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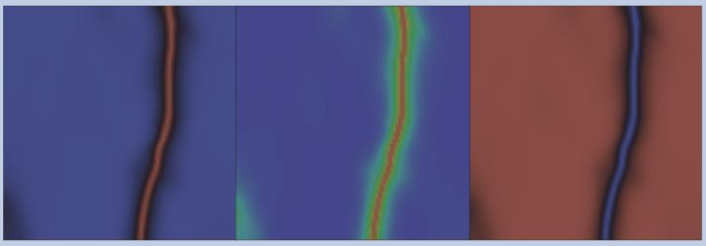

3rd International Workshop on Plasticity, Damage and Fracture of Engineering Materials

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Contents

About

IWPDF 2023

These proceedings contain the abstracts presented at the 3rd International Workshop on Plasticity, Damage and Fracture of Engineering Materials organized in a hybrid mode by Middle East Technical University in Istanbul, Türkiye. In addition to the in-person poster and oral presentations, which were broadcasted live to the online participants, the virtual pre-recorded contributions were uploaded to a YouTube channel before the meeting. Subjects of the workshop focused mainly on plasticity-damage and fracture as two main topics. Both computational and experimental studies were presented at the meting, focusing on a better understanding of how the material microstructure, loading and environmental conditions affect deformation, degradation and failure of engineering materials. The organizers wish to thank all the invited keynote lectures and the technical session contributors attending from all over the world to discuss the recent developments in the field. The papers of the workshop will be published in the Procedia Structural Integrity (Open Access). The support from Middle East Technical University, REPKON Machine and Tool Industry and Trade Inc., ESIS (European Structural Integrity Society), ESAFORM and Borçelik is gratefully acknowledged.

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Keynote Lectures

Damage and fracture in deformation of materials and deformation-based manufacturing

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Keywords: Void initiation and growth, damage and fracture, damage criteria and prediction.

Deformation of materials and deformation-based manufacturing, viz., materials forming, are respectively the most practical engineering activity and the efficient manufacturing process, while the latter is widely employed to fabricate net-shape or near-net-shape parts via plastic deformation of materials. From manufacturing aspect, this traditional manufacturing process of metal forming has been being revitalized as many attractive advantages and uniqueness such as high productivity, superior mechanical properties, excellent material utilization, low production cost, and being able to fabricate the complex geometries and features of deformed parts, etc., cannot be replaced by other manufacturing processes. In this process, the design of deformed parts, forming process and tooling, defect prediction and avoidance, and product quality assurance and control are becoming more and more critical. All of these activities need to consider the damage and fracture in the deformation process of materials. Therefore, a scientific insight into the formation and occurrence of damage and fracture and an in-depth understanding of their mechanism and behaviors are crucial. In this talk, the mechanisms of the initiation, coalesce, growth of voids in the plastic deformation of materials, the formation and occurrence of damage and fracture, and their mechanisms, behaviors, and prediction and avoidance via experiment and simulation will be presented. The talk will thus give an overview of the state-of-the-art in damage and fracture research.

Stress redistribution in dwell fatigue of titanium alloy from in-situ characterisation and crystal plasticity modelling

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Keywords: Dwell fatigue, Titanium alloys, Crystal plasticity

Cold dwell fatigue in Titanium aero-engine alloys is the degradation and failure process in which microcracks, or facets, nucleate typically within 15° of basal planes of (hard) HCP grains orientated with their c-axes at or about parallel to principal stress direction. A key driving force has been argued, through use of crystal plasticity (CP) modelling methods [1], to be creep deformation in an adjacent (soft) grain well-orientated for slip leading to stress redistribution onto the hard grain which occurs during cycle hold times (the dwell period), and over progressive cycling [2]. In addition, dwell facet nucleation and growth has been found to be associated with macrozones (or 'MTRs') which are millimetre-sized polycrystal regions with strong texture [2]. So far as we are aware, the key mechanistic argument for soft-grain creep and load shedding onto an adjacent hard grain have not yet been demonstrated or measured in experiment. The work presented in this paper addresses this important absence.

Titanium alloy Ti-6Al-4V samples containing macrozones have been characterized with EBSD and speckled to facilitate DIC displacement measurement to allow in-situ full-field spatial intra-macrozone strain measurement in three-point bend test samples under dwell fatigue loading. A novel (but with simplifications) methodology to extract out spatial elastic strains, and hence stresses with knowledge of anisotropic stiffnesses, at peak load at the beginning and end of the cyclic dwell period is presented and supported by considerations of stress equilibrium checks and CP modelling. Hence, full-field intra-macrozone stresses both during dwell periods and over cycles of fatigue loading have been obtained and are presented.

Both soft-grain creep and redistribution of stress (load shedding) onto hard grains during the load hold time have been observed and quantified, and the associated dwell time constant for 66% of redistribution to have occurred has also been quantified, thus addressing the importance of the duration of the cycle dwell period. In addition, the in-situ DIC studies have allowed full-field strain and stress quantification over multiple cycles such that the cyclic change to redistributed stresses from cycle to cycle has also been quantified. The experimental observations reinforce that the hold period in dwell fatigue of Ti alloys does generate creep and load shedding and that cycling progressively drives up the stresses on the hard macrozones thus supporting many of the previous hypotheses from CP modelling. A quantitative assessment of how well CP models reflect experimental measurements of stress redistribution onto hard grains is also discussed.

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Parametrically-Upscaled Constitutive Model (PUCM) and Crack Nucleation Model (PUCNM) for Fatigue Predictions in Ti Alloys

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Keywords: Parametric Upscaling, RAMPS, Fatigue Crack Nucleation

This talk will give an overview of the Parametrically Upscaled Constitutive Model (PUCM) and Parametrically Upscaled Crack Nucleation Model (PUCNM) for Ti alloys [1-6], whose polycrystalline microstructures include micro-texture regions (MTRs). The micromechanics-informed PUCMs differ from conventional phenomenological models in their unambiguous depiction of constitutive parameters and their dependencies. The PUCMs are thermodynamically consistent, macroscopic constitutive models, whose coefficients are explicit functions of Representative Aggregated Microstructural Parameters (RAMPs), representing statistical distributions of morphological and crystallographic descriptors of the microstructure, e.g., texture and grain size distributions. The microstructure-dependent constitutive parameter functions are effective for establishing connections between microstructure and relevant higher-scale material response. They enable computationally efficient simulations with significant speedup over detailed lower-scale models and conventional multi-scale models. Development of the PUCMs requires a comprehensive framework, involving material characterization, micromechanical analysis using calibrated models, identification of characteristic forms of constitutive relations, sensitivity analysis, computational homogenization, machine learning and validation with experimental data. Furthermore, the upscaling platform is coupled with uncertainty quantification (UQ) and propagation. The PUCM/PUCNM tool is used to predict deformation and fatigue crack nucleation in aerospace structures under monotonic and cyclic loading conditions.

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Simulations of the Directed Energy Deposition process to manufacture parts in M4 High Speed Steel

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Keywords: Deep Learning, High Speed Steel, Additive Manufacturing

This lecture presents all the steps required to reach a framework for the robust optimization under uncertainty in the directed energy deposition (DED) of M4 High-Speed Steel [1]. These developments were applied to identify optimal process parameters for robust manufacturing of printed parts with a stationary melt pool depth and low consumed energy under uncertainty within the multiple layers of a bulk sample.

Based on 2D finite element simulations validated by experiments [2], a surrogate model using a feedforward neural network (FFNN) was developed for a fast and accurate prediction of the temperature evolutions and the melting pool sizes in a metal bulk sample (3D horizontal layers) manufactured by the DED process. The uncertainty characterization and propagation within the process were studied in [3] and prepared the possible use of robust optimization.

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Fatigue crack propagation in laser peened materials: A holistic simulation approach

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Keywords: laser shock peening, fatigue crack growth, simulation

Laser shock peening (LSP) is known as efficient modification technique to generate deep compressive residual stresses in metallic structures. These compressive residual stresses are capable to reduce the fatigue crack propagation (FCP) rate, which results in an extension of the structural lifetime and/or maintenance intervals in terms of a damage tolerant design philosophy. Considering that residual stresses are also in equilibrium, it is obvious that generated compressive residual stresses are accompanied by balancing tensile residual stresses. However, as tensile residual stresses are supposed to accelerate the FCP rate, the overall residual stress field has to be known, when modification techniques, such as LSP, are applied. To support our understanding of these phenomena, a holistic virtual twin [1] from LSP process simulation [2] to the prediction of FCP rate is set-up and used in a close linking with experiments. The underlying multi-step simulation approach consists of four steps: (i) LSP process simulation for a representative volume to predict resulting plastic strains; (ii) transfer and extrapolations of these plastic strains to a relatively large LSP-treated area; (iii) calculation of the overall residual stress field as well as the stress intensity factor (SIF) range and rate; (iv) estimation of the FCP rate based on FCP equations. An 'experimental simulation' validates the simulation chain, where calculated SIFs are applied to untreated material. The FCP rate of the untreated material and experimentally determined FCP rate of LSP-treated material agree well, which indicates the calculation of realistic SIFs. The study reveals also the contribution of crack closure [3] in terms of FCP retarding mechanism.

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Spatially resolved eigenstrain analysis across the scales: methods, distributions, insights

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Keywords: diffraction, strain tomography, stress classification, eigenstrain

Deformation within hierarchically structured materials is characterized by the complexity that is related to the mechanisms, scale, and the tensorial nature of the eigenstrains (inherent strains) that represent 'material memory' of prior inelastic processes. Solid mechanics requirements of total strain compatibility and stress equilibrium link eigenstrain to the measurable distributions of elastic strains within the body. In the course of thermal, environmental and deformation processing of materials, eigenstrains may undergo evolution through plastic deformation, phase transformation, etc. Depending on the scale of consideration, eigenstrains may be associated lattice defects and distortions, slip bands, crack tip zones and other microstructural features. Although it may be possible to quantify eigenstrain distributions directly, in most practical cases they need to be deduced from residual elastic strains (r.e.s.) that can be assessed by non-destructive diffraction techniques or by material removal methods, such as hole drilling or sectioning.

Digital Image Correlation (DIC) that has gained popularity as a means of experimental mapping of deformation is characterized by scale independence that allows its application to images obtained at different magnification using various microscopy techniques. A particular application of interest to the present topic is the micro-ring core milling (FIB-DIC for short) as a means of residual stress and eigenstrain evaluation. This approach has made it possible to probe residual stresses of Type I, II and III and to determine their statistical distributions in deformed metallic alloy samples for comparison with crystal plasticity FEM simulations [1].

The author will discuss the possible origins of the observation that elastic strains (and stresses) tend to obey gaussian statistical distributions, while plastic strain (eigenstrain) distributions tend to be lognormal [2].

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Hydrogen Assisted Cracking Through Mixed-Mode Hydrogen-Sensitive Cohesive Zone Model

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Keywords: hydrogen induced fracture, cohesive zone modeling, hydrogen diffusion.

