an asymmetrical cross section, analytical simulation, two linearly distributed load occupying various possible, positions, large deformations, crack on the face of the column

Damage to frame structures during earthquakes is often the result of exceeding the shear stresses at the beam-column connection [1]. The determination of shear stresses requires the exact knowledge of the shear forces. In the current Eurocode 2, these shear forces are determined capacitively, which means that we cannot calculate them exactly as a result of the applied load. This paper introduces a mathematical model of the beam, which takes into account the dimensions of the beam on the height, as well as the material properties of the materials used [2-6]. This study considers a frame beam with an asymmetrical cross-section. The loading is with two linearly distributed loads, symmetrically located on the beam. The derivations of the formulas are carried out using the Menabrea's theorem. The support reactions between the beam and the column, along the lateral edge of the beam, are determined. The results for a specific beam are shown. The shear force is calculated using the exact forces determined by the newly derived formulas. To confirm the results, a comparison is made between the new shear force and that determined by the approximate method recommended in the literature. The difference is up to 15%. A comparison is also made with the shear force determined according to Eurocode 2. The difference varies from -22% to +28%

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# Micro-Mechanism Informed Artificial Neural Network Framework for Hot Forming Constitutive Modeling of Aluminum Alloys

# $\underline{\text{Yo-Lun Yang}}^{*1}$ , Cheng-Ling Tai $^2$ , Wan-Ling Chen $^3$ , Sundarakannan Rajendran $^{1,4}$ , Vigneshwaran Shanmugam $^1$

- <sup>1</sup> Graduate Institute of Manufacturing Technology, National Taipei University of Technology, Taipei, Taiwan
- <sup>2</sup> Department of Materials Science and Engineering, National Taiwan University, Taipei, Taiwan
- <sup>3</sup> Metal Processing R D Department, Metal Industries Research and Development Centre, 1001 Kaonan Highway, 81160 Kaohsiung, Taiwan
- <sup>4</sup> Department of Mechanical Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai 602105, India

Keywords: Artificial neural network, Constitutive modelling, Thermomechanical coupling

Accurate prediction of material behaviour under variable thermal-mechanical conditions remains a central challenge in hot forming of temperature-sensitive alloys. This study introduces a novel Micro-Mechanism Informed Artificial Neural Network (MMIANN) framework for constitutive modelling of AA7075 aluminium alloy during Hot Form Quench (HFQ) processing. Unlike conventional models that rely on fixed empirical formulations, MMIANN integrates microstructural evolution mechanisms—dynamic recrystallisation, dislocation density evolution, and precipitation kinetics—into a hybrid physics-neural framework. The model is trained using data from controlled thermal-mechanical tests performed on a Gleeble 3800 simulator, incorporating simultaneous deformation and quenching across a range of cooling rates (25-75°C/s). The neural network architecture includes dedicated branches for predicting temperature, stress, grain size, and subgrain evolution, all constrained by thermodynamic laws to ensure physical admissibility. Adaptive blending coefficients balance data-driven learning with physics-based modelling, enabling robust extrapolation across the parameter space. Validation against experimental stress-strain data and EBSD-based microstructural measurements demonstrates exceptional predictive accuracy, with R<sup>2</sup> values exceeding 0.96 for all outputs. Processing maps generated from the trained MMIANN reveal the underlying mechanism transitions that govern material response, identifying critical regimes where work hardening, recovery, and precipitation interact. Importantly, the framework captures the complex coupling between strain-induced heating and external cooling, enabling accurate temperature evolution predictions during deformation. The MMIANN approach offers a powerful and generalisable tool for constitutive modelling under non-isothermal conditions. By embedding microstructural physics into neural networks, it bridges the gap between mechanistic understanding and data-driven modelling, advancing predictive capabilities for advanced forming processes in aerospace and automotive applications.

<sup>\*</sup> y.yang@ntut.edu.tw

# A Comparative Study of Optimization Methods for Crystal Plasticity Constitutive Models

### Sadik S. Acar\*, Tuncay Yalçinkaya

Department of Aerospace Engineering, Middle East Technical University, Ankara 06800, Türkiye

Keywords: Crystal plasticity modeling, Parameter identification, Optimization methods

The reliability of crystal plasticity simulation results depends strongly on the accurate identification of constitutive parameters, which remains a challenge due to the number of required simulations, nonlinear nature of the complex models and the range of loading conditions that some models are expected to perform well consistently. Over the years, various optimization methods have been employed to calibrate crystal plasticity parameters, ranging from classical gradient-based methods to global search methods and surrogate-based approaches. Each of these techniques comes with certain advantages and limitations with respect to convergence, computational efficiency, and robustness to noisy or incomplete data. At the same time, the selection of the constitutive framework, whether a phenomenological power-law model or a combined isotropic-kinematic hardening model, further influences the complexity of the calibration problem. In this work, the parameter identification problem for crystal plasticity is evaluated thoroughly by systematically considering three optimization methods in combination with two constitutive models. The aim is not only to measure their relative performance but also to provide an understanding into how selected optimization method and constitutive law have a coupled effect. The workflow consists of simulations employing representative volume elements and various loading conditions, rather than focusing on specific applications. This approach allows possible future extensions to different materials and loading paths. By comparing local, global, and surrogate-based optimization methods, this work provides a concise overview and benchmark of calibration methods in crystal plasticity.

<sup>\*</sup> sadik.acar@metu.edu.tr

# Elastic-Plastic Deformation and Damage Behavior of 316L Rupture Disc Material: An Experimental Study and Numerical Calibration

### Benjamin Treude\*, Ulf Reinicke, Denis Anders

Group for Computational Mechanics and Fluid Dynamics, TH Köln - University of Applied Sciences, 51643 Gummersbach, Germany

Keywords: Rupture Discs, Ductile Damage, Finite Element Simulation

Metallic rupture discs are indispensable safety devices in the process industry, protecting pressurized components from hazardous overpressure scenarios. Upon reaching a critical pressure, they activate in a controlled manner to prevent catastrophic failure. Tensile-loaded rupture discs are widely used due to their structural efficiency and flexibility. These discs consist of thin, dome-shaped membranes made of ductile, cold-rolled stainless steel with thicknesses well below 1 mm. Depending on process requirements, the membranes are customized with predefined rupture features such as perforations or pre-notches, resulting in a wide range of stress configurations [1]. As a result, the performance of modern rupture discs is currently verified almost exclusively through costly and time-consuming experimental burst tests. To enable a transition toward numerical simulation of such bursting events, a material model designed to accurately capture the elastic-plastic deformation and damage behavior under the specific stress states encountered in thin sheet metals is required. In this study, an extensive experimental program was conducted to characterize the material response up to fracture of annealed austenitic stainless steel 316L with a thickness of 0.356 mm. The investigation comprised uniaxial tensile and Nakajima tests. Tailored specimen geometries were employed to access a broad range of stress triaxialities and Lode angle parameters. In-plane deformation fields were captured up to fracture using stereo digital image correlation. The experimental data enabled the derivation of true stress-strain curves and the calibration of a strain-hardening law valid up to the post-necking regime. All tests were complemented by finite element simulations using the commercial FE code Abaqus. The material behavior was modeled using isotropic von Mises plasticity, and force-displacement responses were matched to experimental results. The ductile damage model implemented in Abaqus was used to describe the onset of damage, incorporating stress triaxiality and Lode dependence. Post-necking behavior and damage evolution were modeled using an energy-based regularization approach to minimize mesh sensitivity and capture progressive material degradation. This study presents a validated plasticity and damage model for thin annealed 316L stainless steel sheets, tailored for simulating tensile-loaded rupture discs. The developed material model provides deeper insight into the mechanics of rupture discs and supports the design optimization of safety-critical components. Ultimately, it contributes to improved process safety and reduced environmental impact in the chemical and process industries.

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<sup>\*</sup> benjamin.treude@th-koeln.de

# Residual Stresses in Cold-bent Spiral-welded L485 Steel Pipes

Amirhossein Jabbari Mostahsan<sup>1</sup>, Zahra Silvayeh<sup>1</sup>, Peter Auer<sup>1</sup>, Andreas Hütter<sup>1</sup>, Norbert Enzinger<sup>1</sup>, Stefan Fink<sup>2</sup>, Michael Obermann<sup>3</sup>, <u>Josef Domitner</u>\*<sup>1</sup>

Keywords: Spiral-welded pipe, Residual stresses, Cold bending

Spiral-welded steel tubes and pipes used for gas pipelines can exhibit complex residual stresses, which arise from automated thermo-mechanical manufacturing in the factory (forming, welding, sandblasting, coating) and from subsequent cold bending of the pipe at the construction site [1]. Achieving detailed information about the actual stress state of the material is crucial in pipes for gaseous hydrogen transport, as particularly localized tensile stresses may enhance the hydrogen solubility and absorption, promoting hydrogen-induced failure [2,3]. Therefore, this work focuses on near-surface residual stress measurements on representative straight and cold-bent L485 (API 5L X70) steel pipes with nominal diameter DN 800 and the wall thickness of 12.5 mm. Residual stresses measured in depths of less than 1 mm to the inner surface using the hole drilling method were compared at different circumferential positions in the base metal, the spiral weld and the heat-affected zone (HAZ). The stress state at the inner surface of the pipe is of special interest, as this surface is permanently exposed to the gas flowing through the pipeline during service and, thus, it is more susceptible to crack initiation. Representative weld cross-sections were etched for visualizing the microstructures of the base metal, the HAZ and the weld metal. Moreover, hardness profiles were captured to distinguish the different zones more easily from each other. In general, compressive residual stresses that are considered as beneficial for the durability of the pipe were measured on the straight pipe in the depth of about 0.4 mm to the surface. Cold bending tended to reduce the compressive residual stresses, and even tensile residual stresses were measured on the surface at the inner bending radius. As confirmed in a previous study [3], the weld and the HAZ exhibited much higher tensile residual stresses than the base metal, particularly in hoop direction. Hence, investigations of, e.g., the hydrogen embrittlement susceptibility should primarily focus on the HAZ and on the spiral weld rather than on the base metal of the pipe.

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<sup>&</sup>lt;sup>1</sup> Graz University of Technology, Research Group of Lightweight and Forming Technologies, Institute of Materials Science, Joining and Forming, Inffeldgasse 11/I, 8010 Graz, Austria

<sup>&</sup>lt;sup>2</sup> Energienetze Steiermark GmbH, Leonhardgürtel 10, 8010 Graz, Austria

<sup>&</sup>lt;sup>3</sup> Österreichische Vereinigung für das Gas- und Wasserfach, Schubertring 14, 1010 Wien, Austria

<sup>\*</sup> josef.domitner@tugraz.at

# Effect of Stacking Sequence and Ply Dispersion on the Tensile Behavior of Carbon/Glass Hybrid Composites

Tarık Kara, Yiğitkan Korkmaz, Ahmet Çevik\*, Barış Akış, Onur Ali Batmaz, Görkem Eğemen Güloğlu, Demirkan Çöker

Department of Aerospace Engineering, Middle East Technical University, Ankara 06800, Turkey

Keywords: carbon/glass hybrid composite, stacking sequence, hybrid effect

Composites are increasingly being used in structural applications in industries like aerospace, automotive, and marine that demand high performance materials because of their high strength to weight ratio and affordability. Carbon and glass fibers are the most commonly used types of reinforcement in composite materials. Carbon fiber is stronger than glass fiber but has lower elongation. Literature research shows that using different types of fibers, usually referred to as low elongation (LE) and high elongation (HE) fibers, enhances the mechanical properties of composites due to the synergistic effect called hybrid effect [1-3]. Specifically, the increase in the failure strain of the LE fiber within a hybrid composite, relative to its failure strain in a nonhybrid LE fiber composite, is described as the positive hybrid effect [1]. However, the underlying mechanism of this phenomenon is not yet well established. This study aims to investigate the effect of stacking sequence on the tensile properties of inter-ply plain woven carbon/glass hybrid composites by examining the position of high-elongation fiber plies (either on the outer surfaces or embedded within the laminate), the degree of ply dispersion, and the sublaminate thickness influence the hybridization mechanisms. Composite plates having stacking sequences of  $[G_3/C_2]_s$ ,  $[C_2/G_3]_s$  and  $[G/C/G/C/G]_s$ , along with non-hybrid carbon and glass composites for comparison, were manufactured using the VARTM (Vacuum Assisted Resin Transfer Molding) method. The individual specimens were cut from these composite plates with water jet. Tensile tests were conducted using 250 kN MTS universal servo-hydraulic test machine with a test speed of 1 mm/min. The Digital Image Correlation (DIC) method was utilized to obtain the full-field strain distribution over the mid-region on both the main face and the side surface of the specimens. Failure sequence of hybrid composites was recorded using high-speed camera from the side-view at 300k frame per second (FPS). All stacking sequences show similar stiffness values; however, despite having the same number of carbon (4) and glass (6) fiber plies, the  $[G_3/C_2]_s$  configuration demonstrates pseudo-ductility, which is gradual and non-catastrophic failure response with extended strain before fracture, due to the constraining effect of the high-elongation glass plies on the low-elongation carbon plies.

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<sup>\*</sup> cevik.ahmet@metu.edu.tr

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# Modeling the Long-term Strength of Metallic Materials at Different Temperatures using a System of Kinetic Equations for Creep Deformation and Damage Parameter

### Regina Saitova\*, Alexander Arutyunyan

Department of Elasticity, Saint Petersburg State University, Saint Petersburg 198504, Russia

**Keywords:** creep, damage parameter, long-term strength criterion

The problem of high-temperature creep and long-term strength of metallic materials is demanded in such important fields of modern engineering, as thermal and nuclear power plants, aircraft and spacecraft, etc. Because these effects are observed in elements of many important engineering objects, the problem of brittle fractures became a subject of numerous theoretical and experimental research. The damage conception was introduced in the mechanics of materials to describe long-term strength under conditions of high-temperature creep. This conception has been developed in the fundamental works of Kachanov [1] and Rabotnov [2]. In the work, to describe the creep and long-term strength, a damage conception is used. A system of interconnected kinetic equations for the creep rate and damage parameter is formulated [3, 4]. A compressible medium is considered and the mass conservation law is taking into account. The damage parameter is specifying in the form of the ratio of the current density of the material to the initial one. Exact and approximate analytical solutions of these equations are obtained. The theoretical long-term strength curves are plotted and compared with the experimental results for NCF 750-B (Ni based 15.5Cr-2.5Ti-0.7Al-1Nb-7Fe) superalloy [5]. It is shown, that the experimental results are in good agreement with the theoretical ones. A description of the system parameters depending on temperatures is given. Thus, the proposed system of interrelated kinematic equations allows us to describe the creep and long-term strength behavior of metallic materials at different temperatures.