Metals, particularly high-strength steels, are susceptible to the phenomenon known as hydrogen embrittlement. Hydrogen embrittlement is observed when the metal interacts with a hydrogen-producing environment, particularly intensified under conditions of high pressure and humidity. This interaction allows small hydrogen particles to readily diffuse into the metallic material and relocate within the crystal lattice. Consequently, under stresses below the yield point of metallic materials, both ductility and load-bearing capacity are significantly reduced, resulting in cracking and potentially catastrophic brittle failures. While extensive documentation exists on the micro-mechanical and physical aspects of the hydrogen-assisted fracture, a complete understanding is yet to be achieved. In this study, the constitutive J2 plasticity model is integrated with both a mixed-mode cohesive zone formulation, see [1] for an example study, and a multi-trap hydrogen transport model [2] to simulate the failure process. Unlike some of the literature studies [3], the presented model effectively couples the hydrogen transport model with the cohesive zone formulation to account for the effects resulting from the hydrogen redistribution during crack tip propagation. This approach also allows for the prediction of intergranular fracture and the precise representation of the material's sensitivity to hydrogen content. To validate the results obtained from the integrated framework, numerical examples from the literature are analyzed, and comparisons are made with experimental data.

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Unified Mechanics Theory: An Entropy-Based Uncertainty Quantification for Monotonic Tensile Failure of A36 Steel

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Keywords: Newtonian Mechanics, Thermodynamics, Unified Mechanics Theory, 1-D analytical modelling, thermodynamic-frameworked continuum damage mechanics, monotonic tensile failure, tensile strength, A36 steel

Tensile yielding and fracture failures occur as a result of plastic deformation, an irreversible degradation process, in a steel material. Historically, tensile failures in steel members have been predicted by analysing and designing structural members in accordance with the provisions of the structural building codes (e.g., National Structural Code of the Philippines or NSCP) or by extrapolating empirical curve-fitted models using phenomenological data on structural member failure. The design provisions of NSCP for structural members are also based on phenomenological data that went through laboratory trialand- error analyses. The current study contributes to the centennial effort of the scientists and physicists to unify Newtonian Mechanics and Thermodynamics and strengthen the proof for the applicability of the Unified Mechanics Theory in construction and structural engineering. The researchers employed the said theory to predict or quantify the failure uncertainty of A36 steel when subjected to monotonic tensile loading condition. Using one-dimensional analytical modelling, the unified mechanics theory was used to derive a one-dimensional predictive model for failure prediction. The proposed analytical model was used to predict the A36 steel's tensile strength. It is demonstrated in this study that using a simple predictive model based on the material's fundamental equations derived by the researchers and thermodynamics associated with material degradation, the unified mechanics theory can be used to predict the tensile strength of an A36 steel.

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Effect of Nozzle Diameter on Tensile and Fracture Behavior of 3D-Printed FDM-PLA Samples

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Keywords: Fused Deposition Modeling (FDM), Nozzle diameter, Fracture resistance

The Fused Deposition Modeling (FDM) technique is a subcategory of 3D printing processes that works by extruding a fine polymeric filament through a nozzle on the heated platform. Polylactic Acid (PLA) is among the mostly used materials in the FDM technique with good applicability in the medical industry [1].

In recent years, researchers have tried to figure out how the manufacturing processes in the FDM technique can influence the mechanical performance including the basic mechanical properties [2] as well as the fatigue and fracture behavior [3]. Most of the studied manufacturing parameters were raster angle, layer orientation and printing speed [4]. Meanwhile, little information about the effects of nozzle diameter on the mechanical properties of 3D printed polymers is available. Therefore, the current paper surveys the influence of nozzle diameter on the mechanical properties and mode I fracture behavior of FDM-PLA specimens. Four different nozzle diameters of 0.4, 0.6, 0.8, and 1 mm with two raster configurations of 0/90° and 45/-45° were considered. Dog-bone and Semi-Circular Bending (SCB) samples were designed and printed for tensile and fracture tests, respectively. Also, to evaluate the fracture resistance of FDM-PLA pre-cracked samples, the critical value of J-integral (J_c) was used and calculated through finite element analysis.

The experimental results indicated that 1 mm nozzle diameter with the raster angle of 45/-45° could provide higher mechanical properties compared to other cases. This was also true for the fracture experiments where the SCB samples printed through the 1 mm nozzle diameter and 45/-45° raster orientation had the highest value of J_c (10400 J/m^2). Besides, the paths of crack extension were monitored and discussed comprehensively.

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Experimental and numerical investigation of ductile damage and fracture under biaxially loaded tensile reverse loadings

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Keywords: Biaxial experiment, Reverse loading, Ductile damage and fracture

Although many studies on the behavior of metal sheets are based on experiments with uniaxially loaded specimens, the engineering structures are often imposed by multi-axial cyclic loading in manufacturing processes and applications. Therefore, biaxially loaded cruciform specimens are used to investigate the plastic, damage, and fracture behavior under monotonic proportional or non-proportional loading conditions [1-2]. Recently, it has been detected that the damage and fracture behavior is remarkably influenced by different low-cycles reverse loadings [3-4].This presentation deals with the experimental and numerical analysis of the plastic, damage, and fracture behavior caused by biaxial non-proportional tensile reverse loadings. A series of tensile reverse loading tests with biaxially loaded specimens superimposed by different shear preloads are performed during the experiments. Digital image correlation monitors and analyzes the global force-displacement behavior and the local strain fields. The various damage mechanisms are revealed through scanning electron microscopy of fractured surfaces. In the numerical part, an anisotropic elastic-plastic-damage two-surface uncoupled continuum model is utilized to predict material behavior in both macro- and micro-levels. The proposed material model provides accurate numerical results compared to the experimental ones.

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Nomenclature of Yield Criteria for Isotropic Materials

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Keywords: π plane, limit surface, systematization

The choice of the yield criterion is crucial for reliable material description and design results. Numerous yield criteria proposed over the last 150 years are hardly used because their utility is not obvious. In addition, the cost of material testing, parameter adjustment, and complexity of implementation often outweigh the benefits of accurate material description. There is no clear procedure for selecting the best criterion for a particular application.

The mathematical expressions for the yield criteria can be very different, making it difficult to compare them directly for the best fit. However, possible shapes of yield criteria in the π-plane are limited by the convexity bounds. The upper and lower bounds are referred to as extreme yield figures. Extreme figures can take the shape of isogonal and isotoxal polygons of trigonal or hexagonal symmetry. Regular polygons are limit cases of the extreme yield figures [1, 3]. This work proposes a unique nomenclature of the criteria based on their geometric shapes and orientation in the π-plane, e.g., VON MISES $\bigcirc$, IVLEV $\hat{3}$, MARIOTTE $\overline{3}$, TRESCA $\hat{6}$, SCHMIDTISHLINSKY $\overline{6}$, SOKOLOVSKY $\widehat{12}$, among others. Circumflex ˆand macron refer to an upward pointing tip or upward facing flat base of the regular shape in the π-plane, respectively.
The generalized yield criteria can be characterized by the regular polygons and the circle in the π-plane that they contain. There are known six criteria that are of interest: $\hat{3} - \hat{6} - \overline{3}, \hat{3} - \bigcirc - \overline{3}$, $\hat{3} - \overline{6} - \overline{3}, \hat{6} - \widehat{12} - \overline{6}$, $\hat{6} - \bigcirc - \overline{6}$, $\hat{6} - \overline{12} - \overline{6}$. The criteria involving less than three of the basic geometries are edge cases and excluded from our discussion.

Based on the introduced nomenclature, a verification standard for the yield criteria is developed and the number of the useful yield criteria is reduced to a few manageable cases. The C^0 and C^1 continuous criteria that contain five basic geometries $\hat{3} - \hat{6} | \bigcirc | \overline{6} - \overline{3}$ and $\hat{6} - \widehat{12} | \bigcirc | \overline{12} - \overline{6}$, and that satisfy the plausibility conditions [1] are significant. Their usage eliminates the need to develop and select specific criteria for classes of materials like alloys, polymers, etc.

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Fuel Tank Design at Inner Pressure

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Keywords: Burzyński-plane, triaxiality, Poisson's ratio

Multiaxial stress states in components are evaluated using stress analysis methods: stress angle, triaxiality factor, equivalent stress. However, when designing with VON MISES criterion adjusted based on the tensile test, under-dimensioning may occur for multiaxial tensile loading. Such loading cases are crucial in the design of the tanks under internal pressure.

Generalized strength criteria require data from additional tests: shear, compression, equibiaxial tension, etc. However, these tests are often costly and may be subject to excessive scatter, sometimes beyond the accuracy of the design.

The basic idea of this work is to define the safety at the multiaxial tensile loading in the absence of measured data. For this purpose, the deviation 5...10% from the predicted value with VON MISES criterion is set at the balanced biaxial tensile loading. The required parameter is calculated using this deviation and can be expressed as a plastic POISSON's ratio.

Three adapted strength criteria are implemented for design: BERG, original HUBER and modified HUBER [1, 2] These criteria describe pressure-insensitivity under compression but limit the hydrostatic tensile stress. The limit surfaces represent the scaled VON MISES cylinder in the principal stress space C^1 -capped with SCHLEICHER ellipsoid at the different cross sections $I_1 = \sigma_0^T$ (uniaxial tension, BERG criterion: no uniaxial compression / uniaxial tension difference), $I_1 = \sigma_{30}^S$ (shear, HUBER criterion) or $I_1 = \sigma_{60}^C$ (uniaxial compression, modified HUBER criterion). The subscripts describe the stress angle θ of the corresponding loads.

The stress analysis is performed in a post processor of commercial FEM software Altair Radioss® and Ansys®. In order to determine the weak points of the designed component, the deviation of the proposed stress criteria from VON MISES criterion is varied in the dimensioning phase. The impact of this method is demonstrated with an automobile fuel tank made of HDPE. The selection of the criterion depends on the modelling concept: conservative (BERG), universal (HUBER) or progressive (modified HUBER). Based on the introduced criteria, optimization of thermoplastic components can lead to new design concepts.

Our evaluations with the discussed criteria have shown, that approx. 10% deviation from the predicted value with VON MISES criterion at the equibiaxial tension can be recommended as a first step in the pre-design. These results are transferrable to similar components.

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Fixture for 2D Compression Test with Uniaxial Testing Machine

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Keywords: Design, Equibiaxial compression, Optimization

2D compression test is essential for design of critical parts. Equibiaxial compression test can be easily performed using a circumferential clamp (Figure 1). The load F is applied using a uniaxial testing machine. The eccentricity e_x is utilized to obtain uniform stress distribution. The gap e_y is estimated from the uniaxial compression test data. Specimen "biting" at the overhang area of the gap is minimized with a compensator. Friction is reduced by lubricating the contact area. Partially overlapping curved sheets can be placed in the contact area.