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<sup>\*</sup> rigastr@yandex.ru

# Parametric Finite Element Study of the Effect of Process Details in the Deep Drawing of Cylindrical Cups

Miguel Angel Ramirez<sup>1</sup>, Jorge Luis Flores Alarcon<sup>2</sup>, Leopoldo Ruiz-Huerta<sup>3,4</sup>, Ignacio Alejandro Figueroa<sup>2</sup>, <u>Rafael Schouwenaars</u>\*<sup>5,6</sup>

- <sup>1</sup> Centro Tecnológico Aragón, Facultad de Estudios Superiores Aragón, Universidad Nacional Autónoma de México. Av. Rancho Seco s/n, Cd. Nezahualcóyotl, 57130, Estado de México, México
- <sup>2</sup> Instituto de Investigaciones en Materiales, Universidad Nacional Autónoma de México, Ciudad Universitaria, Del. Coyoacán, Ciudad de México 04510, Mexico.
- <sup>3</sup> Instituto de Ciencias Aplicadas y Tecnología (ICAT), Universidad Nacional Autónoma de México (UNAM), Circuito Exterior S/N, Ciudad Universitaria, Mexico City, 04510, México
- <sup>4</sup> National Laboratory for Additive and Digital Manufacturing, MADiT, Mexico
- <sup>5</sup> Departamento de Materiales y Manufactura, Facultad de Ingenieria, Edificio O, Universidad Nacional Autonoma de Mexico. Ciudad Universitaria, Coyoacan, 04510, Ciudad de Mexico, Mexico <sup>6</sup> Ghent University, Materials Science and Technology, Department of Electromechanical, Systems and Metals Engineering, Technologiepark 46, 9052, Ghent, Belgium.
- \* Rafael.Schouwenaars@UGent.be

**Keywords:** Cup drawing, Finite element modelling, Friction, Strain rate sensitivity

The cup drawing test or earing test is a benchmark for the evaluation of anisotropic plasticity finite element models [1]. Modern descriptions of anisotropic yield loci, either by advanced empirical approaches [2] or based on crystal plasticity models [3] often provide precise descriptions of the earing profile of the cups. Other variables generally receive less attention, like the average cup height, the wall thickness and the drawing force vs. punch displacement. These variables are only weakly dependent on the yield locus formulation but are strongly affected by the tool design, the blank holder force, friction coefficient and the constitutive description of the material, i.e., the tensile curve and strain rate sensitivity. This work presents a brief overview of recent results in the field of anisotropic plasticity modelling, which will be contrasted against other important factors, such as the press type and the operational parameters. These are varied according to the strategy of a factorial design, providing important information in two ways. Firstly, it shows which one of the measurable variables is most sensitive to each of the modelling parameters and, secondly, it is found which of the parameters must receive priority attention during the elaboration of more advanced finite element models and the development of new experimental designs.

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# Mechanical and Physical Characteristics of Cyclic Degradation of Stainless Steel with Different Grain Sizes

### A.I. Bolotnikov\*, M.R. Tyutin, L.R. Botvina

Baikov Institute of Metallurgy and Materials Science of the Russian Academy of Sciences, Moscow, 119334, Russian Federation

**Keywords:** 12Cr18Ni10Ti stainless steel, cyclic degradation, acoustic emission, digital image correlation

To assess the condition of structural steels, it is necessary to study the kinetics of changes in the mechanical and physical properties of the material under cyclic loading, as well as to analyze the influence of the microstructure on these kinetics. This is important for the development of more effective scientific and methodological approaches for assessing the degradation of structural steels under service conditions.

To study these regularities, experiments were conducted on specimens of 12Cr18Ni10Ti austenitic stainless steel, a material widely used in industry, with varying grain sizes. Cyclic degradation was performed on specimens with a continuous radius between ends on an Instron 8801 testing machine (maximum load of 100 kN) at 1.6 times the yield strength, with a stress ratio of R = 0.1 and loading frequency f = 20 Hz up to a relative lifetime of N/N<sub>f</sub> = 0.5. After preliminary cyclic loading, tensile tests were performed using acoustic emission (AE) and digital image correlation (DIC) methods. The effects of cyclic degradation on the following mechanical and physical properties were analyzed:

- $\bullet$  Fracture energy (A<sub>F</sub>), tensile strength (US), yield strength (YS);
- Total number of AE events  $(\sum N_{AE})$ , activity  $(\dot{N}_{AE})$ ,  $b_{AE}$ -value, rise angle (RA), average frequency (AF), peak frequency (PF), and frequency centroid (FC);
- Maximum value of principal strain ( $\varepsilon_{1\text{max}}$ ), areas of weakly ( $S_L$ ) and strongly ( $S_H$ ) deformed plastic zones, estimated by DIC.

It was found that increasing the grain size enhances tensile strength and fracture energy, while reducing both yield strength and fatigue strength. The fracture process of specimens, both in the initial state and after cyclic degradation, proceeds through five stages, characterized by changes in the measured parameters [1].

Cyclic degradation leads to the following changes in AE and DIC parameters: FC, PF and RA increase, while  $b_{AE}$ -value, AF,  $\sum N_{AE}$ ,  $\dot{N}_{AE}$  and  $\varepsilon_{1max}$  decrease. A pronounced break appears on the deformation curves in the yield strength range, which is probably associated with the deformation-induced martensite formation during preliminary cyclic loading. Additionally, the duration of the final fracture stage is reduced. The identified changes in the mechanical and acoustic emission parameters were associated with strain hardening of the material and structural changes after preliminary cyclic loading.

<sup>\*</sup> kubikmaster@yandex.ru

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# **Learning Microstructural Evolution**

### Aytekin Demirci\*1, Stefan Sandfeld<sup>1,2</sup>

Keywords: Dislocation Dynamics, Machine Learning, Data-driven methods

A dislocation is a line defect within a crystal lattice that allows slip and governs plastic deformation. Understanding and predicting the evolution of dislocation networks is essential for modeling the plastic behavior of crystalline materials. In discrete dislocation dynamics (DDD) simulations, individual dislocation lines are explicitly tracked, capturing phenomena such as dislocation multiplication, annihilation, and interactions. However, DDD becomes computationally prohibitive as system size increases.

Our in-house Discrete-to-Continuum (D2C) software converts discrete dislocation structures into continuum measures—namely, total dislocation density and geometrically necessary dislocation (GND) tensor components —defined on a regular grid. These high-dimensional fields serve as inputs for a machine learning pipeline that predicts their spatiotemporal evolution under applied loading. Since three-dimensional simulation grids produce very large datasets, we first apply dimensionality-reduction techniques (e.g., principal component analysis and latent representations from autoencoders) to extract the most prominent features. By tracking these reduced descriptors over time, we identify fundamental evolution patterns and use them to generalize the simulation trajectory. Finally, a combination of deep learning and statistical reconstruction methods maps the condensed representation back to the full continuum fields, resulting a complete prediction of dislocation evolution.

We anticipate that this methodology will reproduce key qualitative features of dislocation pattern formation while offering significant computational speed-ups over traditional workflows. By bridging discrete and continuum descriptions, our framework paves the way for real-time, multiscale simulations of plasticity and the development of continuum constitutive laws that incorporate evolving microstructure.

<sup>&</sup>lt;sup>1</sup> Institute for Advanced Simulations – Materials Data Science and Informatics (IAS-9), Forschungszentrum Jülich GmbH, 52425 Jülich, Germany

<sup>&</sup>lt;sup>2</sup> Chair of Materials Data Science and Materials Informatics, Faculty 5 – Georesources and Materials Engineering, RWTH Aachen University, 52056 Aachen, Germany

<sup>\*</sup> a.demirci@fz-juelich.de

# Fatigue Analysis of 3D Printed Sustainable PLA Composites Reinforced with Glass Fiber

### Shabbir Muneer\*1, Keshavamurthy Ramaiah2, Vinay Kumar Rajaiah3

- <sup>1</sup> School of Structural and Environmental Engineering, Bahrain Polytechnic, Issa town, Kingdom of Bahrain
- <sup>2</sup> Department of Mechanical and Automobile Engineering, Christ University, Bangalore 560074, India
- <sup>3</sup> Department of Mechanical Engineering Dayananda Sagar College of Engineering Bangalore 560074, India
- \* shabbir.muneer@polytechnic.bh

**Keywords:** Sustainability, PLA Composites, Glass Fiber Reinforcement, Fatigue Behavior, Additive Manufacturing

This study investigates the fatigue behaviour of polylactic acid (PLA) composites reinforced with glass fibers at varying weight percentages. Additive manufacturing was performed using fused deposition modeling (FDM), with process parameters selected based on previously established optimal conditions to ensure consistent mechanical performance [2]. The primary focus was to evaluate how different glass fiber contents influence the fatigue life of the printed composites [1][2]. Experimental testing revealed that increasing the glass fiber content generally enhances tensile strength, though the effect on fatigue life is more nuanced and strongly dependent on the reinforcement level. Notably, composites with highest percentage of glass fiber content exhibited the most favorable fatigue performance, suggesting a balance between stiffness and resistance to crack initiation and propagation [3]. The findings provide key insights into optimizing fiber-reinforced PLA composites for applications requiring enhanced durability under cyclic loading [3][4].

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# Investigation of Proton Irradiation Induced Microstructural Evolution in ODS-Inconel 625 Produced via LPBF

<u>Ömer Faruk Koç</u> $^{*1,2}$ , Selen Güner Gürbüz $^2$ , Emin Yeltepe $^2$ , Kadir Tuğrul Demirci $^3$ , Ilhan Bükülmez $^2$ , Erhan Aksu $^2$ , Eda Aydoğan $^4$ 

- <sup>1</sup> Nuclear Energy and International Projects General Directorate, Ministry of Energy and Natural Resources, Ankara 06520, Türkiye
- <sup>2</sup> Nuclear Energy Institute, Turkish Energy Nuclear and Mineral Research Agency, Ankara 06980, Turkey
- <sup>3</sup> Department of Materials, The University of Manchester, Manchester M139PL, UK
- <sup>4</sup> Department of Metallurgical Materials Engineering Engineering, Middle East Technical University, Ankara 06800, Türkiye
- \* omer.koc@enerji.gov.tr

**Keywords:** Proton irradiation, nuclear energy, dislocation loop formation

This study explores the effect of oxide dispersion strengthening (ODS) on the proton irradiation response of Inconel 625 (IN625) alloys produced by laser powder bed fusion (LPBF). A novel ODS-IN625 alloy containing 0.3 wt% Y<sub>2</sub>O<sub>3</sub> and 0.4 wt% Hf was developed, achieving >99.9% densification and enhanced mechanical properties at elevated temperatures in pre-irradiation tensile tests. Proton irradiation was performed on several IN625 variants—including ODS, non-ODS additively manufactured, and commercial alloys—in both as-built and heat-treated conditions, using 3 MeV protons at  $\sim$ 300°C to an irradiation dose of 0.1 dpa. The proton irradiation beamline relevant to material irradiation with 3 MeV protons was built as part of the present project. A vacuum irradiation chamber has been constructed, incorporating a heating system, Faraday cup, beam screen, and real-time monitoring instrumentation. To mitigate radiation-induced electronic failure, all sensitive power supplies and measurement equipment are located outside the irradiation zone, with remote control and data acquisition managed via a centralized control system. This setup enables precise regulation of irradiation parameters such as temperature and dose, ensuring repeatability and operational safety. After proton irradiation of Inconel samples, X-ray diffraction (XRD), nanoindentation and transmission electron microscopy (TEM) were employed to characterize irradiation-induced damage especially the dislocation density. The study aims to understand the role of ODS and additive manufacturing in influencing irradiation behaviour, providing insight into microstructural evolution and damage mechanisms under proton exposure for Inconel 625 which is one of the candidate materials for molten salt reactors.

# A Novel Bayesian Optimization Approach for Design of Architected Materials

#### Haris Moazam Sheikh\*

Department of Aeronautics and Astronautics, University of Southampton, Southampton, UK

**Keywords:** Architected metamaterials, Defect-Engineering, Bayesian Optimization

The advances in modeling, fabrication, and testing of architected materials have promulgated their utility in engineering applications, such as ultralight, reconfigurable, high-energy absorption materials, as well as different engineering domains. The unique internal topological features, rather than the materials themselves, dictate these unusual properties and a significant portion of current research is focused on exploring novel geometric designs of micro/nanoarchitectures to achieve or discover exceptional mechanical properties. In particular, lattice structures that mimic crystal microstructures consisting of different unit cells or with strategically removed beam lattice members, defined as engineered defects, can emulate mechanisms in crystal microstructures, e.g., dislocation motion and strain hardening mechanisms, such that they have superior strength, energy-dissipation, and controllable failure. However, despite the aggressive advancement in recent years, the exploration of novel topologies is inhibited due to extremely expensive high-fidelity computer simulation costs and the sheer number of geometric features. Historically the design process for meta-materials has been driven by designers' ingenuity, drawing inspiration from biological materials, from crystalline cell structures, even the artistic fields of origami and kirigami. But human nature tends to favor the familiar, and depending on just designer's ingenuity is insufficient. Our work addresses key challenges in meta-material design by introducing a systematic framework powered by our novel Mixed-variable Multi-Objective Bayesian Optimization (MixMOBO) algorithm. This algorithm is capable of efficiently optimizing expensive blackbox problems. By strategically incorporating defects into beam lattice structures, we demonstrate the framework's effectiveness through two distinct design applications: (1) highstrain energy density lattice structures [1], and (2) Cauchy-symmetric lattice structures [2]. In both cases, our approach identified designs that significantly outperformed existing lattice structures. This study highlights how a structured optimization methodology can uncover nonintuitive mechanisms for enhancing mechanical meta-materials and illustrates the potential of defect engineering to improve mechanical performance.

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<sup>\*</sup> h.m.sheikh@soton.ac.uk

# Vibration Analysis of ABS and PETG Composite Cracked Plates

Hilal Doganay Kati\*1,2, Muhammad Khan<sup>1</sup>, Feiyang He<sup>1</sup>, Yousef Lafi A Alshammari<sup>1,3</sup>

**Keywords:** Dynamic response, damage identification, modal analysis, 3D printing, FDM, ABS, PETG

Cracks in structures significantly alter their dynamic behaviour, such as natural frequency, mode shape, and vibration amplitude, by reducing structural integrity and stiffness. These defects can substantially shorten the service life of structural components and may lead to progressive failure if undetected. Therefore, identifying and characterising cracks is a critical task in maintaining structural reliability. Vibration-based methods, particularly experimental modal analysis, are widely recognised as practical and non-destructive techniques for crack detection, especially in large or inaccessible components. These techniques have been extensively applied to metallic structures such as beams and plates. However, recent advances in additive manufacturing (AM) have enabled the fabrication of lightweight, complex polymeric structures at lower costs, broadening the application of such methods to new material systems.

This study investigates the dynamic response of polymeric composite plates produced using fused deposition modelling (FDM) with two thermoplastic materials: acrylonitrile butadiene styrene (ABS) and polyethylene terephthalate glycol (PETG). Five different damage scenarios involving artificial cracks were introduced into the plates. In all scenarios, the crack initiation point and orientation angle were kept constant, while only the crack length was varied. Experimental modal analysis was conducted to assess the vibrational behaviour of the intact and damaged specimens. Additionally, the same geometries and damage configurations were modelled in ANSYS, and numerical modal analysis was performed. The results from the experiments and numerical simulations were compared to evaluate the accuracy of the Finite Element Method (FEM) in capturing crack-induced changes in dynamic properties. The outcomes of this study are expected to support the development of vibration-based health monitoring strategies for 3D-printed polymeric structures.

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<sup>&</sup>lt;sup>1</sup> Centre for Life-cycle Engineering and Management, Cranfield University, Bedford, MK430AL, United Kingdom

<sup>&</sup>lt;sup>2</sup> Faculty of Engineering and Natural Sciences, Department of Mechanical Engineering, Bursa Technical University, 16310, Bursa, TURKEY

<sup>&</sup>lt;sup>3</sup> Mechanical Engineering Department, Engineering College, Northern Border University, King Fahad Road Arar 92341, Saudi Arabia

<sup>\*</sup> Hilal.Doganay@cranfield.ac.uk

# Manufacturing Effects on Microdamage-Induced Nonlinearity and Mechanical Properties of Unidirectional GFRPs

## Özgün Şener\*1,2, Fırat Ergin<sup>3</sup>, Altan Kayran<sup>1,2</sup>

- <sup>1</sup> Department of Aerospace Engineering, Middle East Technical University, Ankara 06800, Turkey
- <sup>2</sup> METUWIND Center for Wind Energy Research, Middle East Technical University, Ankara 06800, Turkey
- <sup>3</sup> Bristol Composites Institute, University of Bristol, Bristol BS8 1TR, UK

Keywords: GFRP, Microdamage, Manufacturing Method, Mechanical Behavior

With their outstanding mechanical performance in the fiber direction and inherently low weight, unidirectional (UD) fiber-reinforced polymers (FRPs) have found widespread usage in high-performance structural applications across many industrial fields. Nonetheless, under off-axis loading scenarios, UD FRPs are characterized not only by low strength and stiffness, but also by nonlinear response induced by the polymer matrix. The nonlinear behavior of composites primarily originates from the progressive accumulation of distributed matrix microdamage during the mechanical loading, which in turn leads to a gradual degradation of their mechanical properties [1]. A notable approach for modeling matrix-induced microdamage at the lamina scale is Schapery Theory (ST) [2], which uses the laws of the thermodynamics and a work potential theory to predict the onset and the development of the microdamage within the composites. The ST incorporates transverse and shear microdamage functions to relate the stiffness degradation to the energy dissipated throughout the loading process. Enhanced Schapery Theory (EST), as an extension of the ST, further accounts for the transverse and shear cracking in the matrix as well as fiber fracture mechanisms [3]. In this study, the nonlinear behavior of UD Glass Fiber Reinforced Plastics (GFRPs) manufactured via vacuum infusion (VI) and hand layup (HL) methods is investigated. Although the mechanical performance of these composites has been widely studied, the specific influence of manufacturing method on their nonlinear response remains relatively unexplored. The objective of this study is to quantitatively characterize the nonlinear behavior using the microdamage functions. These functions are incorporated into the Continuum Damage Mechanics (CDM)-based Enhanced Schapery Theory, serving as a progressive failure analysis (PFA) framework to capture the initiation and evolution of microdamage, and eventual failure of the composite. The preliminary results confirm that Schapery functions effectively capture microdamage evolution in VI laminates. The study will be extended to HL laminates to assess and compare the mechanical properties and microdamage function parameters between the two manufacturing methods.

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<sup>\*</sup> osener@metu.edu.tr

# A Numerical Investigation of Parameter Sensitivities in Phase Field Modeling of Brittle Hydrogen Embrittlement

### Shaghayegh Nazar\*, Maria Francesca Milazzo, Edoardo Proverbio

Department of Engineering, University of Messina, Messina 98166, Italy

Keywords: Hydrogen embrittlement, Phase field model, Fracture

Predictive modeling is crucial for understanding and mitigating hydrogen embrittlement (HE) in metallic materials. Phase field models (PFMs) offer a continuum approach for simulating fracture phenomena to HE [1]. This work presents a numerical investigation into the parameter sensitivities of an established coupled chemo-mechanical phase field model framework for hydrogen assisted cracking, specifically focusing on the brittle-elastic response regime. Finite element analysis is employed to simulate hydrogen assisted cracking in a benchmark notched square plate geometry, allowing for systematic evaluation of physical parameters associated with the hydrogen-induced fracture energy degradation (degradation coefficient  $\chi$ , segregation energy  $\Delta g_b^{0\, \text{II}}$ ), loading kinetics (applied displacement rate  $\dot{u}$ ), the intrinsic model length scale ( $\ell$ ), and numerical discretization (mesh refinement) [2]. The results demonstrate that the predicted brittle fracture behavior is highly sensitive to the parameters defining the material's degradation law ( $\chi$  and  $\Delta g_b^{0\, \text{III}}$ ) and the applied loading rate ( $\dot{u}$ ), highlighting the importance of accurately characterizing degradation and diffusion. These findings provide vision into the application and interpretation of the PFM for brittle HE, emphasizing the dominant role of parameters.

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<sup>\*</sup> shaghayegh.nazar@studenti.unime.it

# Nanometric Cutting of Single-crystal Silicon: A Molecular Dynamics Study on Deformation Mechanisms and Subsurface Damage

### Tirimisiyu Olaniyan\*1, Nadimul Faisal1, James Njuguna1,2

**Keywords:** ductile mode machining, ultraprecision machining, brittle materials, molecular dynamics

The demand for ultraprecision components in optics, optoelectronics, and MEMS/NEMS devices has increased tremendously. This necessitates advanced machining techniques capable of producing exceptional surface integrity and dimensional accuracy on a nanometre scale. Among the key materials used in these applications is silicon. However, silicon machining at the nanoscale poses significant challenges, such as tool wear and poor surface finish, due to its hardness and low fracture toughness [1]. Although there is widespread use of ultraprecision machining, the fundamental mechanisms governing ductile regime cutting of brittle materials (e.g. silicon) at the nanoscale are still not adequately addressed or understood. This is because this type of machining involves a complex interplay of phenomena that includes tool geometry, crystallographic orientation, phase transformation, and others. These phenomena consist of the complicated interaction of numerous processes, which are difficult to observe and elucidate experimentally [2]. Most of these phenomena have been described and believed to be easily observed using molecular dynamics (MD) simulation [3]. To address this, the study employs molecular dynamics (MD) simulations to investigate the orthogonal nanometric cutting behaviour of single-crystal silicon using a diamond tool with a 0° rake angle and -10° clearance angle. Simulations were conducted at varying depths of cut (1 nm, 2 nm, and 3 nm) to analyse deformation mechanisms, chip morphology, dislocation activity, and cutting forces. The simulations were performed using the LAMMPS code and analysed with OVITO for structural and phase transformations. The results reveal that chip formation and phase transformations, including transitions from the diamond cubic structure of silicon atoms to -Si, bct5-Si, Si-III, Si-XII, and amorphous silicon, constitute the deformation mechanism and are cutting depth-dependent. At 1 nm cutting depth (undeformed chip thickness), the process resembles scratching with minimal subsurface damage and no dislocations. At 3 nm, significant subsurface damage and dislocation activity indicate increased plastic deformation and cutting resistance. Cutting forces and friction coefficients correlate with depth, with 2 nm offering a balance between material removal and tool wear. These findings provide critical insights into optimising nanometric cutting parameters for improved surface integrity.

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<sup>&</sup>lt;sup>1</sup> School of Computing, Engineering and Technology, Advanced Materials Research Group, Robert Gordon University, Aberdeen, Scotland

<sup>&</sup>lt;sup>2</sup> National Subsea Centre, Sir Ian Wood Building, Robert Gordon University, Aberdeen, Scotland.

<sup>\*</sup> t.olaniyan@rgu.ac.uk

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# Influence of Temperature on Nanoindentation and Fracture Properties of Spark Plasma Sintered Ti-48Al-2Cr-2Nb Alloy

### Mahlatse Mphahlele\*1, Motsi Matlakala<sup>2</sup>

- <sup>1</sup> Department of Mechanical and Mechatronics Engineering, Cape Peninsula University of Technology, Cape Town, 7535, South Africa
- <sup>2</sup> Department of Mechanical Engineering Sciences, University of Johannesburg, Auckland Park, 2092, South Africa

Keywords: Fracture, Nanoindentation, Thermal Stability, TiAl

Emerging developments in advanced design concepts focus on the capacity to endure elevated service temperatures and the use of thinner sections without sacrificing specific strength and modulus. Titanium materials are suitable for these sophisticated designs, providing around 45% mass reduction relative to traditional stainless steels [1]. In particular, gamma titanium aluminide (TiAI) encompasses low diffusivity, high thermal conductivity, retention of strength at elevated temperatures, minimal thermal expansion, excellent structural stability, and significant hardness, in contrast to traditional titanium alloys [2]. This study investigated a spark plasma sintered (SPsed) TiAl intermetallic alloy with a notional composition of Ti-48Al-2Cr-2Nb (at. %). The tests involved assessing thermal stability using a laser flash analyser (LFA) at temperatures of 25, 300, 600, and 900 °C. Following exposure of the samples to these temperatures, plasticity was assessed via nanoindentation, and fracture behaviour was evaluated by examining the fractured surfaces with a scanning electron microscope (SEM). The results indicated that the thermal capacity, diffusivity and conductivity of the SPSed TiAl material diminish with temperature up to 300 °C, after which they increase with rising temperature. The load-displacement curves indicated that the sample exposed to a temperature of 600°C prior to testing exhibited minimal penetration depths under various loads, relatively high hardness (H) and elastic modulus (E), and remarkable H/Er and H<sup>3</sup>/Er<sup>2</sup> ratios, signifying enhanced anti-wear characteristics. The fracture modes of the SPSed TiAl alloy are influenced by temperature; samples subjected to temperatures ranging from 25 to 300°C generally exhibit brittle fracture, whereas the sample exposed to 600 °C demonstrates signs of plasticity before ultimately fracturing in a brittle manner.

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<sup>\*</sup> ramimphahlele@gmail.com

# Strain Gradient Crystal Plasticity Models for Polycrystalline Aggregate

# Amirhossein Lame Jouybari\*1,2, Samir El Shawish1, Leon Cizelj1,2

- <sup>1</sup> Jožef Stefan Institute, Jamova cesta 39, Ljubljana, Sl-1000, Slovenia
- <sup>2</sup> University of Ljubljana, Jadranska ulica 19, Ljubljana, SI-1000, Slovenia

**Keywords:** Crystal Plasticity, Polycrystalline aggregate, Fast Fourier transform method, Grain boundary

This study presents Strain Gradient Crystal Plasticity (SGCP) models within a thermodynamically consistent framework, formulated in terms of the MicroSlip and MicroCurl models [1]. The MicroSlip SGCP model is based on the gradient of cumulative shear strain, while the MicroCurl model is formulated using the Nye tensor. The governing balance equations and the length scale are derived using the principle of virtual power and the Clausius Duhem inequality. To solve both the classical and generalized balance laws, the Fast Fourier Transform (FFT) homogenization method is employed as an efficient computational approach. These balance laws are explicitly coupled within the FFT-based algorithm, ensuring an accurate numerical implementation. Polycrystalline simulations are performed using both the MicroSlip and MicroCurl SGCP models, considering different length scales and higher-order interface conditions at grain boundaries. The results indicate that the SGCP models exhibit additional strain hardening compared to the CCP framework, which is attributed to the dislocation pile-up mechanism within the microstructure. Moreover, increasing the length scale enhances the hardening response and leads to a broader distribution of shear bands. The influence of different grain boundary conditions, MicroFree, MicroContinuity, and MicroHard, is also investigated. It is observed that under the MicroFree and MicroContinuity conditions, shear bands propagate across grain boundaries, whereas in the MicroHard condition, they terminate at the boundaries. This phenomenon may be associated with grain boundary embrittlement, potentially caused by oxidation or hydrogen dissolution.