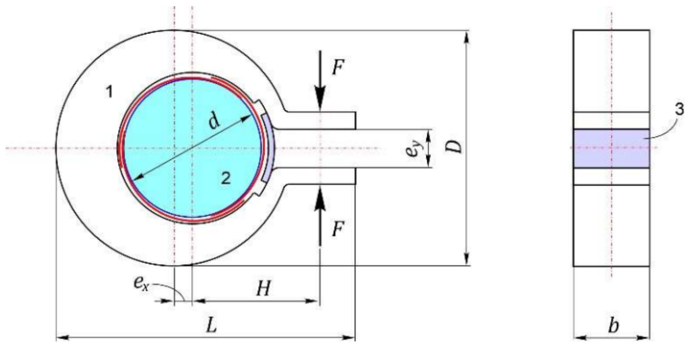

Figure 1: 2D compression test: 1 - compression clamp, 2 - specimen, 3 - compensator.

When designing the fixture with FEM, the optimization objectives include the following:

- simultaneous plastification of the clamp in the entire contact area and
- equal change of the inner radii of the clamp Δ at the selected angles ϕ during loading.

The recommended thickness of a metal or polymer foam specimen is $b = d/2$. For the testing of sheet specimens made e.g., of fiber-reinforced polymers, a groove is provided on the grips in the contact area to ensure specimen fixation and stability during loading. The depth of the groove is matched to the thickness of the specimen. The clamp material is plasticized during the test. The reuse of the clamp after the test with subsequent mechanical treatment is under discussion.

The specimen is speckled with a statistically distributed black & white pattern. This allows the two-dimensional strain on the specimen surface to be evaluated by digital image correlation as function of the load F and the gap closure e_y in a subsequent post-processing step.

Stress calculations are performed using reverse engineering. The experiments can be carried out in a thermal chamber. The obtained material data are crucial for model selection and parameter adjustment in responsible modelling [1].

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Assessing Fatigue Life Characteristics of API X65 Steel under the Effects of Corrosion in Deep-Sea Environment

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Keywords: Fatigue, Stress-Life, Durability

The aim of this study is to assess the fatigue life characteristics based on the effectsof corrosion for API X65 steel under deep-sea environment. In the oil and gas industry,assessing the pipeline failure caused by corrosion is important especially when dealing withcrack growth that is induced by internal and external cyclic loads. Likewise, the strength ofoffshore pipelines is affected by the presence of cracks due to the variation of loads, materialproperties and the corrosive effects due to salinity and pH values. During the service life ofsubsea pipelines, corrosion fatigue crack growth is a common occurrence that often results ina decrease in their strength and loss of asset integrity which frequently leads to pipelinecracking [1,2]. Therefore, evaluating the durability of pipelines is essential because of theinterdependence between corrosion fatigue, pipeline material properties, crack dimensions,geometric design and load ratios [3]. Tensile test is carried out for welded and non-weldedspecimens that were not submerged and submerged for 48 hours in sea water condition. Thisis based on the salinity and pH test values of the seawater condition sourced from the coastalarea of Port Dickson, Malaysia. In addition, the microscopic features and chemical compositionwere examined through FESEM and EDX on the fractured surface of the pipeline material. Afatigue stress-life (S-N) curve is plotted using the Basquin equation based on values obtainedfrom the UTS/mechanical testing. These results calculated using the Basquin equation, it wasfound that the endurance limit of API X65 steel is 276.3MPa. Finite element modelling for thecompact tension was carried out for three different load ratios (0.1, 0.4, and 0.7). The finiteelement analysis of the pre-cracked CT specimen shows that the stress intensity factor isproportionally linear with the length of crack and load ratio. Hence, this study confirms thatthe FE analysis provides a relevant alternative approach for fatigue life estimation of API X65steel using crack growth as a function of corrosion fatigue mechanism.

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Hot-Dip Aluminizing of Flow-formed AISI 4140 Steel

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Keywords: Hot-dip aluminizing, Flow forming, Microstructure

Flow forming is a cold deformation technique for the manufacturing of axisymmetric components. During the flow forming, a rotating initial tube (preform) is pushed by rollers through the thickness direction of the tube. After the process, the tube elongates along the flow forming direction with a corresponding reduction in its thickness. Cold plastic deformations recognizably cause increasing lattice imperfections such as point defects and dislocations in the structure, which could then have an effect on diffusion characteristics of the material [1-2]. In order to explore such an effect of flow forming, a flow formed AISI 4140 steel and an annealed 4140 steel were subjected to the HDA process in a molten Al7020 bath at 750° C for 4 minutes, and a subsequent diffusion annealing was performed at 800°C, and their coating characteristics such as coating thickness and hardness were compared. The results indicated that the coating thickness of the flow formed samples was higher (80 μm) than that of the annealed sample (μm) after the HDA process. Diffusion annealing increased the coating thickness of both samples five times, reaching 400 μm and 250 μm for the flow formed and the annealed samples, respectively. Comparing the measured thickness of the coatings revealed that flow forming accelerates diffusion during the HDA process, probably due to the defect structure induced by the flow forming. On the other hand, the coating hardness was in between 1000-1100 HV for both samples, implying that the initial condition of the sample does not have a remarkable effect on hardness after the HDA process.

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Crack Formation after Diffusion Annealing of Hot-Dip Aluminized AISI 4140 Steel

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Keywords: Hot-dipped aluminizing, Microstructure, Crack formation

Hot dip aluminizing (HDD) is a surface treatment process in which a metal substrate is coated with a layer of aluminum to enhance its corrosion ad oxidation resistance. However, crack formation can occur during the HDA process possibly due to presence of thermal stresses within the coatings arising from mismatch in thermal expansion coefficients of the aluminide layers and the substrate, brittle nature of the aluminide phases and process parameters. Therefore, optimization of the HDA process parameters such as temperature, dipping time and cooling rate from the dipping temperature might help reducing the possibility of crack formation. Additionally, subsequent diffusion annealing might have an effect on crack formation and overall integrity of the aluminized coating [1-2]. In this study, an AISI 4140 low alloyed steel was subjected to the HDA process in an Al-11wt.% Si bath at 750°C for 9 minutes and subsequent annealing was performed at 750°C, 850°C and 950°C. Examination of the diffusion annealed samples indicated that there were some cracks within the coatings of the samples, which were annealed at 750°C and 850°C, while there was no cracking on the surface of sample annealed at 950°C. The results were comparatively evaluated by considering the process parameters and the characteristics of the aluminide layers, and was attributed to the formation of ductile and brittle aluminide phases depending on the applied annealing temperature.

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Watching the grain boundaries slide

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Keywords: intergranular fracture; thermal activation; in situ microscopy

Unlike their strengthening contributions at ambient temperature, grain boundaries are the *Achilles' Heel* of polycrystalline alloys at elevated temperatures. The enhanced atomic motion diversifies the plasticity micro-mechanisms, complicating the resultant damage and fracture mechanisms. Grain boundary sliding is one such example. Provided the extensive efforts using post-mortem characterizations, time-resolved studies of grain boundary sliding are scarce, and unambiguous understanding of its role in plastic strain accommodation and damage nucleation is still lacking. In this talk, we will present an in situ SEM-based high-temperature investigation of grain boundary sliding in a model Co-based alloy [1,2], emphasizing the mechanistic insights into plastic flow and damage inception. We will show that grain boundary sliding is not only correlated with a rare serrated-to-stable plastic flow transition, but also accommodates more than 20 % plastic strain at 750 °C under a strain rate of 10^{-4} s^{-1}. With the aid of electron channeling contrast imaging, we also underpin the involvement of dislocation cross-slip in accommodating grain boundary sliding. Based on the testing conditions and the experimental observations, a series of deformation micro-events are identified and their roles in intergranular damage nucleation will also be discussed.

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Fatigue Crack Initiations in Metallic Sealing Rings Subjected to Complex Deformation History

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Keywords: crack initiation; microstructure; rolling; nickel based superalloy; crystal plasticity

Metallic sealing rings made from nickel-based superalloys are critical components of aero engines that prevent the leakage of high-pressure liquid or gas fuel. As one of the main failure modes, fatigue cracking has been a concern for the aerospace industry because the formation of even a micro-crack may cause an aviation accident. For the purpose of manufacturing fatigue-resisting sealing rings, much effort has been spent on the lifetime of predicting under fatigue loadings. However, the fatigue analysis of metallic sealing rings is challenging due to several aspects. On the one hand, the diameter of the rings (>100mm) is orders of magnitude higher than the geometrical characteristics of its cross-section (<1mm), the deformation history, especially the stress distribution from manufacture to service, is very complex and varies with the forming procedure and in-service conditions. On the other hand, the fatigue crack initiation in superalloys is extremely microstructural-sensitive. Hence, the crack prediction must be considered at both the component- and microstructure-scale. In this study, a macroscopic finite element model has been established to investigate the deformation history from forming W-shaped rings to service under multiple fatigue conditions. The stress status at critical regions, e.g., the crest and trough of the W-ring, was extracted and applied as the boundary conditions in a microstructure-based crystal plasticity model. The fatigue lives of the component under different forming processes and service conditions were estimated based on the local stored energy [1] evolution. The threshold of stored energy for fatigue crack initiation was determined by integrating three-point bending experiments and the corresponding modeling analysis [2]. The conclusions of this work can provide theoretical guidance for the manufacturing of high-performance metallic sealing rings.

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Fracture, deformation route, and mechanical performance of welded cold-formed ultra-high strength steel S1100

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Keywords: fracture, weld, ultra-high strength steel

Cold forming has a crucial role in fabricating hollow sections commonly used in steel structures. Further, assembling steel structures requires arc welding as a joining process to leverage the full potential of steel to achieve economic structures with relatively acceptable strength-to-weight ratios [1]. However, the mechanical performance and fracture behavior of ultra-high strength steels, especially when they are simultaneously subjected to cold-forming and welding, still require further research. Hence, further study is crucially required to fill these knowledge gaps to avoid catastrophic failures in steel structures [2]. Consequently, quench and tempered ultra-high strength steel S1100 was selected for this study to investigate the influence of cold-forming and pre-strains on the mechanical performance and fracture behavior of the new generation of ultra-high strength steels after arc welding. To do so, base metals with different bending radii, representing various levels of cold-forming, were welded via gas-metal arc welding. Next, the welded joints were subjected to uniaxial quasi-static tensile loads to evaluate their mechanical performance after welding and calculate their strength, ductility, and toughness parameters. In addition, digital image correlation was also used with the tensile tests to study the plasticity and final failure. Further, macrographs by optical microscopy and fractography via scanning electron microscopy were utilized to investigate the fracture locations and mechanisms of the welded joints. The results confirmed the reliability of the welded joints in steel structures. In addition, the fracture of the welded material was identified as ductile, regardless of its cold-forming degree. Heat-affected zone softening, as a common drawback associated with welded ultra-high strength steel, did not adversely affect the fracture mechanism of welded S1100.