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<sup>\*</sup> Amirhossein.Lame@ijs.si

# Influence of stress-state-dependent yield functions on plasticity and damage modeling of AA2024-O in flow forming

### Hande Vural\*,1, Aptullah Karakaş2, Tuncay Yalçinkaya1

**Keywords:** Bai-Wierzbicki yield criterion, Flow forming, Damage modelling

Flow forming is an advanced metal forming technique widely used in the aerospace and defense industries for the production of tubular components. Due to high thickness reduction ratios and complex stress states, materials undergo severe plastic deformation, which makes accurate material modeling critically important. To describe such behavior, various yield criteria have been proposed in the literature, with the classical von Mises (VM) yield function and the stressstate-dependent Bai-Wierzbicki (BW, [1]) model being among the most commonly adopted approaches. In our previous studies on the Inconel 718 (IN718) superalloy, the VM function successfully predicts the plastic response across different specimen geometries [2]. However, tests conducted on the AA2024-O alloy show that the VM criterion does not achieve the same accuracy, particularly under varying stress states. To overcome this limitation, the stress triaxiality and Lode parameter dependent yield function proposed by Bai and Wierzbicki [1] is implemented in Abaqus/Explicit through a VUMAT subroutine, which enables an improved representation of the plastic response of AA2024-O across different specimen geometries. Following the plasticity modeling, simple and computationally efficient single-parameter uncoupled damage models [3] are applied. These models are combined with both VM and BW yield functions, and the results are compared in detail in terms of stress-strain distributions and damage accumulation.

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<sup>&</sup>lt;sup>1</sup> Department of Aerospace Engineering, Middle East Technical University, 06800 Ankara, Türkiye

<sup>&</sup>lt;sup>2</sup> Repkon Machine and Tool Industry and Trade Inc., 34980 Şile, Istanbul, Türkiye

<sup>\*</sup> handev@metu.edu.tr

# Role of Comonomer Type in Determining Environmental Stress Cracking Resistance in Polyethylene

### Federico Olla\*1, Marco Contino1, Dino Ferri2, Francesco Scavello2, Luca Andena1

Keywords: Polyethylene, Fracture Mechanics, Environmental Stress Cracking

The long-term durability of polyethylene (PE) products is primarily limited by failure mechanisms such as Slow Crack Growth (SCG) and Environmental Stress Cracking (ESC). While traditional testing methods provide useful material rankings, they often lack the predictive power needed for robust engineering design. This work presents a quantitative evaluation of ESC resistance in different PE grades using a Linear Elastic Fracture Mechanics (LEFM) framework, aiming to establish clear relationships between morpho-structural parameters and fracture toughness. Four PE materials were analyzed: two linear low-desnity (LLDPE) grades with different comonomer type (1-butene vs. 1-hexene), a high molecular weight LLDPE, and a high-density (HDPE) homopolymer. The results confirm that molecular weight is a dominant factor in enhancing fracture resistance. More importantly, the study reveals the decisive role of comonomer type: the LLDPE with 1-hexene (longer side chains) exhibits significantly higher resistance to crack initiation and propagation compared to its 1- butene counterpart, despite having similar bulk structural parameters [1]. Furthermore, the investigation identifies three distinct fracture regimes when testing in a surface-active environment, determined by the applied stress intensity factor (K): (1) a high-K regime dominated by the material's inherent toughness, (2) an intermediate-K, flow-controlled regime, and (3) a low-K regime where full plasticization of craze fibrils drastically reduces lifetime [2]. By validating the LEFM approach, this study provides a transferable framework to guide the design of PE materials for improved long-term durability.

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<sup>&</sup>lt;sup>1</sup> Dipartimento di Chimica, Materiali e Ingegneria Chimica "Giulio Natta", Politecnico di Milano, Milano 20133, Italy

<sup>&</sup>lt;sup>2</sup> Versalis S.p.A., Mantua Research Center, Mantova 46100, Italy

<sup>\*</sup> federico.olla@polimi.it

# HLEBI (Homogeneous Low Potential Electron Beam Irradiation) Induced Strengthening of Proof Stress, Tensile Strength and Fracture Strain of 3D-Printed Short Carbon Fiber Reinforced Polylactic Acid (3D-SCFRPLA)

<u>Hirotaka Irie</u>\*1, Helmuttakahiro Uchida<sup>1,2</sup>, Kouhei Sagawa<sup>1</sup>, Eiichi Miura<sup>1,2,3</sup>, Michael C. Faudree<sup>2,4</sup>, Michell Salvia<sup>5</sup>, Hideki Kimura<sup>1,2</sup>, Yoshitake Nishi<sup>1,2,3,5</sup>

- <sup>1</sup> Graduate School of Engineering, Tokai University, 4-1, Kitakaname, Hiratsuka, 259-1292, Japan
- <sup>2</sup> Doctoral Graduate School of Science & Technology, Tokai University, 4-1, Kitakaname, Hiratsuka, 259-1292, Japan
- <sup>3</sup> KISTEC (Kanagawa Institute of Industrial Science & Technology), 705-1, Shimoimaizumi, Ebina, Kanagawa, 243-0435, Japan
- <sup>4</sup> Faculty of Liberal Arts and Science, TCU (Tokyo City University), Yokohama,224-8551, Japan <sup>5</sup> ECL (Ecole Centrale de Lyon), Ecully Cedex 69134, France

**Keywords:** toughness, electron beam irradiation, 3D-printing, short carbon fiber, Polylactic acid, tensile test

Although it is a serious problem for industrial applications, the short carbon fiber reinforced Ecofriendly Polylactic acid (PLA) articles shaped by 3D-printing (3D-SCFRPLA) shows weakness as well as brittle [1-2]. In order to improve the strength and fracture toughness, an optimal dose of HLEBI (homogeneous low potential electron beam irradiation) applied to both sides of 3D-SCFRPLA samples was found to increase the strength as evaluated by the parameters of proof stress ( $\sigma_p$ ), tensile strength ( $\sigma_{ts}$ ) and nominal tensile fracture strain including heterogeneous deformation ( $\epsilon_f$ ) and resistance energy of homogeneous deformation (Ehd). A low dose of HLEBI of 33 kGy at a low acceleration potential of 210 kV applied to both sides of 3D-SCFRPLA samples increased  $\sigma_p$ ,  $\sigma_{ts}$ , and  $\epsilon_f$  substantially higher than those for the untreated samples. The additional HLEBI dosage conditions apparently decreased all values less than untreated samples, consistent with typical radiation damage effects. Improvement in strengthening can be explained by enhanced CF/PLA interface adhesion induced by interface activation induced during dangling bonds generated by the irradiation, as well as by creating coherency in the interspace of solidification texture through relaxation of the polymeric chains via the polarization induced by electron charging [3].

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<sup>\* 4</sup>CEMM011@tokai.ac.jp

# Crystal Plasticity Finite Element Analysis of Wedge Indentation in Bulk and Bridge-Shape BCC Tungsten

Tevfik Ozan Fenercioğlu\*1, Michael Budnitzki1, Jin Wang2, Ruth Schwaiger2, Stefan Sandfeld1

Keywords: Crystal plasticity finite element method, Nanoindentation, BCC tungsten

The mechanical behavior of materials at different scales is being quantified through nanoindentation techniques (see e.g. [1]). This study employs crystal plasticity finite element modeling (CPFEM) to investigate nanoindentation behavior in body-centered cubic (BCC) single crystal tungsten, with a comparative focus on the effects of mechanical confinement in bulk versus bridge-type configurations. The bulk indentation setup is modeled under plane strain conditions, while the bridge configuration simulates a suspended micro-scale ligament with free boundaries, introducing distinct stress states and deformation modes. Simulations are conducted using a ratedependent CPFEM framework to analyze local slip activity, lattice rotation, and the evolution of crystallographic misorientation. Element-level analysis in the plastic zone beneath the indenter reveals notable differences in deformation behavior between the two configurations. In particular, bridge-type configuration results in pronounced lattice rotation due to modified boundary conditions and localized stress distributions. The study further identifies critical limitations of CPFEM in regions of severe deformation especially beneath the indenter tip where high strain gradients and excessive element distortion occur. This comparative modeling effort highlights both the strengths and current limitations of CPFEM in capturing orientation-dependent plasticity in BCC metals. The insights gained enhance the interpretation of experimental nanoindentation data and underscore the need for advanced modeling approaches to resolve mesoscale deformation phenomena under complex loading conditions.

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<sup>&</sup>lt;sup>1</sup> Institute for Advanced Simulation, Forschungszentrum Juelich GmbH, 52068 Aachen, Germany

 $<sup>^2</sup>$  Institute of Energy and Climate Research, Forschungszentrum Juelich GmbH, 52425 Juelich, Germany

<sup>\*</sup> o.fenercioglu@fz-juelich.de

# Predicting Embedded Crack Growth Behaviour Using S-Version Finite Element Method for AlSi10Mg Material

Nur Azihanim Abu Bakar<sup>1</sup>, <u>Mohd Shamil Shaari</u>\*<sup>1</sup>, Mohd Akramin Mohd Romlay<sup>1</sup>, Akiyuki Takahashi<sup>2</sup>

**Keywords:** metallic additive manufacturing, computational fracture mechanics, stress intensity factor (SIF)

dditive Manufacturing (AM) enables high-precision fabrication with minimal waste, making it vital in aerospace and automotive industries. However, AM components, particularly AlSi10Mg alloy, often face internal defects such as porosity and lack of fusion, leading to embedded cracks and reduced structural reliability under tensile loading. This study investigates the embedded crack growth behavior of AlSi10Mg using the S-version Finite Element Method (S-FEM), which combines a global-local mesh overlay technique with computational fracture mechanics. Validation is conducted through Paris' Law and Newman– Raju formulations. The simulation applies a 100 MPa tensile load to three aspect ratios (a/c = 0.5, 1.0, 2.0). Stress intensity factors (SIF) obtained from S-FEM are well aligned and closely with analytical results, showing low RMSE values of 0.13, 0.40, and 1.41, respectively. Qualitative analysis shows uniform crack propagation in a/c = 1.0 due to geometric symmetry, while a/c = 0.5 and 2.0 display linear trends as crack fronts separate from the surrounding geometry. These findings confirm S-FEM's efficiency in accurately predicting fatigue crack growth with reduced computational cost. The study supports the application of S-FEM as a reliable predictive tool for AM components in safety-critical environments.

<sup>&</sup>lt;sup>1</sup> Faculty of Mechanical and Automotive Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, 26600 UMPSA Pekan, Pahang, Malaysia

<sup>&</sup>lt;sup>2</sup> Department of Mechanical and Aerospace Engineering, Faculty of Science and Technology, Tokyo University of Science, 2641 Yamazaki, Noda, Chiba, 278-8510, Japan

<sup>\*</sup> shamil@umpsa.edu.my

# Preventing Failure in Cold Forging Dies Before Use: Neuro-Regression Modeling Assisted Shrink Fit Parameter Optimization

### Hande Savran\*, Tayfur Yavuzbarut, Kemal Bartu Aydın

Norm Tooling, R&D Center, İzmir, Türkiye R&D Center, İzmir, Türkiye

**Keywords:** shrink fit, cold forging die, modeling, optimization

This study presents a comprehensive data mining analysis conducted on frequently utilized cold forging die components, retrieved from a manufacturing database spanning the past year. Key geometric and material parameters, including outer case diameter, core outer and inner diameters, core height, material types, and angular configurations, were systematically collected. These parameters were subsequently correlated with the "Shrink Fit" performance, specifically evaluated under static conditions (0 MPa internal pressure), representing the absence of internal load. Experimental measurements were performed via simulation-supported software testing, and the resulting shrink fit ratio values were plotted against the ratio of the core outer diameter to its inner diameter. A predictive model was built by using multiple nonlinear neuro-regression approach. The results consistently demonstrated a clear inverse relationship: under static conditions, shrink fit ratio values decreased steadily from approximately %9.5 units to nearly %7.0 units as the Core Outer Diameter / Core Inner Diameter ratio increased from approximately 1.4 to 3.0. This trend indicates that a larger outer-to-inner core diameter ratio leads to reduced structural shrink fit ratio in the absence of internal pressure. The initial steep decline observed between ratios of 1.4 and 1.8 suggests a highly sensitive geometric region where minor changes can significantly compromise shrink fit ratio. Beyond a ratio of approximately 2.2, the curve flattened, implying a diminishing influence of the ratio on shrink fit ratio beyond this threshold. This behavior underscores that oversizing the outer diameter relative to the inner diameter can compromise initial form stability, which is critical in die design prior to pressurization. Consequently, a lower Core Outer Diameter/Core Inner Diameter ratio is vital for achieving higher initial shrink fit ratio and ensuring more reliable dimensional control during assembly. These findings were instrumental in establishing critical geometric limits for shrink fit ratio at 0 MPa, thereby facilitating the design of more robust and fracture-resistant die assemblies...

<sup>\*</sup> handeparlak35@gmail.com

# Multi-Objective Optimization of Aerospace Grid Panels Using RSO and MOGA

#### Shahrukh Khan\*, Saifur Rahman Bakaul

Department of Aerospace Engineering, Aviation and Aerospace University, Bangladesh, Lalmonirhat 5500

**Keywords:** Aerospace Grid Panels, Multi-object Genetic Algorithm (MOGA), Response Surface Optimization (RSO)

The work focuses on optimizing the critical buckling loads of six aerospace-grade aluminum stiffened panels using Ansys's built-in Response Surface Optimization (RSO) module. The stiffened panels analyzed include Iso grid type I, Iso grid type II, Waffle grid, Anisogrid, Xgrid, and Bigrid. These panels are evaluated under in-plane compressive loading conditions and optimized for critical buckling load using a Multi-Objective Genetic Algorithm (MOGA). This technique identifies Pareto optimal solutions representing the trade-offs between conflicting objectives and selects the most desirable design points. The primary goal is to maximize the critical buckling load by varying the stiffened panel thickness, stiffener thickness, and height while constraining the 3.8 kg mass. A Taguchi L81 orthogonal array is utilized to generate a design point for the present analysis. In addition, a genetic aggregation model is selected to fit the response surface. Numerical outcomes suggest that the Iso grid type I panel achieves the highest buckling value of 391.64 kN, which is 53.28% higher than that of the Bigrid stiffened panel, the latter showing the lowest value of 208.68 kN among all the panels. The Xgrid panel shows a high buckling load of 369.70 kN. On the other hand, the Anisogrid and Iso grid type II panels perform moderately with buckling loads of 312.90 kN and 293.01 kN, respectively. In contrast, the waffle panel falls into the criteria of the poorperforming panel, with a critical buckling load of 260.58 kN.