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Integrated model calibration for anisotropy, hardening and rupture - Application to the clinching process

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Keywords: Material model calibration, Finite element analysis, Rupture tests, Sheet metal, Clinching.

To accurately predict the ductile rupture or failure using uncoupled rupture models for a given material, specific model parameters are required. These parameters are difficult to determine in a direct approach from experiments and need to be estimated using a hybrid experimental and numerical analysis, which accuracy relies on the quality of the anisotropy and hardening model calibration. In this study, material model parameters are estimated for AA6016-T4 and AA5182-O thin sheets. The methodology to determine material parameters of a combination of Swift-Voce hardening law and Yld2004-18p yield criterion is based on inverse identification over a full database made of quasi-homogeneous tests and specific rupture tests. The experimental data are obtained from sheet metal samples in the form of either stress-strain curves or load-displacement curves and local strain evolution measured by digital image correlation. To validate the simulation results, three additional tests on notched specimen are considered. The failure model parameters for a shear modified uncoupled Lou's rupture criterion are then determined using an average value of the triaxiality ratio and the Lode parameter at the material point of maximum equivalent plastic strain. The final aim of this study is the numerical prediction of the strength of a clinched joint of dissimilar AA6016-T4/AA5182-O sheets and the occurrence of rupture is numerically investigated at different stages.

Nanoscratching of Polycrystalline Copper Examined Through Strain Gradient Crystal Plasticity

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Keywords: Crystal plasticity, scratching, size effect

Nanoscratch tests, where a specimen is scratched with a nano-scale indenter, have been recognized as a significant tool for assessing the mechanical and tribological attributes of materials. This study investigates the deformation mechanisms and material response during nanoscratch test of polycrystalline Cu through finite element method utilizing a lower-order strain gradient crystal plasticity framework. Test results such as the reaction forces on the indenter, apparent friction coefficient, and pile-up topography change with different grain diameters and different crystal textures. This behavior is examined with the aforementioned strain gradient theory where the density of geometrically necessary dislocations is calculated to get size-dependent material response. The crystal plasticity framework is implemented into ABAQUS as a user material subroutine (UMAT) and validated through comparisons with single crystal Cu experiments in the literature. A 3D mesh is generated to model the scratch specimen at grain level. A Berkovich indenter causes deformation on the specimen using displacement-controlled boundary conditions, as opposed to force-controlled experimental conditions. Scratch simulations are carried out on copper specimens with average grain diameters between 4 μm - 8 μm and crystal orientations distributed randomly or aligned with the scratch direction.

Study of different initiation and propagation criteria in the XFEM modelling of scarf adhesive joints

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Keywords: Adhesive joint, Structural adhesives, Scarf joint, Cohesive zone models, eXtended finite element method.

There are numerous applications for adhesive bonds, which are used in various industry sectors, from aerospace to footwear. In the aerospace and aeronautics sector, its use is extremely important, as it is possible to obtain strong and light connections, capable of resisting corrosion. There are several factors that affect the behavior of an adhesive joint. Thus, there is a need to assess the impact of these main factors on the bond strength, such as the type of adhesive (brittle, ductile or transition of both) and the overlap length (L_0). On the other hand, scarf joints find application in high-responsibility structures, including composite structures, due to their high efficiency. In this case, one of the most relevant geometric parameters is the scarf angle (α).

The main objective of this work is to carry out a study to estimate the mechanical behavior of scarf adhesive joints as a function of α and the type of adhesive. Thus, an experimental and numerical study of scarf joints was carried out using the Extended Finite Element Method (XFEM), in which different adhesives such as the Araldite® AV138, the Araldite® 2015 and the SikaForce® 7888 were applied. Aluminum (AW6082-T651) adherends were used in joints with different α, being subjected to a tensile load, in order to evaluate their performance and validate the applicability of the XFEM for the purposes of strength prediction. Therefore, the values obtained experimentally and numerically were compared for each of the adhesives and α to validate the XFEM numerical method for determining the mechanical behavior of adhesive joints. The results obtained in the scope of this work allowed to clearly validate that the XFEM numerical method returns results very close to those obtained experimentally.

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Cohesive zone evaluation of different design solutions for adhesive joints in canoeing boats

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Keywords: Canoeing, Adhesive joints, Structural adhesive, Composites, Numerical modeling, Finite element method, Cohesive zone model.

Canoeing is a nautical sport that appeared in history thousands of years ago simply as a means of survival. Nowadays, this sport is practiced all over the world as a hobby or as a means of competition. Given the desire to improve the quality of construction and performance of boats, currently their manufacture is focused on the use of composite materials. Although there are countless ways to join the different components that exist, the one that stands out the most is adhesive bonding. On the other hand, for a manufacturing company of these boats to remain competitive in the market, it is required the continuous improvement of these joints in terms of strength and manufacturing cost. In this work, an adhesive joint existing in a canoeing boat is numerically studied, more specifically the joint between the hull and the deck of a kayak. To evaluate the performance of this adhesive joint, it is necessary to know the types of materials implicit in this type of joint, as well as the main geometric parameters. Initially, the adhesive used was tensile tested with bulk adhesive specimens and the respective data was processed to obtain the material parameters required for the analysis. To achieve the goal of this work, a numerical analysis is performed, in which the existing joint configuration was tested, different geometric changes were analyzed and different types of adhesives that can bring improved properties to this adhesive bond were considered. The numerical work consisted of an elastic stress analysis of the adhesive layer and prediction of stiffness and strength, by cohesive zone modelling (CZM), using the ABAQUS software. To use the CZM to study the different joint configurations, a prior validation of the technique was performed with experimental data obtained in a previous work. Initially, this numerical study enabled to successfully validate the CZM and, then, to numerically evaluate the influence of geometric changes according to different adhesive types, allowing the verification of which geometry best adapts to each adhesive type that was considered.

Strength and Ductility Loss of Magnesium-Gadolinium due to Corrosion in Physiological Environment

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Keywords: Biodegradable magnesium, Corrosion localisation, Damage modeling.

Magnesium (Mg) and its alloys are becoming increasingly popular as alternatives to permanent implant materials due to their biodegradability, biocompatibility and ability to promote bone growth. We propose a computational framework to study the effect of corrosion on the mechanical strength of magnesium samples. Our work is motivated by the need to predict the residual strength of biomedical Mg implants after a given period of degradation in a physiological environment. To model corrosion, a mass-diffusion type model is used that accounts for localised corrosion using Weibull statistics. The overall mass loss is prescribed (e.g., based on experimental data). The mechanical behavior of the Mg samples is modeled by a state-of-the-art Cazacu-Plunkett-Barlat plasticity model [1] with a coupled damage model. This allowed us to study how Mg degradation in immersed samples reduces the mechanical strength over time. We performed a large number of in vitro corrosion experiments and subsequent mechanical tests to validate our computational framework. Our framework could predict both for tension and compression tests the experimentally observed loss of mechanical strength and ductility due to corrosion [2]. Our study confirmed that it is important to consider the surface/volume effect of the samples during corrosion testing and numerical analysis.

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Microplane Model for Inelasticity and Fracture of Transversely Isotropic Polymer Composites

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Keywords: Microplane inelasticity, Microplane fracture, anisotropic polymer composite

A new microplane model based on cylindrical geometry in which the cylinder axis coincides with the longitudinal direction is developed for a general 3D inelastic fracturing analysis by finite element method of transversely isotropic fiber reinforced polymer composites.

Most models available in literature do not address the 3D general loading. Furthermore, they remain in the mesoscale which makes large scale finite element calculations impossible. The proposed model bridges the mesoscale material behavior to macroscale behavior using the stress equilibrium developed for cylindrical geometry. To this end, Microplane level stress–strain relations for tension, compression and shear for both longitudinal and transverse directions are formulated to optimally fit experimental data [1]. An explicit algorithm is formulated and coded into a VUMAT user subroutine for use with commercial finite element software ABAQUS.

The model is suitable for the analysis and design of large structures made of fiber reinforced polymer composites unlike the competing mesoscale models. A detailed algorithm for the calibration of the model is identified using the common test data available in the literature. The predictive capacity of the model is demonstrated by comparing the model predictions against test data in (i) longitudinal tension, (ii) lateral tension, (iii) longitudinal compression, (iv) lateral compression and (v) longitudinal shear. In addition, rare size effect test data that includes the post-peak fracture of multilaminate composite is used to test the predictive capability of the proposed model.

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Damping in Functionally Graded Shafts under Torsion: an Analytical Approach

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Keywords: energy damping, torsion, functionally graded material.

The present paper addresses the question for the damping of the energy in functionally graded shafts loaded in cyclic torsion. In particular, a shaft of circular crosssection is researched here. One of the motives for conducting this research is that the previous energy dumping studies deal mainly with beams of rectangular cross-section subjected to bending [1, 2]. Another motive is that the functionally graded materials are commonly used in modern engineering for manufacturing of various components and members of constructions and machines [3]. Very often the functionally graded members and components are subjected to cyclic loading. Under such loading conditions, the question for analysis of dumping is of prime significance. The analysis of dumping is closely related to the problems of safety and reliability of the engineering constructions, machines and equipments. The shaft that is researched in the present paper is rigidly fixed in both ends. A torsion moment is applied near the mid-span. A stress-strain relationship of the type of Ramberg-Osgood is used in the analysis of the dumping. The three material parameters of the stress-strain relationship are distributed continuously along the cross-section radius since the material is functionally graded in radial direction. The distribution is treated by using exponential functions. The analysis of dumping goes through researching of the parameters of the stressed and strained state of the shaft with considering of the material non-linearity. In the context of analyzing of the stressed and strained state of the shaft, relevant equations of equilibrium are compiled and solved. After that, the distribution of the parameters of the unit damping energy along the radius of the shaft cross-section is derived. The total dumping energy in the shaft is found-out by integrating of unit damping energy. The solution derived offers very good possibilities for obtaining of numerical results with purpose of clarifying how the total dumping energy is influenced by different factors such as distribution of material parameters along the radius of the cross-section, geometry of the functionally graded shaft, boundary conditions and parameters of the external loading.

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Considering the Time Factor in Longitudinal Fracture Analysis of Functionally Graded Constructions

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Keywords: time factor, bending, longitudinal fracture.

The current theoretical paper aims to explore how the longitudinal fracture in beam-type functionally graded engineering constructions is biased by the time factor. As known, there is a clear tendency of increasing the usage of functionally graded materials in various spheres of engineering [1]. The beam studied here has non-linear viscoelastic behavior. Besides, the beam is functionally graded through its thickness. The beam is subjected to static loading. The theoretical model used for dealing with viscoelastic behavior is set-up by linear as well as non-linear springs and dashpots. Two parameters of the model (the modulus of elasticity and the coefficient of viscosity of the non-linear spring and dashpot) are continuously varying with time (actually the basic motive for the present study consists in the fact that previous studies dealing with time-dependent modulus of elasticity [2] or coefficient of viscosity [3] use linear viscoelastic models). Also, all of the model parameters are distributed continuously through the beam thickness. The first step in the analysis consists in extracting of the time-dependent non-linear relation between stress and strain by treating the stressed and strained state of the components of the viscoelastic model when the latter is subjected to a constant stress. Then this relation is used when extracting of the time-dependent strain energy release rate. The solution of the strain energy release rate is confirmed by analyzing the time-dependent strain energy in the beam. It is found that the strain energy release rate is biased in a significant degree by the factor of time. In particular, the strain energy release rate-time curve has rising mode. Another issue that is clarified as a result of the present study is the effect of the variation of the modulus of elasticity and the coefficient of viscosity with time on the strain energy release rate. It is found that the strain energy release rate reduces when the values of the parameters used for treating the dependency of the modulus of elasticity and the coefficient of viscosity on time rise.

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Accounting for Viscoelastic Non-linearity and Temperature Influence in Delamination Analysis

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Keywords: viscoelastic non-linearity, temperature, delamination.

This paper addresses the question for accounting of viscoelastic non-linearity at theoretical analysis of delamination in multilayered beam constructions with considering temperature influence. The multilayered materials are widely used in engineering [1]. The main impulse for carrying-out the present study is that previous papers dealing with temperature influence on delamination usually apply linear viscoelastic material models for treating the behavior of the beam constructions [2]. The viscoelastic model used in this analysis is set up by a non-linear spring put in parallel to a non-linear dashpot. A linear-elastic spring and a linear dashpot are also included in the model. The latter is under strain varying exponentially with time. The material parameters of viscoelastic model are distributed continuously through the thickness of layers since the material is inhomogeneous. The stress-strain-time relationship of the model is obtained by analyzing the work of the model components under varying strains. This relationship is incorporated in the delamination analysis of the beam construction subjected to external loading and temperature influence. For this purpose, the secant modulus is extracted and applied when analyzing delamination by the integral J. The temperature influence is accounted for by introducing a change in the secant modulus that is used in the solution of the integral J. Thus, the solution of the integral J accounts for both external loading and temperature variation. The solution of the integral J is confirmed by the strain energy release rate. The latter is found-out by using the complementary strain energy in the beam obtained with considering the external loading and the temperature change. A parametric investigation is performed. One of the important observations is that the integral J reduces when the temperature rises. This finding is confirmed by the strain energy release rate that is found-out by using the secant modulus (the latter is changed in order to take into account the temperature variation). The analysis performed in this paper also reveals how the delamination behavior of the multilayered non-linear viscoelastic beam construction is influenced by various parameters of the temperature change, external loading and geometry of the beam.

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Finite Element Simulation of Crack Propagation in Brittle Plates

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Keywords: FEM fracture modeling

A method for modeling fracture in stiff plates of uniform thickness is presented. The Mindlin-Reissner plate theory within the framework of the finite element method is utilized. The fracture criterion is based on the Rankine theory, in which a crack is initiated when normal traction at a node exceeds a given tensile strength. The traction is calculated as a path integral around a crack tip or a tentative split. The propagation direction is such that the normal traction at the crack tip is maximized. A time-based criterion for crack initiation and propagation is added to the model, which yields better correspondence with the experimentally observed fracture patterns. The proposed methodology was implemented in an in-house code. Initial validation shows excellent agreement between the proposed methodology's predictions and the realistic fracture patterns of ice floes.

In recent years, substantial efforts have been dedicated to studying ice fracture – a process that can take different forms depending on the scale, geometry, and type of ice. The current work focuses on modeling the brittle fracture of ice floes under bending caused by ocean waves. Ice floes having an approximately uniform thickness can be modeled accurately by relying on plane assumptions (i.e., 2D mesh) in finite element analysis (FEA). This approach has been employed for modeling large-scale ice sheets and wave-ice interactions, and the same assumption is utilized in the current work. The fracture model uses the tensile strength criterion [1], where the fracture initiation relies on maximal normal component of the traction vector. At each node of the mesh, a tentative fracture direction is selected, and the traction vector is then computed as a line integral on each side of a tentative split.

The proposed numerical approach shows an excellent agreement with the observed fracture patterns in natural ice floes and laboratory experiments. The current results are primarily qualitative, but the model shows potential for application in ice mechanics as well as other areas of engineering where bending brittle plates are considered. The formulation is limited to an applicable range of strain rates (currently the wave loading rates), but can be adjusted for a particular engineering application or to consider additional physical phenomena.

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Excellent structure of water filtration system manufactured using additive manufacturing

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Keywords: Micro channel; Additive manufacturing; Water filtration

The use of Micro Channel 3D Printing on filtration of distilled water and sawdust solutions was successfully implemented in the present study. The system was utilized to see the clarity of the filtered distilled water as well as to measure the filter power of Micro Channel. The specimen was manufactured in terms of weight of solution per unit time of test. This study evaluated the ability of Micro Channel 3D Printing to filter distilled water solution and sawdust (size 600 microns) on Micro Channel specimen. The filter capacity was set of 1 mm and 0.5 mm in diameter. The independent variable of this filtering test was uses six solutions with different percentage compositions (0-5%). The test was carried out on two dependent variables, namely the filtering variable for one minute and the filtering variable for 60 minutes (dry variable). This research also examines the dimension that is most effective and can be used for the diameter of the channel hole. The evaluation was used microscopic test, considering the type of resin used, namely plant-based resin that safe for use in general conditions. This research also shows some failures during the printing process and some solutions that can overcome these problems.

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Tensile, Fracture and Damage Resistance Characterization of 3D Printed PLA with Morse Code Architectures

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Keywords: 3D printing, Fracture, Damage tolerance.

Fused deposition modelling (FDM) is one of the most popular additive manufacturing technologies. Therefore, understanding and improvement in mechanical properties and damage resistance of FDM fabricated structures have become important. In this study tensile and fracture properties of 3D printed PLA are quantified as function of, building direction, filling pattern and raster angle. Tensile strength and failure strain are found to be the same for hexagonal and line filling patterns. Highest fracture toughness and total damage resistance were found for the 90° raster angle [1]. In a previous study, Morse-code inspired architectures of dashes and dotes manufactured by laser machining in single edge notch bend specimens of a brittle polymethylmethacrylate (PMMA) were shown to improve damage tolerance of the material by 20-24 times [2]. In order to improve damage tolerance of 3D printed fabricated structures, a combination of dot and dash like architectures were printed. The dot-like features act as crack arrestors and the dash-like features work as crack deflectors. A combination of simulations and experiments have been performed to determine and quantify the effect of the size and arrangements of these features on crack driving force and fracture resistance. Crack initiation resistance has been defined in terms of initiation work of fracture per unit area (WOF_o) and overall damage resistance has been defined in terms of total work of fracture per unit area (WOF_T). WOF_o per unit area of bulk is the highest and shows maximum load bearing capacity while WOF_T is the lowest for bulk and highest for a combination of alternative layers of dashes and dots. A 1172% increase has been observed from WOF_o to WOF_T for SH case. This indicates that architecturing is an effective means to improve overall damage resistance of 3D printed structures.

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On Applying the Neuber's Rule to Spectral Fatigue Damage Estimation Under Elasto-plastic Strain

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Keywords: Spectral fatigue, plasticity, strain-based spectral damage

Spectral methods (frequency domain approaches) are commonly used for estimating fatigue damage of vibrating structures in high-cycle fatigue regime, where the material is linear elastic [1]. In the low-cycle fatigue regime, by contrast, material exhibits plasticity, so the structural response is non-linear. For this reason, the applicability of spectral methods in low-cycle fatigue regime is open to debate. Few studies exist in the literature that include plasticity in the spectral methods by means of the Neuber's rule and the Ramberg-Osgood constitutive model [2, 3]. The Neuber's rule approximates the elasto-plastic stress and strain responses by using the stress and strain results of an elastic analysis. This paper aims to provide a critical analysis of the existing strain-based spectral methods based on Neuber's rule. After developing a rigorous theoretical formulation, the spectral damage estimations are compared with simulation results obtained in the time domain by the use of cyclic plasticity models with kinematic and isotropic hardening effects (Chaboche and Voce models). The findings allow us to shed light on the range of applicability of the existing strain-based spectral methods, while also providing ideas for possible further improvements.

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On the Diversity of Fracture behavior in a brittle Solid with Sets of Preexisting Small-Scale Cracks

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Keywords: Cluster of fractures, Reverse fracture, Unzipping fracture.

As mentioned earlier [1, 2], understanding the multiscale fracture behavior of brittle materials is of crucial importance non only in engineering applications but also in seismology where an earthquake source, usually assumed as one single, relatively large fracture region but in reality composed of relatively smaller multiple fractures, behaves mechanically in diverse ways, emit waves with different characters and may cause a single seismic event or even a cluster of earthquakes and earthquake swarms. For understanding the complex fracture processes, by employing the experimental technique of dynamic photoelasticity using highspeed video cameras, we have been simultaneously observing global, large-scale material behavior and local, smaller-scale evolution of waves and fractures in two-dimensional linear elastic brittle polycarbonate specimens. Each specimen has sets of preexisting small-scale parallel cracks prepared by a digital laser cunner and modeling a large-scale geological normal fault plane, and in is subjected no external quasi-static and impact loads. Here we show some recent examples of the diverse fracture behavior observed in brittle birefringent solid specimens under tensile/compressive external loading. The fracture behavior is considerably dependent non only on the loading conditions but also on the initial inclination angle and distribution pattern of the sets of parallel cracks, and the behavior can be very complex especially in and around the sets of cracks. Developing fractures, both in quasi-static and dynamic manners, do not always break the specimen in an "unzipping" way, i.e. the specimen is not always divided along a perforation line consisting of small-scale cracks. Rather, the diverse fractures can easily jump no remote places, propagate back-and-forth or reversely move in the opposite direction compared with the initial one. Our findings may play a role in comprehending the generation mechanism of a cluster of fractures in brittle solids in general.

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On the Dynamics of a Granular Medium Subjected to Multiple Impact Loads

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Keywords: Stress transfer in granular media, Granular collapse, Granular buckling.

Fracture and collapse of granular materials may be observed in a variety ofengineering applications, including earthquake-induced slope failures, debris flows, as well ascontrolled surface fracturing of asteroids due to impact loads given during sample-returnspacecraft missions. However, as stated in our previous study [1, 2], the mechanical propertiesof granular materials, especially, granular fracture dynamics, have not been completelyunderstood yet. So far, using the experimental technique of dynamic photoelasticity inconjunction with high-speed video cameras, we have recorded dynamic stress transfer andwave / fracture development in two-dimensional granular media. Each granular medium, madeof penny-shaped birefringent polycarbonate particles, has been placed on a rigid horizontalplane with some inclination (slope) angle and subjected to a single dynamic impact load on itstop free surface. From the experimentally recorded transient particle motion and dynamic stressdevelopment, we have found two distinct failure patterns: (1) complete collapse or mass flowcaused by unidirectional (force-chain-like) stress transfer; and (2) toppling-type separation ofthe slope face of the medium due to widely spreading multi-dimensional waves [1]. In addition,we have examined the buckling phenomena of granular media and evaluated the effect ofconfinement and material heterogeneities on granular fracture dynamics through experimentalphotoelastic observations and numerical discrete element simulations [2]. In this contribution,we study the dynamic interaction of particle motion induced by multiple impact loads, andfurther conduct laboratory photoelastic experiments. We show how transient particle motion,stress transfer and failure patterns inside a granular medium can change according to thevariation of the dynamic loading conditions.