<sup>\*</sup> aero.shahrukh93@bsmraau.edu.bd

# Multi-scale Analysis of Orientation Deviations in CMSX-4 Turbine Blade

### Merthan Özdemir\*, Sadik S. Acar, Orhun Bulut, Tuncay Yalçinkaya

Department of Aerospace Engineering, Middle East Technical University, Ankara 06800, Türkiye

**Keywords:** CMSX-4, DAMASK, Orientation, Non-octahedral slip systems

In aerospace engine industry, CMSX-4 material has a significant position for the most critical parts of the turbomachinery such as turbine blades. Properties like improved creep strength, better thermal fatigue resistance and anisotropy (orientation) control are achieved thanks to its single crystal body. However, deviation of crystal orientation problems may arise depending on the circumstances of the production of such single crystal turbine blades [1]. In this study, a multiscale framework is developed to investigate the effects of crystal orientation variations, using ABAQUS for macroscale modeling and DAMASK for microscale modeling. A strain history of a node from macroscale model of turbine blade is obtained from an ABAQUS analysis, whose material parameters fitted to experimental data provided in literature [2]. Then it is given to a representative volume element (RVE) model in DAMASK as load input using a rate-dependent crystal plasticity constitutive model. The variations of crystal orientations are prescribed by using deviation angle  $\beta$  and randomness angle  $\alpha$  in RVE model with different sets of corresponding angles. The orientation dependent mechanical responses of RVEs are analyzed under cyclic loading with load-hold-unload periods.

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<sup>\*</sup> merthan.ozdemir@metu.edu.tr

# OXFORD-UMAT: An Efficient and Robust Crystal Plasticity Framework for Single and Polycrystal Applications

### Eralp Demir\*1, Chris Hardie2, Edmund Tarleton1

Keywords: crystal plasticity, FEM, GND, backstress, irradiation, residual stresses.

Crystal plasticity-based finite elements have been available for almost half a century starting with pioneering studies of Pierce, Asaro, and Needleman [1]. We have developed OXFORD-UMAT a crystal plasticity solver consisting of two different solvers that uses Cauchy stress and slip increments that offer efficiency or robustness levels that are demanded by large-scale simulations demanded by industry applications [2]. The code is available on Github open to public as a userdefined material subroutine (UMAT) for Abaqus in modular form [3]. The model can be used for applications in both 2D and 3D. The model is equipped with strain gradient models for the length scale-dependence of the strength. A new strain gradient model is available in which the solution is obtained by restricting the geometrically necessary dislocation densities (GND) to the active slip systems [4]. The back stress in the solver can be obtained by Armstrong-Frederick or a new GNDbased formulation [5]. Furthermore, the irradiation effects can be modelled through a simplified or rigorous treatment of irradiation-induced strengthening and softening. The proposed approach has proven capability to simulate various case studies including nanoindentation, micro-cantilever beam bending, nano-scratch tests, irradiation effects, residual stresses, transgranular fracture with cohesive elements and intragranular fracture using extended finite elements. The crystal plasticity framework delivers a highly accessible and intuitive interface for advanced microstructuresensitive modeling, empowering users to delve into the intricate dynamics of material behavior with unprecedented ease and precision.

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<sup>&</sup>lt;sup>1</sup> Department of Engineering Science, University of Oxford, Parks Road, Oxford, OX1 3PJ, UK

<sup>&</sup>lt;sup>2</sup> UK Atomic Energy Authority, Culham Centre for Fusion Energy, Oxfordshire OX14 3DB, UK

<sup>\*</sup> eralp.demir@eng.ox.ac.uk

# Three-dimensional Automatic Fatigue Crack Growth Procedure using Mesh Adaptation and Singular Elements

#### Hocine Kebir\*

Laboratoire Roberval, Department of Mechanical and Material Engineering, : Université de Technologie de Compiègne, France

**Keywords:** Dual boundary element method, Singular elements, Fracture mechanics, 3D crack propagation

In the present paper, a dual boundary element mesh adaptation procedure for 3D fatigue crack growth is presented. A six-node triangular singular element with plane geometry is developped to mesh crack front. Special shape functions with  $\sqrt(r)$  variation at the crack front are used to represent the displacements field and Stress Intensity Factors are calculated using a displacement extrapolation method. The computed SIFs are in good agreement with those obtained by other approaches (analytical or XFEM). Crack propagation is simulated using an incremental crack extension analysis and stress intensity factors computed for each crack growth increment. At each crack growth increment, both the curve where the new crack front intersect the free surface and a local area around it are rediscretized according to a strategy based on a local mesh adaptation procedure. The whole crack propagation is totally automatic, with repeated remeshing at each extension without user intervention. The procedure was effectively employed to simulate the propagation of both embedded and surface cracks under mixed mode loading and the given examples show the accuracy and ability of the method to simulate a crack path consistent with qualitative expectations.

<sup>\*</sup> Hocine.kebir@utc.fr

# Combined Experimental and Numerical Investigation of Laser Shock Peening for Fatigue Crack Retardation in Additively Manufactured Aluminum Alloy Sheets

Dominik PoeltI\*1, Anton Odermatt2, Volker Ventzke2, Nikolai Kashaev2, Benjamin Klusemann1,2

**Keywords:** finite element analysis, additive manufacturing, fatigue crack propagation

Additive manufacturing (AM) was developed to industrial applicability and viability over the past decade. While it promises near final shape fabrication, defects in fabrication and a complex residual stress state lead to a high scatter in the mechanical properties of AM specimen and ultimately to an inferior fatigue life, e.g. faster fatigue crack propagation (FCP) [1]. Laser shock peening (LSP) is a highly controllable technique for advantageous local manipulation of the residual stress (RS) field: Compressive stresses near the surface retardate the propagation of an initial crack. A validated process model can predict fatigue performance and avoid costly and timeconsuming testing [2]. For this work, a wire-fed laser metal AM (LMD) process manufactured walls made of the aluminum alloy AA-5087. Standardized C(T)50-specimen are extracted by subtractive milling and undergo a subsequent treatment of LSP. Finally, the fatigue performance is evaluated through FCP tests. This work establishes a multi-step, finite-element process model for all three subprocesses: A simulation of a small number of laser shots using an adequate material model enables the use of the eigenstrain method to model large-area LSP treatment. The RS field after the AM process, determined from a thermomechanical model, is superposed with the eigenstrains from LSP. Using fracture mechanics, the total stress intensity factor at the crack tip is determined to predict the FCP rate of the C(T)50 specimen. The results, gained from a macroscopic material model, back up the claim that residual stresses influence the fatigue performance more than microstructure. Furthermore, the relation of build direction and initial crack orientation is investigated.

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<sup>&</sup>lt;sup>1</sup> Institute of Production Technology and Systems, Leuphana University Lüneburg, Germany

<sup>&</sup>lt;sup>2</sup> Helmholtz-Zentrum Hereon, Institute of Materials Mechanics, Geesthacht, Germany

<sup>\*</sup> dominik.poeltl@leuphana.de

### Design Optimization and Analytical Investigation of 3D-Printed Composite Lattice Structures

### Thomas Panagiotopoulos\*1, Michel Mansour1, Constantine David2, Dimitrios Tzetzis3, Konstantinos Tsongas1, Apostolos Korlos1

- <sup>1</sup> Advanced Materials and Manufacturing Technologies Laboratory, Department of Industrial Engineering and Management, School of Engineering, International Hellenic University, 57400 Thessaloniki, Greece
- <sup>2</sup> Manufacturing Technology and Production Systems Laboratory, Department of Mechanical Engineering, School of Engineering, International Hellenic University, 62124 Serres, Greece
- <sup>3</sup> Digital Manufacturing and Materials Characterization Laboratory, School of Science and Technology, International Hellenic University, 57001 Thessaloniki, Greece

Keywords: additive manufacturing, lattice structures, mechanical performance

The demand for lightweight, high-performance structures in transportation and mobility sectors has driven the development of architected materials and advanced additive manufacturing techniques. Among these, 3D-printed lattice structures offer unique opportunities to tailor mechanical response through geometry and material design. When combined with composite filaments—thermoplastic matrices reinforced with discontinuous high-performance fibers such as carbon, glass—these structures exhibit enhanced mechanical properties with programmable stiffness [1]. The focus was placed on identifying structural configurations and filament compositions that promote either bending- or stretching-dominated behavior, depending on the application requirements. A parametric design framework was developed to explore a wide range of lattice topologies, enabling systematic analysis of their influence on global beam response under tensile and bending loads [2,3]. Analytical expressions were formulated to predict the mechanical performance of the composite lattice beams, allowing for the evaluation of key parameters such as bending stiffness, stress distribution, and deformation mechanisms. The relationship between unit cell architecture and dominant deformation mode was critically examined. The results indicated that specific combinations of lattice geometry and filament composition could be tailored to exhibit either bending-dominated or stretching-dominated behavior. This tunability demonstrates the potential of such structures for customized mechanical performance in lightweight structural components, particularly in sectors where directional stiffness and load-specific response are critical.

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<sup>\*</sup> thomas.a.panagiotopoulos@gmail.com

cated by selective laser melting. Materials, 17(17), 4433.

# Influence of Loading Control in obtaining Tensile Strength and Fracture Properties of Rock

S V Dharani Raj<sup>\*1</sup>, Thanh Nhan Nguyen<sup>1</sup>, Zili Huang<sup>1</sup>, Giang D. Nguyen<sup>1</sup>, Murat Karakus<sup>2</sup>, Ha H. Bui<sup>3</sup>, Dat Phan<sup>1</sup>

- <sup>1</sup> School of Architecture and Civil Engineering, The University of Adelaide, Adelaide, Australia
- <sup>2</sup> School of Chemical Engineering, The University of Adelaide, Adelaide, Australia
- <sup>3</sup> Department of Civil Engineering, Monash University of Adelaide, Clayton, Australia

**Keywords:** snapback, tensile strength, fracture energy

Understanding the behavior of brittle materials such as rock is very important when mining for valuable geological materials and minerals. In this regard, understanding Snapback behavior, a post-peak strain reversal response, exhibited by class-II brittle rocks [1] is of utmost importance. The control method used during the testing influences the fracturing behavior of the specimen and hence the obtained strength and fracture energy. Therefore, it is crucial to understand the influence of the control methods in the tensile and fracture behavior of rocks for accurately characterizing fracture properties. In view of this, conventional Brazilian disc tests on Sandstone specimens have been carried out in parallel with the snapback control based on AUSBIT (Advanced Universal Snapback Indirect Tensile) testing method [2]. AUSBIT utilizes an indirect control approach, to stabilize fracturing process and hence enables capturing snapback behavior. This stabilization also effectively helps minimize dynamic effects to obtain intrinsic properties. The experimental results reveal significant variations in tensile strength measured using the AUSBIT method compared to traditional Brazilian Disc testing while also providing good estimation of fracture energy compared to three-point bending tests. This discrepancy highlights the effectiveness of AUSBIT in accurately reflecting the underlying fracture mechanisms through indirect strain-rate control. These findings offer important insights into rock fracture behaviors and support the potential of AUSBIT as a valuable tool for studying fracturing behavior in brittle materials, thus helping in better understanding the

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<sup>\*</sup> a1882372@adelaide.edu.au

# Comparison of FE and SPH analyses for predicting the ballistic impact response of Weldox 700E

#### Yunus Emre Ozsoy\*, Hande Vural, Tuncay Yalçinkaya

Department of Aerospace Engineering, Middle East Technical University, Ankara 06800, Turkey

**Keywords:** Smoothed particle hydrodynamics (SPH), Finite element method (FEM), Ballistic impact

Ballistic impact resistance of high-strength steels is of great importance in both military and civilian protection systems, where multi-layer configurations are often adopted to enhance energy absorption and delay perforation [1,2]. Numerical methods such as the Finite Element (FE) method and Smoothed Particle Hydrodynamics (SPH) provide valuable tools for modelling ballistic impact phenomena [3,4], reducing the need for extensive experimental testing and enabling the evaluation of multiple configurations. In this study, the ballistic response of Weldox 700E steel is investigated using FE and SPH approaches. Experimental data are adopted from [5], where Weldox 700E plates are tested under blunt and ogival projectile impacts. A temperature- and strain-ratedependent Modified Johnson-Cook (MJC) plasticity model is implemented in VUHARD, while the MJC damage model and several single-parameter uncoupled damage models are integrated into VUSDFLD. Explicit simulations are carried out in Abagus for target configurations including 12 mm monolithic, 6 mm monolithic, and  $2 \times 6$  mm double-layered. The FE method exhibits good agreement with experimental results for ogival-nosed projectiles, whereas significant deviations are observed for blunt-nosed projectiles. In contrast, the SPH approach provides more accurate predictions for blunt-nosed projectile impacts. Furthermore, a comparative assessment of different damage models was conducted, including simplified single-parameter formulations benchmarked against the MJC predictions.

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<sup>\*</sup> yunus.ozsoy@metu.edu.tr

### Investigation of Tensile Behavior in FRP-reinforced Concrete Ties with Various Bond-slip Models

<u>Lei Yuan</u>\*<sup>1</sup>, Chao Wang<sup>1</sup>, Jaime Gonzalez-Libreros<sup>1</sup>, Zheng Huang<sup>2</sup>, Lennart Elfgren<sup>1</sup>, Gabriel Sas<sup>1</sup>

Keywords: FRP-reinforced concrete ties, FEM, Bond-slip models

FRP-concrete bond-slip behavior significantly affects the stress transfer and mechanical properties of FRP-RC structures. The assumption of a perfect FRP-concrete bond is often used in FEMbased studies of FRP-RC structures. However, this assumption can reduce the accuracy of the simulated results, particularly in those practical cases where the FRPconcrete bond is insufficient. Several studies have investigated the complexities of FRPconcrete interaction and proposed bondslip models to address this issue. In tensile tests on FRP-RC ties, the increased length allows for the development of multiple cracks and the assessment of distributed FRP-concrete interaction in the tensile stress field. The applicability of bond-slip models for simulating tensioned FRP-RC ties requires evaluation. In this study, the tensile response of FRP-RC ties is investigated through FEM, incorporating various bondslip models from pullout tests via cohesive element approach. The analysis focuses on crack development, load-deformation behavior, and the distribution of slip and bond stress. A comparative study between the CMR (Cosenza-Manfredi-Realfonzo) and mBPE (modified Bertero-Popov-Eligehausen) models is conducted to investigate the influence of bond-slip model's ascending branch slope on structural response. The effect of bar diameter is also investigated. This study allows for an examination of the role of FRP-concrete bond-slip behavior in the structural response of ties and tension-critical zone of beams.

<sup>&</sup>lt;sup>1</sup> Division of Structural and Fire Engineering, Luleå University of Technology, 97187, Luleå, Sweden

<sup>&</sup>lt;sup>2</sup> Department of Structural Engineering, Tongji University, 200092, Shanghai, China

<sup>\*</sup> lei.yuan@ltu.se

# Assessing Grain Size Effects on Hydrogen-Assisted Cracking via Strain Gradient Crystal Plasticity

#### Berkehan Tatli\*, Tuncay Yalçınkaya

Department of Aerospace Engineering, Middle East Technical University, Ankara 06800, Türkiye

**Keywords:** strain gradient crystal plasticity, cohesive zone modelling, hydrogen enhanced decohesion

Hydrogen embrittlement is a critical degradation mechanism in metallic materials, where absorbed hydrogen atoms significantly reduce ductility, fracture toughness, and fatigue resistance [1]. This phenomenon compromises the structural integrity of components across a wide range of engineering applications. Although hydrogen-assisted cracking has been well studied at the macroscopic scale, the effects of microstructural features at the mesoscale are yet to be fully understood. When analyzing hydrogen redistribution at this scale, the role of grain boundary constraints in hydrogen transport should be considered, as strain gradient hardening is known to play an important role in fracture [2]. Regardless of specimen size, the plastic zone ahead of a crack tip is very small and develops sharp spatial gradients of deformation, which create plastic strain gradients and geometrically necessary dislocations (GNDs). In these regions, hydrostatic stress gradients become strongly localized and significantly affect the redistribution of hydrogen at the grain scale. Driven by these considerations, and to investigate the influence of grain size as a key microstructural feature, this study employs a strain gradient crystal plasticity framework coupled with a hydrogen diffusion model and a potential-based mixed-mode cohesive zone model to simulate crack initiation and propagation in polycrystalline microstructures. The model captures the effects of strain gradients on hydrogen transport through GND-induced diffusion paths and on the hydrogen-enhanced decohesion mechanism by amplifying stress concentrations [3]. Simulations are performed on microstructures with varying grain sizes to evaluate the influence of grain morphology. The findings are compared with existing literature, and the influence of grain size are re-examined alongside the contributions of non-local strain gradient effects.

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<sup>\*</sup> berkehan.tatli@metu.edu.tr

### Flat-Plate Voided Slabs: Design and Construction COnsiderations

#### Ahmad Tarawneh\*1, Roaa Alawadi<sup>2</sup>

- <sup>1</sup> Department of Civil Engineering, The Hashemite University, Zarqa, Jordan
- <sup>2</sup> Department of Civil Engineering, Applied Science Private University, Amman, Jordan

Keywords: Voided slab, flexural strength, shear and stiffness reduction factors

The voided slab system has been widely used in Europe, and it is gaining more acceptance in the United States, Middle-East, and other parts of the world for its various advantages. The reduced self-weight of voided slabs can result in longer spans, less load on columns and foundations, less seismic load, and economical design [1]. The specific structural behavior of voided slabs must be considered in design and construction; therefore, several studies investigated the strength and serviceability limit states of voided slabs. However, the ACI 318-19 does not provide explicit provisions for voided slabs [2]. This paper aims to provide guidelines for engineers to outline the voided slab system and highlight design and construction considerations for the system. The paper discusses the development, flexural design, deflection, one-way shear, punching shear, local punching, fire resistance, and construction considerations. The paper shows utilizes experimental databases [3] to show that a voided slab system can be designed using the current ACI provisions with some considerations.

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<sup>\*</sup> ahmadn@hu.edu.jo

### A Materials Informatics Approach to Understand Damage, Fracture and Degradation in Lithium Ion Batteries

#### Anil Kunwar\*1, Nele Moelans<sup>2</sup>

**Keywords:** Lithium ion battery, Named entity recognition, Diffusion induced stress, Cyclic mechanical damage, Micro-cracking, Electrical response, Battery informatics, Self-attention

Lithium-ion batteries (LIBs) are pivotal for energy storage, yet their longevity and safety are hindered by damage, fracture, and degradation processes. This study introduces a materials informatics [1] framework to systematically analyze these phenomena using advanced natural language processing and network analysis. From a curated set of seminal works on LIB degradation, a word cloud and co-occurrence network are generated to extract key terms [2-5], including but not limited to "electrode cracking," "SEI formation," "cyclic mechanical damage," "diffusion-induced stress," and "electrical response." These key terms inform a SciBERT-based multihead attention mechanism [6,7] to score the relevance of arXiv preprint abstracts, enabling the creation of a targeted database of pertinent studies. the prevalence and context of critical terms related to damage, fracture, and degradation in LIBs, including micro-cracking and electrical response, are statistically quantified. This scalable, data-driven approach maps the research landscape, identifies emerging trends, and highlights key mechanisms like diffusion-induced stress for further experimental and computational exploration, fostering the development of durable, high-performance LIBs.

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<sup>&</sup>lt;sup>1</sup> Faculty of Mechanical Engineering, Silesian University of Technology, Gliwice 44-100, Poland

<sup>&</sup>lt;sup>2</sup> Department of Materials Engineering, KU Leuven, Leuven 3001, Belgium

<sup>\*</sup> anil.kunwar@polsl.pl

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### To the Analytical and Numerical Solutions for the Toroidal Shells Subjected to Mechanochemical Corrosion

#### Alexander Ilyin\*

Department of computational methods in mechanics, Saint-Petersburg State University, Saint-Petersburg 199034, Russia

Keywords: Toroidal vessel, Curved tube, Corrosion, Stress-assisted wear, Analytical solution

The availability of analytical solutions for the durability of toroidal shells subjected to simultaneous action of pressure and aggressive environments would significantly accelerate the process of engineering design. Most of the works devoted to mechanochemical corrosion of pressurized shells are focused on the study of pipes and spherical vessels [1-2]. Unlike a circular cylinder under plane strain conditions, a toroidal shell under pressure has a nonuniform distribution of the circumferential stresses along the surface. This paper examines several existing approximate closed-form static solutions for pressurized toroidal shells [3-4] and evaluates their accuracy against finite element simulations. Modifications to these solutions are proposed to enhance their precision in strength analysis. Additionally, approximate analytical solutions are derived to estimate the lifetime of toroidal shells subjected to one- or double-sided mechanochemical corrosion under internal and external pressures. Notably, it is demonstrated that mechanochemical effects can shift the location of maximum stresses on the inner surface. The influence of a symmetry conditions on finite element results was also examined. A comparative analysis was performed for the results obtained using a full torus cross-section model and a half-section torus model with applied symmetry conditions.

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<sup>\*</sup> st111425@student.spbu.ru

# The Effect of Post-processes on Microstructure and Mechanical Performances of Inconel 718 Produced by Cold Spray Additive Manufacturing

#### Oğuzhan Kurt\*, Mehmet Mutlu, Aptullah Karakaş, Tevfik Ozan Fenercioğlu

Repkon Machine and Tool Industry, Istanbul 34980, Türkiye

Keywords: Cold Spray Additive Manufacturing, IN718, Post Heat Treatment

Cold Spray Additive Manufacturing (CSAM) presents a promising solid-state route for fabricating nickel-based superalloys like Inconel 718, especially when minimizing thermal distortion and oxidation is critical [1]. However, the as-sprayed structure often suffers from high porosity and limited ductility, necessitating effective post-processing. In this study, Inconel 718 samples produced via CSAM were subjected to varying post-heat treatments (PHT) and hot isostatic pressing (HIP) to assess their influence on porosity, microstructure, and mechanical behavior. While aging after 1200°C PHT led to brittle fracture, increasing the PHT temperature to 1230°C significantly reduced porosity and restored ductility. The addition of HIP allowed for similarly improved outcomes at lower PHT temperatures (down to 1066°C), demonstrating a thermal processing advantage. Microstructural characterization revealed recrystallization of dendritic features and the formation of fine-grained structures, with nanoscale  $\gamma'$  and  $\gamma''$  precipitates forming during aging. The combination of optimized thermal and pressure treatments led to enhanced tensile properties, including strength values exceeding AMS 5663 standards. These results provide a practical framework for tuning CSAM process parameters to achieve near-wrought quality in IN718 components, with implications for both manufacturing and repair applications in demanding service environments.

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<sup>\*</sup> oguzhan.kurt@repkon.com.tr

### Evaluation of Uncoupled Ductile Damage Models in Deep Drawing of AA2024

#### Sümeyye Tekbas\*, Hande Vural, Tuncay Yalçinkaya

Department of Aerospace Engineering, Middle East Technical University, Ankara 06800, Türkiye

Keywords: anisotropy, uncoupled damage model, deep drawing

Deep drawing is a widely used sheet metal forming process in the automotive, aerospace, and many other industries due to its ability to produce components with a high strength-to-weight ratio. The anisotropic behavior of sheet metals resulting from the rolling process can be modeled using different criteria. Among these, one of the most commonly applied approaches in the literature is the Hill'48 yield criterion, which has been widely applied to aluminium alloys and DC04 steel sheets [1,2]. The parameters of the Hill'48 criterion can be determined through two alternative methods: based on r-values (Hill'48-R) or on yield stresses (Hill'48-S). This difference in parameter identification has a significant influence on the accuracy of fracture predictions. Therefore, examining the interaction between anisotropy descriptions and ductile damage models is essential for achieving reliable fracture assessment. In this study, a numerical investigation of the deep drawing behavior of AA2024-T3 aluminium alloy is presented. Isotropic von Mises, Hill'48-R, and Hill'48-S yield criteria are combined with ten widely used uncoupled ductile damage models in metal forming [3,4]. All numerical simulations are performed in Abaqus/Explicit, and the predicted damage accumulation is systematically compared with experimental data reported in the literature [5]. The results indicate that the choice of anisotropy representation, together with the selected damage model formulation, strongly influences the accuracy of fracture prediction.

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<sup>\*</sup> sumeyye.tekbas@metu.edu.tr

### Neural Network Interatomic Potentials for Open Surface Nano-mechanics Applications

Amirhossein Naghdi Dorabati\*<sup>1</sup>, Franco Pellegrini<sup>2</sup>, Emine Küçükbenli<sup>3</sup>, Dario Massa<sup>1</sup>, Javier Dominguez–Gutierrez<sup>1</sup>, Efthimios Kaxiras<sup>4</sup>, Stefanos Papanikolaou<sup>1</sup>

**Keywords:** Machine Learning Interatomic Potentials, Plastic Deformation, Nano-mechanical testing

Material characterization in nano-mechanical tests may provide information on the potential heterogeneity of mechanical properties. Here, we develop a robust neural-network interatomic potential (NNIP) [1, 2], and we provide a test for the example of molecular dynamics (MD) nanoindentation, and the case of body-centered cubic crystalline molybdenum (Mo). We employ a similarity measurement protocol, using standard local environment descriptors, to select ab initio configurations for the training dataset that capture the behavior of the indented sample. We find that it is critical to include generalized stacking fault (GSF) configurations, featuring a dumbbell selfinterstitial on the surface, to capture dislocation cores, and also high-temperature configurations with frozen atom layers for the indenter tip contact. We develop a NNIP with distinct dislocation nucleation mechanisms, realistic generalized stacking fault energy (GSFE) curves, and an informative energy landscape for the atoms on the sample surface during nanoindentation. We compare our NNIP results with nanoindentation simulations, performed with three existing potentials – an embedded atom method (EAM) potential, a gaussian approximation potential (GAP) [3], and a tabulated GAP (tabGAP) [4] potential – that predict different dislocation nucleation mechanisms, and display the absence of essential information on the shear stress at the sample surface in the elastic region. Finally, we compared our NNIP nanoindentation results with experiments, showing reliable predictions for reduced Young's modulus and observable slip traces.