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Surface Transverse Crack Growth in Steam Turbine Shaft

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Keywords: Transverse Vibration, Steam Turbine Shaft, Crack Growth.

Operation of steam turbine structural elements is characterized by heavy mechanical and thermal loading in corrosive environment. One of the main consequences of such operation conditions is damage of steam turbine structural elements, which accumulates for a long time and finally develops into local damage of a crack type. The initial defects in turbine structural elements appear in the process of their manufacture because almost all technological operations such as forging, turning, and milling, heat treatment damage the surface layers of the material in the form of pores and micro-cracks. Besides a huge amount of stress concentrators in turbine structural elements is the additional reason of crack initiation and growth.

The stage of crack growth usually is relatively short and may lead to catastrophic failures if crack will not be detected in time. The intensity of crack growth is dependent on operational factors and crack resistance characteristics of rotor steel. To estimate the edge transverse crack growth rate in steam turbine shaft in the process of transverse vibrations when rotor passes through the first critical speed the analytical model has been developed. As a model object the high-pressure rotor of the K-210-130 steam turbine was chosen. The durability of cracked rotor in terms of start-ups number was estimated with the fracture mechanics theory based on the calculated stresses in the cracked area, as well as on the experimentally determined crack growth rate for the rotor steel.

As it was demonstrated, the angular acceleration, rotor's eigenfrequency and geometrical characteristics have the most essential impact on the intensity of crack growth. Thus, the intensity of crack growth can be decreased crucially by the increase of angular acceleration and/or rotor's diameter and by the decrease of rotor's eigenfrequency. Of the factors, which are the mechanical properties of rotor steel, the damping characteristic is most influential. In such a way, the creation of high damping rotor steels and the utilization of effective mechanical dampers are the promising ways to prevent crack growth in turbine rotors.

Optimization of Strain Energy in Crack Structure via Fracture Mechanic Based Microdefects using Peridynamic Informed Topology Optimization

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Keywords: Peridynamic, topology optimizations, micro cracks.

Topology optimizations is vastly used to design light-weighted structures that used in industrial applications. Even tough classical continuum mechanics is implemented commonly to solve topology optimization (TO) problems, but it brings some restrictions to the modeling, analysis, and solution of complex structures with structural discontinuities. On the other hand, peridynamic (PD) theory can overcome these restrictions because of its nonlocal integration nature. Unlike classical continuum mechanics, in this approach, the material does not necessarily require remaining continuous during the simulations. Thus, it ideally becomes a robust approach for dealing with discontinuities such as cracks, damages, and defects. Recently, a comprehensive comparison is done to compare PD-TO to a finite element method based topology optimization (FEM-TO) to justify its need to be used as a superior method to include defects and thus having more reliable framework [1], furthermore by applying same strategy, its effects are expanded to various studies [2,3]. During additive manufacturing process occurrence of micro crack is inevitable so including micro cracks during design stage helps to prevent unwanted future failure. This paper presents an application of peridynamic based topology optimization (PD-TO) to establish a framework to optimize of micro crack characteristics. Even though there are various studies including defects in PD-TO framework, to the best of Author's knowledge, there is no study to include fracture-based defect and thus this paper try to investigate the effect of microdefects which may cause due to the various uncertainty during production and by applying their characteristic in exact location by using fracture mechanics based TO, the model is optimized and thus the strain energy can be improved significantly. To this end, the PD-TO model is derived using an in-house MATLAB code. By utilizing the fracture mechanics, best micro cracks orientations and length are optimized. For each structure, strain energy density distributions are compared between different topologies. As a result, importance of predicting unwanted micro cracks during design stage of a macrostructures is presented.

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Failure criterion taking into account porosity and microstructural anisotropy

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Keywords: failure criterion, microstructure, anisotropy

The present work considers a fabric and density-based criterion for predicting the safe limits for porous and anisotropic materials under a general stress state. There are several classic and well-established criteria given in the literature for homogeneous and isotropic materials [1,2]. However, when the material is porous (heterogeneous) and mechanical properties are orientation-dependent (anisotropic), the failure mechanism establishment and the influence of these parameters in predicting failure are still challenging [3]. Natural materials like wood, rock, and biological tissues like bones, as well as synthetic fiber-reinforced composites, exhibit these microstructure features at a significant level. The failure criterion presented in this work is based on morphological measurements and characterization. The volume fraction is considered the primary parameter and microstructure orientation is addressed by the fabric tensor approach. Fabric tensors are understood as symmetric second-rank tensors that characterize a material's structural sensitivity. The concept lies in modeling the material microstructure through tensors of higher rank which characterize both anisotropy and orientation [5]. Among the available methods, the Mean Intercept Length (MIL) boundary-based approach is considered to estimate the fabric tensors. This method proposes to construct the fabric tensor for biphasic materials from planar image sections obtained in micro-CT scans. The approach is based on defining the mean distance between a change from one phase to the other along a specific orientation. In partially oriented microstructures, Underwood (1973) [6] and Whitehouse (1975) [7] observed that when MIL data was disposed on a polar plot and fitted in an ellipse, the corresponding ellipse parameters could be correlated to the material orientation. As imaging techniques become increasingly powerful, this work expects to contribute as a tool to provide more accurate yield criteria by including the effects of porosity and microstructural anisotropy.

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Prediction of Yield Surface and Hysteresis Loop for Cyclic Mechanical Loading for Laser Powder Bed Manufactured Ti6Al4V

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Keywords: Hill Anisotropy, Cyclic Hardening, Titanium Alloy.

Ti-6Al-4V is one of the most common alloys used in jet engines and other aerospace applications. In many of these applications, material is subject to cyclic mechanical loading. However, manufacturing parts made from this alloy using conventional methods such as forging or cutting is a difficult task. Recent work in additive manufacturing offers a convenient way for such parts to be manufactured with relative ease as well as less wastage [1]. Selective Laser melting, powder bed fusion process is one such robust technique. This study intends to define a mathematical model which can be used for predicting the cyclic plastic deformation and subsequent cyclic hardening behavior of a Ti6Al4V material made using laser powder bed process subjected to cyclic loading. The model will consider anisotropic behavior of additively manufactured titanium alloy as well as both isotropic and kinematic hardening behavior. The anisotropy in the material properties is incorporated with the help of Hill Yield Criteria [2]. Combined isotropic and kinematic hardening behaviors are modeled using Voce's Non-Linear isotropic hardening model as well as Chaboche's Kinematic hardening model [3],[4]. Equations from the two models are combined with the Hill 48 criteria to develop an equation which predicts the yield surface of the complex anisotropic behavior combined with isotropic and kinematic hardening. This yield surface is then plotted for a few different loading conditions. This combined model is then used for prediction of the hysteresis loops for the same loading conditions which can then be utilized for predicting the life of the sample.

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Localizing Implicit Gradient Damage Based Modelling of Quasi-brittle Failure with Non-planar Cracks

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Keywords: quasi-brittle failure, damage mechanics, localizing implicit gradient damage

Localizing implicit gradient damage (LIGD) is a gradient extended model which is equipped with a decreasing internal length scale with damage evolution, [1]. The model is thermodynamically consistent and resolves the well-known problems of conventional implicit gradient damage (CIGD) model such as artificial diffusion of damage and erroneous predictions of failure initiation and propagation directions. So far, the effectiveness of the model has been demonstrated for two-dimensional quasi-brittle and three-dimensional ductile failure predictions with flat fracture surfaces. It is the aim of this contribution to assess the predictive capabilities of the model for three-dimensional quasi-brittle failures with non-planar cracks. To this end, localizing implicit gradient model is embedded within a tetrahedral element formulation and implemented in commercial finite element package Abaqus through user element (UEL) subroutine. Skew notched prismatic and cylindrical torsion tests are modeled and capabilities of the model are assessed in terms of reaction force-displacement curves as well as the resulting crack surfaces, [2, 3]. Comparison of LIGD and CIGD predictions suggest that LIGD is superior than CIGD. Furthermore, as far as capturing the experimental results is concerned, it performs as good as other alternative modeling frameworks, e.g., mixed finite element formulations.

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Novel bio-filler for additive manufacturing based on geothermal waste materials

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Keywords: Silica Powder; filler material; Additive manufacturing; geothermal waste material

Silica deposit powder from geothermal waste is a useful material that has excellent physical and mechanical properties and is often used in various industries. The characterization of silica deposit powder has a significant part in understanding its structure, composition, and potential application. Key aspects of silica deposit powder characterization successfully highlighted. By using silica as a filler system in additive manufacturing is one of the processes that can utilize silica deposit powder. This material has the potential to be used as a reinforcement mixture with SLA resin for 3D printing. The present study discusses the ability to mix specimens of silica (size 600 microns) and resin with a composition ratio of 1%: 100%. This research aims to gain knowledge about the basic characteristics of silica deposit powder for better understanding and efficient utilization in various applications, especially additive manufacturing. This research also examines the most effective particle sizes to use and adjustments to the length of time required for the mixing and curing processes in order to obtain maximum results [1-6].

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Microstructure-based Numerical Simulation to Predict Mechanical Properties of 316CW Stainless Steel

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Keywords: 316CW Steel, Finite Element Analysis, Irradiation Effect, Nano-indentation, Reactor Vessel Internals

Although most of reactor vessel internals (RVIs) have been designed by austenite stainless steels with high strength and ductility, not only possibility of material property changes due to harsh environments but also a few failures caused by microstructural defects et cetera were reported in the RVIs of operating nuclear power reactors. Particularly, the investigation on irradiated materials is important but direct measurement of their properties is not easy because of complexities associated with preparation of neutron irradiated standard specimens and test facilities. Therefore, recently, several researches were carried out to incorporate irradiation embrittlement depending on dose levels [1] by establishing alternative ion irradiation conditions and using miniature specimens.

In this study, effectiveness of a microstructure-based simulation method was examined through the prediction of as-received and irradiated mechanical properties of 316CW (Cold Worked) stainless steel. At first, dislocation density-related material constitutive parameters were determined by comparing nano-indentation test data [2] and corresponding numerical analysis results. Then, microscopic stress-strain curves were derived based on the calibrated constitutive parameters and converted into macroscopic stress-strain curves in use of existing correlations [3]. Finally, influence of different dose levels was assessed via a series of FEA and the subsequent procedure, of which details and key findings will be discussed.