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NOMATEN Centre of Excellence, ul. A. Sołtana 7, 05-400 Swierk/Otwock, Poland

<sup>&</sup>lt;sup>2</sup> International School for Advanced Studies (SISSA), Via Bonomea, 265, I-34136 Trieste, Italy

<sup>&</sup>lt;sup>3</sup> Nvidia Corporation, Santa Clara, CA, USA

<sup>&</sup>lt;sup>4</sup> John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, USA

<sup>\*</sup> amirhossein.naghdi@ncbj.gov.pl

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### Chemical and Mechanical Stability of 3D-printed HTiO Monoliths for Lithium Recovery from Brines

#### Ewa Knapik\*

Faculty of Drilling, Oil and Gas, AGH University of Krakow, al. A. Mickiewicza 30, 30-059 Krakow, Poland

Keywords: sorbent, lithium recovery, mechanical stability

Lithium recovery from brines is becoming increasingly critical due to the rapid growth of battery technologies. Among the various extraction techniques, sorption methods are the most widely applied, with hydrogen titanate (H2TiO3) demonstrating excellent selectivity for Li<sup>+</sup> ions, chemical stability, and high recyclability [1, 2]. H2TiO3 can be fabricated in multiple engineered forms, including granules, extruded bodies, porous foams, and, more recently, 3D-printed monolithic structures, allowing for optimized mechanical and flow properties [3]. In this study, gyroid-shaped H2TiO3 monoliths with honeycomb-like cross-sections were prepared via SLA 3D printing. The fabrication process included resin-alumina composite printing, high-temperature calcination to generate a porous ceramic skeleton, coating with lithium titanate and a mineral binder, a second calcination, and final acid activation. These monoliths were evaluated for lithium recovery from a real brine containing 196 ppm Li and 224 g/L total salinity. Ten consecutive sorption-desorption cycles were conducted in flowthrough columns, each consisting of 24 h brine percolation and 3 h desorption with 0.2 M HCI. Lithium recovery efficiency was monitored based on Li concentrations in the feed and eluates. The results demonstrated that the sorbent is chemically stable, with mass loss not exceeding 2.43%, although the surface became rougher and more heterogeneous after cycling. Compressive strength decreased from 9.45 MPa after calcination to 7.23 MPa, remaining sufficient for practical column operation. Structural characterization, including BET surface area and pore distribution, as well as SEM-EDS analysis, confirmed the preservation of the sorbent's morphology and elemental composition. The monolithic design, featuring highly porous, tortuous channels, maximized contact between brine and sorbent, contributing to high lithium recovery

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<sup>\*</sup> eknapik@agh.edu.pl

# Solid Particle Erosion: Mechanisms, Models and Anti-Wear Advanced Coatings

#### Hamza A. Al-Tameemi\*1, Amnah M. Ibraheem2, Estabraq K.Abbas 2, Israa H. Hilal2

Keywords: Solid particles erosion, Erosion wear models, Erosion of Advanced Coating

This review provides a foundational understanding of solid particle erosion (SPE)— a major cause of surface damage in machine elements—by examining its core mechanisms, predictive models, and the use of advanced coatings as a countermeasure. The evolution of SPE models, from foundational theories like Finnie's to more comprehensive and applicationspecific models, is presented alongside a critical discussion of their limitations, particularly in addressing complex microstructures, temperature effects, and synergistic erosion mechanisms [1]. A primary focus is placed on the role of advanced coatings as a solution to SPE. The review finds that the anti-wear performance of these coatings, which may include elements like Titanium (Ti), Nickel (Ni), carbides, and Diamond-Like Carbon (DLC) [2], is contingent upon critical properties such as hardness and adhesive strength. Furthermore, it highlights how the precise control of coating composition, microstructure, and deposition parameters, such as those used in techniques like Plasma-Assisted Chemical Vapor Deposition (PACVD), is paramount for achieving superior and customized erosion resistance [3].

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<sup>&</sup>lt;sup>1</sup> Mechanical Engineering Department, College of Engineering, University of Baghdad, Baghdad, Iraq.

<sup>&</sup>lt;sup>2</sup> Scientific Research Commission, Baghdad, Iraq

<sup>\*</sup> hamza.al-tameemi@coeng.uobaghdad.edu.iq

### Geometry Effect on the Tensile Behavior of High-grade Aluminum Tubular Adhesive Joints

Américo J.S. da Costa<sup>1</sup>, Raul D.S.G. Campilho<sup>\*1,2</sup>, José F.B. Martins<sup>1</sup>, Miguel J.R. Queirós<sup>1</sup>, K. Madani<sup>3</sup>

- <sup>1</sup> CIDEM, ISEP School of Engineering, Polytechnic of Porto, R. Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal.
- <sup>2</sup> Institute of Science and Innovation in Mechanical and Industrial Engineering, Rua Dr. Roberto Frias, 400, 4200-465 Porto, Portugal
- <sup>3</sup> Department of Mechanical Engineering, University of Sidi Bel Abbes, BP 89, Cité Ben M'hidi, 22000, Sidi Bel Abbes, Algeria

Keywords: Tubular adhesive joints, Finite Element Method, Cohesive Zone Models

With the growth in the use of structural adhesive joints, especially in the aeronautical industry, there is a need for more accurate simulation tools, such as the finite element method (FEM) which, combined with cohesive zone models (CZM), make it possible to design and predict the performance of these joints. Adhesive joints are widely used in industries such as aerospace, aeronautics, automotive, construction, and electronics.

This work aims to experimentally and numerically evaluate the tensile strength of tubular adhesive joints using the adhesives Araldite AV138 and Araldite 2015. The study analyses the influence of geometric parameters such as the overlap length  $(L_o)$ , the thickness of the adherends  $(t_s)$ , and the outer diameter of the inner adherend  $(d_{si})$  on the mechanical behaviour of the joints. As part of the experimental work, the specimens are manufactured and experimental tests are carried out, with the data analysed later. In the numerical work, models are created in the Abaqus software, using a triangular CZM to simulate the behaviour of the joints until failure. The numerical parametric study aims to evaluate the influence of geometric parameters on the stress distributions and load capacity of the joints.

The tested CZM was successfully validated after comparison with experimental data. The parametric study revealed that the adhesive Araldite 2015 generally performed better in terms of strength and energy dissipation. Increasing  $L_o$  and  $d_{si}$  proved to be very beneficial for the performance of the joints, while varying  $t_s$  showed only slight changes in their behaviour

<sup>\*</sup> raulcampilho@gmail.com

# Tensile and Shear Cohesive Law Estimation of Sheet Molding Compound

Pedro M.M. da Silva<sup>1</sup>, Raul D.S.G. Campilho<sup>\*1,2</sup>, André L. Faria<sup>1</sup>, Abílio J.A. Vieira<sup>1</sup>, Kouider Madani<sup>3</sup>

Keywords: Sheet molding compound, Fracture toughness, Cohesive Zone Models.

In the development of engineering projects, material selection is one of the most critical factors influencing the final product's performance, efficiency, and cost. A correct or incorrect choice directly affects the product's overall quality. Therefore, a comprehensive understanding of material behaviour is essential, requiring accurate determination and documentation of its properties. Sheet Moulding Compound (SMC) is a fibre-reinforced thermoset composite material, widely used in automotive, aerospace, and electrical industries due to its high strength-to-weight ratio, corrosion resistance, and suitability for complexshaped components. This work experimentally and numerically investigates the mechanical behaviour of a SMC with varying concentrations of fiberglass. Experimental fracture tests were conducted to assess the fracture toughness, namely the Double Cantilever Beam (DCB) and End-Notched Flexure (ENF) tests to estimate the tensile  $(G_{IC})$  and shear fracture toughness  $(G_{IIC})$ , respectively. Following the experimental phase, the same tests were replicated through numerical simulations using the Abagus software and cohesive zone models (CZM) to validate and compare the results between the different fibreglass concentrations. The study concludes that increasing the fiberglass content enhances the mechanical properties of the material, particularly when fibres are properly oriented. CZM laws were proposed that can be used in the design of SMC-based structures.

<sup>&</sup>lt;sup>1</sup> CIDEM, ISEP – School of Engineering, Polytechnic of Porto, R. Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal

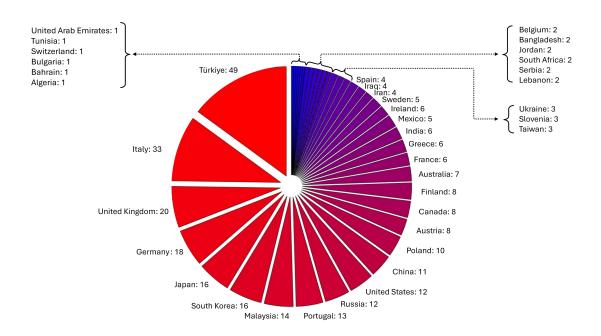
<sup>&</sup>lt;sup>2</sup> Institute of Science and Innovation in Mechanical and Industrial Engineering, Rua Dr. Roberto Frias, 400, 4200-465 Porto, Portugal.

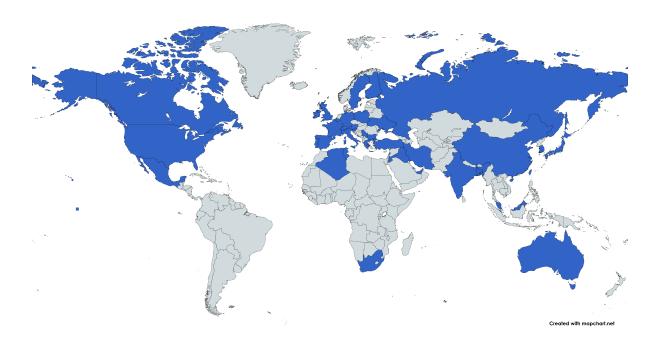
<sup>&</sup>lt;sup>3</sup> Department of Mechanical Engineering, University of Sidi Bel Abbes, BP 89, Cité Ben M'hidi, 22000, Sidi Bel Abbes, Algeria

<sup>\*</sup> raulcampilho@gmail.com

### **Co-authors List**

### **Statistics**





### List

A.I. Bolotnikov	A.A. Baikov Institute of Metallurgy and Materials Science,
	Russia
Abdul Hadi Azman	Universiti Kebangsaan Malaysia, Malaysia
Abdullah Helmi Isahak	Universiti Pertahanan Nasional Malaysia, Malaysia
Abdurrahim Kubat	TUSAŞ Engine Industries, Inc., Türkiye
Abílio Silva	University of Beira Interior, Portugal
Abílio Vieira	Polytechnic of Porto, Portugal
Adem Yılmaz	TUSAS Engine Industries Inc., Türkiye
Ahmad Kamal Ariffin	Universiti Kebangsaan Malaysia, Malaysia
Ahmad Tarawneh	The Hashemite University, Jordan
Ahmed Nsir	University of Quebec in Abitibi-Témiscamingu, Canada
Ahmet Çevik	Middle East Technical University, Türkiye
Ajith Ramesh	Amrita School of Engineering, India
Akiyuki Takahashi	Tokyo University of Science, Japan
Albena Doicheva	University of Architecture, Civil Engineering and Geodesy
	(UACEG), Bulgaria
Albert E. Patterson	Texas A&M University, United States
Albert Patterson	Texas A&M University, United States
Aleksandr Volkov	Saint Petersburg State University, Russia
Alexander Arutyunyan	Saint Petersburg State University, Russia
Alexander Ilyin	Saint Petersburg State University, Russia
Alma Brambilla	Politecnico di Milano, Italy
Alperen Demirtaș	Middle East Technical University, Türkiye
Altan Kayran	Middle East Technical University, Türkiye
Amine Ammar	LAMPA, France
Amir Khodabakhshi	LUT University, Finland
Amirhossein Jabbari Mostahsan	Graz University of Technology, Austria
Amirhossein Lame Jouybari	Jožef Stefan institute, Slovenia
Amirhossein Naghdi Dorabati	NOMATEN Centre of Excellence, Poland
Amnah M. Ibraheem	Scientific Research Commission, Iraq
Américo da Costa	Polytechnic of Porto, Portugal
Ana Reis	University of Porto, Portugal
Ananthu Jayakumar	Amrita School of Engineering, India
Andrea Ceccacci	University of Cassino and Southern Lazio, Italy
Andreas Hütter	Graz University of Technology, Austria
André Faria	Polytechnic of Porto, Portugal
Angelo Tatì	SSPT-TIMAS-MADD, ENEA , Italy
Anil Kunwar	Silesian University of Technology, Poland
Anna Fesenko	Odesa I.I. Mechnikov National University, Ukraine
Anton Odermatt	Helmholtz-Zentrum Hereon, Germany
Antti Kaijalainen	University of Oulu, Finland
Apostolos Korlos	International Hellenic University, Greece

Aptullah Karakaş	REPKON Machine and Tool Industry, Türkiye
Atsushi Kondo	Nippon Institute of Technology, Japan
Aytekin Demirci	Forschungszentrum Jülich, Germany
Azli Arifin	Universiti Kebangsaan Malaysia, Malaysia
Barış Akış	Middle East Technical University, Türkiye
Benjamin Cameron	University of Southampton, United Kingdom
Benjamin Klusemann	Leuphana University of Lüneburg, Germany
Benjamin Treude	TH Köln - University of Applied Sciences, Germany
Berkehan Tatli	Middle East Technical University, Türkiye
Bong-Hwan Kim	Korea Institute of Industrial Technology, South Korea
Byoung-Ho Choi	Korea University, South Korea
Cagri Ayranci	University of Alberta, Canada
Can Erdoğan	Middle East Technical University, Türkiye
Cem Guzelbulut	Kahramanmaras Istiklal University, Türkiye
Chao Wang	Luleå University of Technology, Sweden
Cheng-Ling Tai	National Taiwan University, Taiwan
Chris Hardie	UK Atomic Energy Authority, United Kingdom
Chuin Hao Chin	Universiti Kebangsaan Malaysia, Malaysia
Chunyang Zhang	Northwestern Polytechnical University, China
Constantine David	International Hellenic University, Greece
Daniele Mirabile Gattia	SSPT-TIMAS-MADD, ENEA, Italy
Danylo Selivanov	S.P. Timoshenko Institute of Mechanics, Ukraine
Dario Massa	NOMATEN Centre of Excellence, Poland
Dat Phan	The University of Adelaide, Australia
Davide Bigoni	University of Trento, Italy
Demirkan Çöker	Middle East Technical University, Türkiye
Denis Anders	TH Köln - University of Applied Sciences, Germany
Dimitrios Tzetzis	International Hellenic University, Greece
Dino Ferri	Versalis S.p.A., Italy
Dmitry Dudka	Institute of Petrochemical Synthesis, Russia
Do Yeon Lee	Kyung Hee University, South Korea
Domenico Capuani	University of Ferrara, Italy
Dominik Poeltl	Leuphana University Lüneburg, Germany
Dong-Earn Kim	Korea Institute of Industrial Technology, South Korea
Dong-Hyeon Choi	Kyung Hee University, South Korea
Doruk Özyürek	Middle East Technical University, Türkiye
Eda Aydoğan	Middle East Technical University, Türkiye
Edmund Tarleton	University of Oxford, United Kingdom
Edoardo Proverbio	University of Messina, Italy
Efthimios Kaxiras	Harvard University, United States
Eiichi Miura	Tokai University, Japan
Emilio Martinez-Paneda	University of Oxford, United Kingdom
Emin Yeltepe	Turkish Energy Nuclear and Mineral Research Agency,
	Türkiye