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Uncoupled Damage Models for Ductile Failure in Flow Forming Processes

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Keywords: Flow forming process, Inconel 718, Formability limits.

Flow forming (FF) is an incremental forming process in which the thickness of the material is thinned. During this process, the material undergoes complex stresses and substantial plastic deformation, often leading to cracks due to exceeding its formability limits. It is crucial to predict the forming limit accurately to improve the efficiency and quality of the process. Ductile failure analyses are carried out with finite element (FE) simulations to compare the damage prediction capacities of different ductile failure criteria in the literature. The FF process is studied using different criteria with titanium alloys [1,2], but the results obtained from FE simulations have not aligned well with experimental tests. In contrast, our previous study [3] on FF failure analysis with the nickel-based superalloy Inconel 718 (IN718) showed that the Cockcroft-Latham (CL) damage criterion outperformed the Johnson-Cook (JC) and modified Mohr-Coulomb (MMC) models in predicting damage locations and fracture limits when compared to experimental tests. In this study, the aim is to extend this research by developing several damage criteria modeled for IN718, which then is compared in terms of predicting damage locations and formability limits in the FF process, considering various thinning ratios. Ayada, Ayada-m, Ko-Huh (KH), Le-Roy (LR), McClintock (MC), Oh and Rice-Trace (RC) failure criteria are implemented as a user-defined field subroutine (VUSDFLD) in commercial FE analysis software Abaqus/Explicit. Four distinct tensile test specimens, each characterized by a varied range of stress triaxiality, are employed to calibrate the criteria, and evaluate their capabilities in different stress triaxiality. Then, FE simulations of FF are performed at 37.5%, 50% and 70% reduction ratios using the calibrated models. The obtained results from different models are compared and their performance in predicting the formability limit and crack initiation location is discussed in detail.

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Numerical simulation of TiN thin films fracture - cohesive elements and XFEM method case study

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Keywords: TiN thin film, nanoindentation, finite element modelling, cohesive zones, XFEM

Numerical simulation of fracture development in thin films deposited by the Pulsed Laser Deposition (PLD) method is the main goal of the work. The developed numerical fracture initiation and propagation model is based on two approaches: cohesive elements [1] and XFEM method [2]. TiN thin films deposited on several substrates were selected as a case study for the current investigation. All the samples were examined by nanoindentation test and scanning electron microscopy to evaluate local material properties. In addition, a finite element method supported by inverse analysis was used to convert the measured load-displacement values from nanoindentation into a stress-strain curve for further numerical simulations. The fracture initiation and propagation parameters [3] for both mentioned approaches were also determined with the inverse analysis, considering the geometrical aspects of the film after loading in the goal function. The proposed approach demonstrates the ability to predict local inhomogeneities that can affect the overall mechanical properties of thin films as a result of fracture formation.

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Formulation of a Bilinear Traction-Separation Interface Law in Boundary Elements with Homogenization

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Keywords: Boundary element method, bilinear interface modeling, homogenization

Similar to most conventional composite materials, the interface is generally the weakest part of nanocomposites. For this reason, the behavior of the reinforcement-matrix interface is critical for determining the strength of nanocomposites. Especially in nanocomposites, if no special precautions are taken, the matrix consisting of nano-reinforcements and polymer chains are bound to each other by weak van der Waals interactions and electrostatic interactions. As a result, in most nano-composites under loading, damage first begins as separation at the interface. This study focuses on a key aspect of modeling polymer nano-composites: the interface between the inclusion and the matrix. First, the alternative boundary conditions of homogenization are presented and then implemented in the boundary element method. Afterward, a bilinear interface law [1] between inclusion and matrix is defined in the boundary element-based homogenization method. The homogenized stress responses of a heterogeneous Representative Volume Element (RVE) undergoing debonding are compared with numerical studies from the literature. RVEs, including both single and multi-inclusions, are studied. Comparisons are made with the studies based on modeling interfaces using micromechanics and Mori-Tanaka-based approaches [2], and boundary element method-based approaches [3]. A good agreement is observed between results.

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DIC for multi-scale model validation and structural integrity for fusion

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Keywords: Ductile failure, Multi-scale, Irradiation, Digital image correlation, Simulation.

Realising commercial power from nuclear fusion presents significant structural integrity challenges. Creep and ductile failure models are needed to ensure that fusion components are designed against plastic collapse, capturing both early plastic flow and strainto- failure as a function of stress triaxiality. Traditional notched bar experiments ignore triaxial stress state evolution throughout the test and result in design over-conservatism. Models require experimental validation within a multi-physics parameter space - time, thermal-, mechanicaland irradiation loadings - but representative combined loads are impossible to establish experimentally ahead of plant build. Hence, microstructurally informed predictive models are needed. Here we present a case study on a ferritic-martensitic steel that uses finite element (FE) simulation validated with full-field digital image correlation (DIC) to approach both problems.

FE simulation can be used iteratively as an inverse tool to determine the constitutive behaviour of a material given the surface strain fields measured using optical DIC. We present solutions to the problem of global vs local matching and the need for full uncertainty quantification in reaching acceptable experimental-simulation comparison cost functions. We determine true stress – true strain constitutive laws for large strains in the neck to ductile failure by incorporating strain rate effects and appropriately capturing evolving triaxial stress states. Further, we leverage the DIC and FE-updating framework to enable complex specimen geometry testing, e.g., multiple stress triaxialities within a single specimen, a philosophy coined Material Testing 2.0 [1]. This reduces the number of tests needed for model validation.

Under thermal-mechanical loading, irradiation causes a ductile-to-brittle transition [2]. Bulk neutron damage can be emulated by surface ion irradiation, but the aforementioned approach to model validation in bulk material is unsuitable because only DIC-FE comparisons in the ion irradiated surface layer are valid. We use microstructural-scale DIC to determine fundamental deformation mechanisms in the steel under tension and ion irradiation. These data are used to validate crystal plasticity FE simulations of deformation in the combined thermal-mechanicalirradiation environment and predictions of behaviour in untestable neutron environments.

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Critical Issues Related to the Effect of Residual Stresses on Mixed-Mode Crack Growth Phenomenon

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Keywords: computational fracture, residual stresses, mixed-mode crack growth.

Manufacturing methods that include welding processes might carry a structural failure risk due to residual stress effects. This type of potential failure could be misleading for the analysis of a component subjected to a subsequent load following the welding process. If the problem involves crack propagation phenomenon with fatigue loading, then the overall investigation becomes much more complicated to handle. An effective finite element program [1] for the solution of fracture problems with stationary crack fronts was introduced to the literature in the past. Later, the capabilities of this program were further improved [2] by including crack growth procedures. On the other hand, a notable work [3] analyzed the effect of residual stresses on post-welding behavior of cracked structures, but only considered stationary cracks. Current study demonstrates the features of a recently developed computational tool for understanding the effects of residual stresses on mixed-mode crack growth analysis. In such problems, several issues such as correct modeling of welding simulation, adequate representation of the model details in finite element mesh, estimation of propagation direction, a suitable growth law, determination of an optimum crack increment size, remeshing procedures are among significant matters. Geometrical variations are considered by depicting example problems with both straight and curved crack fronts. It is seen that all issues given above have key roles for the accurate simulation of growing cracks with residual stresses. It should also be noted that neglection or underestimation of residual stress effects might lead to wrong conclusions regarding the fracture output for a particular example. As a follow-up task, the effect of welding parameters on the same problem is being considered.

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Impact of Element Layout and Notching Technique on the Fracture Toughness of FFF-Processed Thermoplastics

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Keywords: Additive manufacturing, fracture mechanics, experimental mechanics

The mechanical performance of additively manufactured (AM) thermoplastic materials and polymer matrix composites is of great interest to designers considering the use of AM processes for manufacturing. While the basic mechanical properties for AM-created parts are well-studied in the literature, the fracture behavior is still an area in need of exploration. The fused filament fabrication (FFF) process is the most common and widely-used AM process for thermoplastic materials and polymer matrix composites. It is a scanning-type AM process which deposits and fuses discrete elements of material to form the part layers. Therefore, the layout pattern of the elements can be expected to greatly affect the fracture toughness of the materials as it affects the available crack paths in the material. In addition, the part shell (layer outline) will have an effect the fracture whenever a crack begins at or reaches a layer boundary as seen with printed notches; this consideration is an important driver for selecting part geometry and notching method. This study explored the effect of notching method and element layout pattern on the calculated fracture toughness for three common FFF materials: Acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), and polycarbonate (PC). To study the effect of notching, both printed and machined notches were used with and without pre-cracking (four different combinations) with ASTM D5045 CT samples (W = 30 mm, B = 6 mm). Three replications were completed (n = 12), with the collected data showing a statistically significant difference between the methods. Once completed and the best notching method selected, a set of similar samples (n = 72) with different element layouts (45-degree raster, gyroid, concentric) and element/bead thicknesses were tested. The results showed a very strong effect, with the fracture toughness ranging as much as 60% depending only on the element size and layout. The conclusions from this study were that both the notching method and the selection of element layout and size had a definite effect on the fracture behavior of three common FFF-processed materials and should be carefully considered when designing parts that will be fabricated using FFF.

Impact of Compact Tension Specimen Size on Fracture Toughness of FFF-Processed Thermoplastics

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Keywords: Additive manufacturing; experimental mechanics; testing methods and standards

The ASTM D5045 standard is one of the most widely-used and cited methods for estimating the fracture toughness of thermoplastic materials. This standard is simple to implement and does not depend on J-integrals and similar tools to estimate fracture toughness. It is well-established in the literature that additively-manufactured (AM) thermoplastic materials fail to satisfy the criterion in this standard for plane strain condition, but there is also a common observation that there is no a strong dependence of the sample size on the fracture toughness values; this suggesting that these materials reach plane strain at a much smaller geometry than the ASTM D-5045 criterion specifies. Given how important this consideration is for design, the present study explored this question by completing a series of experiments on three common thermoplastic materials (acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), and polycarbonate (PC)) manufactured using the fused filament fabrication (FFF) process. The CT specimen was used with three different sample sizes (W = 30, 40, and 50 mm, B = 6, 8, and 10 mm - none of which met the plane strain criterion specified in the standards) with the test run 3 times for a total of 27 tests. Using ANOVA, it was found that there was no statistically significant effect based on sample size. One of the sample runs (W = 30 mm, B = 6 mm) was then repeated with B = 3 mm (3 more tests per material, n = 9) to further test the effect of thickness. As with the first set of experiments, no statistical difference was found in the fracture toughness values. It was concluded that, at least within the size range studied, there is no significant difference in output values based on sample size and that the tests were repeatable across different sample sizes. This suggests that either the samples reached plane strain condition at a smaller size than expected by the standard or that there is not a large difference between plane strain and plane stress conditions for FFF-processed CT samples. Future work in this area will focus on more extreme size differences and other materials.