Emine Küçükbenli	Nvidia Corporation, United States
Enrico Salvati	University of Udine, Italy
Eralp Demir	University of Oxford, United Kingdom
Ercan Gürses	Middle East Technical University, Türkiye
Erhan Aksu	Turkish Energy Nuclear and Mineral Research Agency,
	Türkiye
Eric Velázquez Corral	Universitat Politècnica de Catalunya, Spain
Eric Velázquez-Corral	Universitat Politècnica de Catalunya, Spain
Estabraq Abbas K.	Scientific Research Commission, Iraq
Evan Ma	Xi'an Jiaotong University, China
Ewa Knapik	AGH University of Krakow, Poland
Fatma Tasgin	Middle East Technical University, Türkiye
Federico Olla	Politecnico di Milano, Italy
Fedor Belyaev	Saint Petersburg State University, Russia
Feiyang He	Cranfield University, United Kingdom
Flavio Cognigni	Carl Zeiss S.p.A, Italy
Francesca Berti	Politecnico di Milano, Italy
Francesco De Bona	University of Udine, Italy
Francesco Scavello	Versalis S.p.A., Italy
Franco Pellegrini	International School for Advanced Studies (SISSA), Italy
Fırat Ergin	University of Bristol, United Kingdom
Gabriel Sas	Luleå University of Technology, Sweden
Gabriel Testa	University of Cassino and Southern Lazio, Italy
Gabriele Albertini	University of Nottingham, United Kingdom
Giang D. Nguyen	University of Adelaide, Australia
Gianluca Iannitti	University of Cassino and Southern Lazio, Italy
Giovanni Lancioni	Polytechnic University of Marche, Italy
Grzegorz Cios	AGH University of Krakow, Poland
Görkem Eğemen Güloğlu	Middle East Technical University, Türkiye
Ha H. Bui	Monash University of Adelaide, Australia
Hamidreza Rohani Raftar	LUT University, Finland
Hamza A. Al-Tameemi	University of Baghdad, Iraq
Hande Savran	Nedu Bağlantı Elemanları San. ve Tic. A.Ş., Türkiye
Hande Vural	Middle East Technical University, Türkiye
Haojie Wang	Henan University of Science and Technology, China
Haris Moazam Sheikh	University of Southampton, United Kingdom
Hatem Mrad	Université du Québec en Abitibi-Témiscamingue (UQAT),
	Canada
Helmuttakahiro Uchida	Tokai University, Japan
Hideki Kimura	Tokai University, Japan
Hilal Doganay Kati	Cranfield University, United Kingdom
Hiromasa Yoshizumi	Doshisha University, Japan
Hirotaka Irie	Tokai University, Japan
Hiroyuki Miyamoto	Doshisha University, Japan

Hocine Kebir	Université de Technologie de Compiègne, France
Hossein Gheshlaghi Ghadim	Urmia university, Iran
Hung-Jue Sue	Texas A&M University, United States
Hyun-Kyu Lim	Korea Institute of Industrial Technology, South Korea
Ignacio Alejandro Figueroa	Universidad Nacional Autonoma de Mexico, Mexico
II-Hyun Kim	Korea University, South Korea
Israa H. Hilal	Scientific Research Commission, Iraq
Izzet Tarik Tandogan	Forschungszentrum Jülich, Germany
İlbilge Umay Aydıner	Middle East Technical University, Türkiye
Ilhan Bükülmez	Turkish Energy Nuclear and Mineral Research Agency,
	Türkiye
İremnaz Yücel	Middle East Technical University, Türkiye
İzzet Erkin Ünsal	Middle East Technical University, Türkiye
Jackson Rahm	Texas A&M University, United States
Jacopo Ciambella	Sapienza University of Rome, Italy
Jaime Gonzalez-Libreros	Luleå University of Technology, Sweden
James Njuguna	Robert Gordon University, United Kingdom
Javier Dominguez	NOMATEN Centre of Excellence, Poland
Jelena Lubura Stošić	University of Novi Sad, Serbia
Jeonug Kang	Korea University, South Korea
Jiacheng Sheng	Northwestern Polytechnical University, China
Jiao Luo	Northwestern Polytechnical University, China
Jin Wang	Forschungszentrum Jülich, Germany
Jorge Luis Flores Alarcon	Universidad Nacional Autonoma de Mexico, Mexico
Josef Domitner	Graz University of Technology, Austria
Joseph Fitoussi	Arts et Métiers ParisTech (ENSAM), France
Joshua McNeely	University of Nottingham, United Kingdom
Jose Cesar de Sa	University of Porto, Portugal
José Martins	Polytechnic of Porto, Portugal
João Parente	University of Beira Interior, Portugal
Juha. Uusitalo	University of Oulu, Finland
Juho Havia	LUT University, Finland
Jun Liu	Northwestern Polytechnical University, China
Jun Suzuki	The University of Tokyo, Japan
Kadir Tuğrul Demirci	The University of Manchester, United Kingdom
Kemal Bartu Aydın	Nedu Bağlantı Elemanları San. ve Tic. A.Ş., Türkiye
Kengfeng Xu	Northwestern Polytechnical University, China
Keshavamurthy Ramaiah	Christ University, India
Konrad Perzynski	AGH University of Krakow, Poland
Konstantinos Tsongas	International Hellenic University, Greece
Kouhei Sagawa	Tokai University, Japan
Kouider Madani	University of Sidi Bel Abbes, Algeria
Kourosh Karami	Islamic Azad University, Iran

L.R. Botvina	A.A. Baikov Institute of Metallurgy and Materials Science,
	Russia
Laura De Lorenzis	ETH Zurich, Switzerland
Lei Yuan	Luleå University of Technology, Sweden
Lennart Elfgren	Luleå University of Technology, Sweden
Leon Cizelj	Jožef Stefan institute, Slovenia
Leopoldo Ruiz-Huerta	Universidad Nacional Autonoma de Mexico, Mexico
Livia Cupertino-Malheiros	Imperial College London, United Kingdom
Lorenza Petrini	Politecnico di Milano, Italy
Lorenzo De Noni	Texas A&M University, United States
Lorenzo Malerba	CIEMAT, Spain
Luca Andena	Politecnico di Milano, Italy
Luca Patriarca	Politecnico di Milano, Italy
Luis Espath	University of Nottingham, United Kingdom
Lukasz Madej	AGH University of Krakow, Poland
M.R. Tyutin	A.A. Baikov Institute of Metallurgy and Materials Science,
	Russia
Mahdi Karamabian	University of Galway, Ireland
Mahlatse Mphahlele	Cape Peninsula University of Technology, South Africa
Manuel J. Carvajal Loaiza	Texas A&M University, United States
Marco Contino	Politecnico di Milano, Italy
Marco Pelegatti	University of Udine, Italy
Marco Rossi	Sapienza University of Rome, Italy
Margarita Evard	Saint Petersburg State University, Russia
Maria Francesca Milazzo	University of Messina, Italy
Maria I. Vallejo Ciro	Texas A&M University, United States
Maria Starodubova	Saint Petersburg State University, Russia
Mariem Ben Hassen	Université du Québec en Abitibi-Témiscamingue (UQAT),
	Canada
Matteo Trombettoni	Carl Zeiss S.p.A, Italy
Maziar Toursangsaraki	University of Galway, Ireland
Md Mahmudul Hasan	Virginia Tech, United States
Mehmet Mutlu	REPKON Machine and Tool Industry, Türkiye
Mehmet Okan Görtan	Hacettepe University, Türkiye
Melih Tuyan	Teknorot Steering and Suspension Parts, Türkiye
Mert Güngör	Middle East Technical University, Türkiye
Merthan Özdemir	Middle East Technical University, Türkiye
Michael Budnitzki	Forschungszentrum Jülich, Germany
Michael C. Faudree	Tokyo City University, Japan
Michael Obermann	Österreichische Vereinigung für das Gas- und Wasserfach,
	Austria
Michel Mansour	International Hellenic University, Greece
Michell Salvia	ECL (Ecole Centrale de Lyon), France
Miguel Angel Ramirez	Universidad Nacional Autonoma de Mexico, Mexico

Miguel Queirós	Polytechnic of Porto, Portugal
Min-Seok Choi	Korea University, South Korea
Mingming Tong	University of Galway, Ireland
Mirko Sgambetterra	Italian Air Force - Aeronautical and Space Test Division,
	Italy
Mohamad Faizal Abdullah	Universiti Pertahanan Nasional Malaysia, Malaysia
Mohamed Elleithy	Virginia Tech, United States
Mohaned Djedidi	Université du Québec en Abitibi-Témiscamingue (UQAT), Canada
Mohd Akramin Mohd Romlay	UMPSA, Malaysia
Mohd Khairul Faidzi	Universiti Pertahanan Nasional Malaysia, Malaysia
Mohd Shamil Shaari	Universiti Malaysia Pahang Al-Sultan Abdullah, Malaysia
Motohiro Yuasa	Doshisha University, Japan
Motsi Matlakala	University of Johannesburg, South Africa
Muhammad Khan	Cranfield University, United Kingdom
Muhammad Muaz Mubasyir	Universiti Kebangsaan Malaysia, Malaysia
Murat Baydoğan	Istanbul Technical University, Türkiye
Murat Karakus	The University of Adelaide, Australia
Murat Sarp Koçak	Universitat Politècnica de Catalunya, Türkiye
Myoung-Gyu Lee	Seoul National University, South Korea
Nadimul Faisal	The Robert Gordon University, United Kingdom
Natalya Vaysfeld	King's College London, United Kingdom
Nele Moelans	KU Leuven, Belgium
Nicolas Castin	SCK CEN, Belgium
Nicolò Grilli	University of Bristol, United Kingdom
Nikolai Kashaev	Helmholtz-Zentrum Hereon, Germany
Norbert Enzinger	Graz University of Technology, Austria
Nour Habib	LAMPA, France
Nur Azihanim Abu Bakar	Universiti Malaysia Pahang Al-Sultan Abdullah, Malaysia
Onur Ali Batmaz	Middle East Technical University, Türkiye
Orhun Bulut	Middle East Technical University, Türkiye
Oskar Bera	University of Novi Sad, Serbia
Oğuzhan Kurt	REPKON Machine and Tool Industry, Türkiye
Ömer Faruk Koç	Ministry of Energy and Natural Resources, Türkiye
Özgün Şener	Middle East Technical University, Türkiye
Paulo Reis	University of Coimbra, Portugal
Pedram Parandavar	University of Galway, Ireland
Pedro da Silva	Polytechnic of Porto, Portugal
Peter Auer	Graz University of Technology, Austria
Pinar Acar	Virginia Tech, United States
Piotr Bała	AGH University of Krakow, Poland
Rafael Schouwenaars	Universidad Nacional Autonoma de Mexico, Mexico
Rahaf Homssi	Texas A&M University, United States
	Universitat Politecnica de Catalunya, Spain

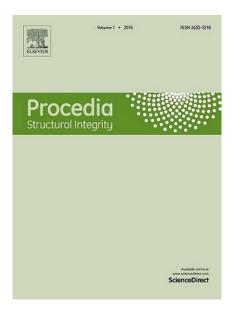
Raul Campilho	Polytechnic of Porto, Portugal
Regina Saitova	Saint Petersburg State University, Russia
Reza Alebrahim	Università degli studi Niccolò Cusano, Italy
Riccardo Panciroli	Università degli studi Niccolò Cusano, Italy
Richard Barrett	University of Galway, Ireland
Roaa Alawadi	Applied Science Private University, Jordan
Roya Darabi	University of Porto, Portugal
Roberto Perrone	Italian Air Force - Aeronautical and Space Test Division, Italy
Ruilin Tang	Southwest Jiao Tong University, China
Ruth Schwaiger	Forschungszentrum Jülich, Germany
S V Dharani Raj	The University of Adelaide, Australia
Saber El Arem	LAMPA, France
Sadik Sefa Acar	Middle East Technical University, Türkiye
Sahar Ismail	Saint Joseph University of Beirut, Lebanon
Sahbi Tamvoura	École Nationale d'Ingénieurs de Sousse, Tunisia
Saifur Rahman Bakaul	Aviation and Aerospace University, Bangladesh
Salvinder Singh Karam Singh	Universiti Kebangsaan Malaysia, Malaysia
Samar Keshavarz	LUT University, Finland
Samir El Shawish	Jožef Stefan institute, Slovenia
Sara Ricci	University of Cassino and Southern Lazio, Italy
Sara West	Texas A&M University, United States
Sean Leen	University of Galway, Ireland
Sebak Oli	University of Manitoba, Canada
Seda Sürücü	Turkish Aerospace Industries, Türkiye
Selen Güner Gürbüz	Turkish Energy Nuclear and Mineral Research Agency,
	Türkiye
Seong-Ho Ha	Korea Institute of Industrial Technology, South Korea
Serdar Kaveloglu	Kahramanmaras Istiklal University, Türkiye
Sergey Kotomin	Bauman State Technical University, Russia
Serhat Onur Çakmak	Middle East Technical University, Türkiye
Seyyed Mojtaba Fakhkhari	University of Quebec in Abitibi-Témiscamingue, Canada
Shabbir Muneer	Bahrain Polytechnic, Bahrain
Shae K. Kim	Korea Institute of Industrial Technology, South Korea
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Taher Azdast	Urmia university, Iran
Takaaki Ikeda	Doshisha University, Japan
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Ulf Reinicke	TH Köln - University of Applied Sciences, Germany
Umud Esat Öztürk	TUSAŞ Engine Industries Inc., Türkiye
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Yaren Aslı Candan	TUSAŞ Engine Industries Inc., Türkiye
Yiğitkan Korkmaz	Middle East Technical University, Türkiye
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Young-Ok Yoon	Korea Institute of Industrial Technology, South Korea
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Yunus Emre Özsoy	Middle East Technical University, Türkiye
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