Study of Temperature-Dependent Motion of GBs in Pure Aluminium by Cellular Automation and Machine Learning Methods

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Keywords: grain boundaries motion, cellular automation, feedforward neural network.

This work is devoted to the theoretical study of grain boundary (GB) motion in pure aluminum based on 3 numerical methods: molecular dynamics (MD), machine learning (ML) and cellular automata (CA). Values of GBs energy are obtained by MD method [1]. Symmetric and asymmetric tilt and twist GBs in the boundary planes (100) and (110) are considered, and the GBs energies are measured for temperatures of 100, 300, 500, and 700 K. The next step is related to the description of the GB energy function as dependent on misorientation and temperature in the form of the forward propagation artificial neural network (ANN). MD simulation data are used to train and test this ANN. Training of the ANN is performed by the Adam algorithm [2] to better accuracy on the test data. The last part of the work is related to the simulation of the GBs motion and microstructure evolution during the dynamic deformation response of the pure aluminum material by the CA method. It is well known that the mobility of GBs is proportional to their energy [3]. Based on this law and the anisotropic energy function in the form of ANN, transition rules for the CA method are derived. The CA grid is superimposed on the level of matter, which is realized within the continuum mechanics framework with according to the Wilkins scheme [4]. The results show that the GBs energy can be divided into minimum and average for the fixed misorientation angle. This is consistent with the works on the study of metastable GBs structures [5]. The ANN trained on MD data shows good accuracy on test data and is capable of describing the evolution of the GBs energy with temperature change as the continuous function.

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Investigation of Recrystallization Behaviors of CuZn30 Alloy After Flow Forming

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Keywords: Flow forming, Recrystallization Annealing, CuZn30

CuZn30 alloy is used widely in the manufacturing of large-caliber round cartridge cases. Generally they are manufactured by cupping of a disc and after that successive deep drawing processes in order to reduce the wall thickness of the material. Annealing process is applied between each process steps to recover formability [1]. The main target of this study is determining to optimum recrystallization annealing conditions of CuZn30 tubes after flow forming operation. Preforms which are used in the study is produced by machining of CuZn30 billets. They are one end closed with an outer diameter of 125.20 mm, wall thickness of 5.2 mm and 300 mm length. Flow forming process parameters are 110 mm/sec feed rate, 160 rpm rotation and 40% thickness reduction ratio. After flow forming, recrystallization annealing operations are applied at different temperatures which are 250°C, 350°C, 450°C and 550°C for 1 hour in atmosphere controlled furnace. Moreover, recrystallization annealing is also applied at similar temperatures in salt bath to decrease operation time. The obtained microstructures and the mechanical properties are investigated to determine optimum recrystallization annealing conditions. Spherical and new grains are obviously generated after recrystallization annealing at 450 and 550°C, but only partial recrystallization is detected at 250 and 350°C in atmosphere controlled furnace. Also, by using salt bath similar results are obtained in a very short times comparing to atmosphere controlled furnace.

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Implementation of Through the Thickness Compressive Stress on the Retardation of Delamination Initiation in Ply-Drop Off Regions

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Ply termination regions, ply drop-offs, are inevitable parts of laminated composite structures used in the aerospace industry, and they are responsible for the early initiation of damage due to material discontinuities in the structure. Therefore, it is necessary to numerically predict the failure initiation in ply drop-off region and design the structure accordingly. However, built-in cohesive elements, used for delamination prediction, provided by the commercial finite element software do not take into account the enhancement of the Mode II fracture toughness and shear strength under compression, which is important in the prediction of delamination in the thick section of a ply drop off [1]. Some studies successfully considered the effects of compressive stress by developing custom cohesive elements [2,3]. However, development of custom cohesive elements can be time-consuming and impractical for simple applications. In this study, a practical implementation of the enhancement of Mode II fracture toughness and shear strength of the layer interface, due to the presence of through the thickness compressive stress, on built-in cohesive elements is presented. ABAQUS commercial finite element software is used for the simulations and user defined field variables (USDFLD) is utilized to incorporate the effect of compressive stress on the behavior of the built-in cohesive elements. Verification studies showed that USDFLD can match the performance of the custom cohesive elements used in the literature. A parametric study of a drop-off model, in which the taper angle is considered as the only variable, showed that thick section delamination initiation load increases as the taper angle increases when the enhancement of the interface properties is considered.

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Innovative Seismic Retrofitting Techniques for Reducing Vulnerability of Reinforced Concrete Structures

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Keywords: Pushover Analyses, Seismic Vulnerability, Seismic Retrofitting.

The occurrence of earthquakes is known as one of the most unpredictable and destructive natural hazards in the world that brings tremendous economic losses and deaths of people. Although the control of structures to improve their performance during earthquakes began to be investigated in the prior times, the implementation of the techniques and construction practices considering the seismic loads just began after 1970. Recent earthquakes such as Pakistan earthquake (2005), Sichuan earthquake (2008), Haiti earthquake (2010) and Chile earthquake (2015) demonstrate the vulnerability of buildings structures. After those devastating events, many seismic zones were upgraded by half or more degree. Consequently, many buildings did not complied with new seismic code requirements and thus needed to be seismically retrofitted. Retrofitting consists of reducing the vulnerability of damage of an existing structure during a future earthquake. It aims to strengthen a structure to comply with the requirements of the current codes for seismic design. Recently, different advanced methods for seismic retrofitting have been reported in the literature. These range for applying different materials such as steel, concrete, fiber-reinforced, polymers, and shape memory alloys as strengthening materials used in various methods applications. In this paper, different innovative techniques used to increase the seismic performance of Reinforced Concrete (RC) structures are presented. It gives the advantages and disadvantages of each retrofit technique and the corresponding characteristics enhancements. Application of one technique (Base isolation technique) is done in a RC prototype structure and comparison on the performance of the structure with and without the retrofitting scheme is carried out. It is concluded that energy dissipation devices are very efficient improving the structure behavior.

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Investigation of the Stress State around the Forming Zone during the Flow Form Process

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Keywords: flow form, explicit analysis, metal forming, stress state

Flow forming process is a cold metal forming process, which has great advantages over conventional forming techniques such as extrusion and tube drawing. Some advantages of the flow forming process are high material utilization, close dimensional tolerances and excellent surface finish. Different types of geometries including thin-walled and axisymmetric cylindrical parts can be manufactured by flow form process. In flow forming process, the preform, which is clamped to a rotating mandrel, is formed by the rollers. After the process, length of the preform is increased by decreasing the outer diameter. However, one of drawbacks of the process is the complex mechanical behavior around the forming zone. Understanding the material flow and stress state around the forming zone is crucial to perform a successful process. In this study, stress state around the forming zone was investigated numerically. After validating of 3-D explicit finite element model with the measured loads from experiments, a detailed examination of the stress state around the forming zone was performed numerically. Effects of different process parameters including feed rate and thickness on the stress state were emphasized. Also, differences between the stress states around the forming zone of the forward and backward flow form processes, which are two different techniques of the flow form process, were stated. It is also shown that different stress states occur at different stages of the process. Finally, the relation between stress state and failure mode was explained.

The Effect of Process Parameters in the Ironing Process

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Keywords: Ironing, Forming, Finite element simulation.

Hot metal forming is one of the most important steps in manufacturing of a large variety of products. One of the oldest metal forming operations, drawing allows excellent surface finishes and closely controlled dimensions to be obtained in long products that have constant cross sections. Ironing in the deep drawing is done by adjusting the clearance between the punch and the rings and allowing the material to flow over the punch. In this study, the effects of process parameters on the ironing process were investigated numerically. The finite element analysis was verified with the measured load from the experiment. After validating of the finite element model, effects of preform temperature distribution, friction coefficient and eccentricity parameters on the force required for forming, the strength of the die and the geometry of the preform were investigated in detail. The present results clearly show that the proper selection of process parameters has a great effect on process outputs such as load, and ironed part geometry.

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Numerical Simulation of Plastic Softening at Elevated Temperatures Using Gradient Damage Methodology

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Keywords: Plasticity; Gradient Damage; Elevated Temperatures

In the present work, gradient plasticity-based damage methodology has been employed to capture the plastic softening behaviour under monotonic loading at elevated temperatures. The conventional approach to capture the stress-strain curve of materials using classical plasticity-based simulation often suffers from its incapability to accurately capture the softening curve. This drawback becomes more pronounced at elevated temperatures where an early onset of softening occurs. Therefore, the present work investigates the stress-strain softening behaviour of steels under tensile load at high temperatures using gradient based elasto-plastic damage methodology. The framework originally developed by [1] has been modified by using a temperature-dependent damage parameter. Furthermore, a damage variable is incorporated in the yield function of the classical plasticity model. The damage accumulation occurs through a non-local strain variable. The process of gradual reduction of stiffness with increasing load captures the softening behaviour of the material. Two example problems are numerically investigated, firstly a S900 steel specimen and secondly a Q960 steel specimen. From experimental evidences in [2], [3], it is found that the present methodology satisfactorily captures the plastic strain behaviour upto 600°C for S900 steels and upto 500°C for Q960 steels. The results are also compared with classical von-Mises plasticity model with Ramberg-Osgood behaviour, and it is observed that the present methodology provides a better agreement with the experimental data.

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Strain Gradient Plasticity Analysis of Amorphous Plasticity

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Keywords: strain gradient plasticity, amorphous plasticity, strain localization, size effect

Amorphous materials, such as metallic glasses, are produced by rapid cooling of liquid materials to prevent crystallization, garnering significant interest for their outstanding mechanical properties and wide-ranging applications in aerospace, micro-electro-mechanical systems (MEMS), and biomedical equipment [1]. Amorphous materials exhibit prominent shear bands, stemming from their heterogeneous, disordered nature. These shear bands represent narrow zones where complex deformation patterns emerge due to intense shear stress. Understanding the deformation characteristics of amorphous materials remains an ongoing goal that has not yet been fully accomplished. In this regard, this study focuses on the numerical modeling of disorder within amorphous materials which uses fluctuating distribution of material parameters [2]. Recent experimental observations indicate that the shear band localization is delayed or even suppressed by reducing the sample size [3]. Therefore, a size dependent model is required to fully uncover the underlying micromechanical phenomenon. In the current work, a lower-order strain gradient plasticity (SGP) framework is employed to numerically analyze and discuss the size effect on microstructure evolution in metallic glasses. Shear band formations under different sized specimens are studied and compared with the classical local plasticity approaches.

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Fatigue Crack Growth Behavior of Friction Stir Welded SS304-Al5083 Dissimilar Joints

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Keywords: Fatigue crack growth behavior, Dissimilar weld, SS304, Al5083

Stainless steel and aluminum joints are desirable for weight reduction in applications like automotive and aerospace. These joints would be inevitably subjected to cyclic loading, which necessitates fatigue crack growth study of dissimilar joints. Friction stir welding is a solid-state joining technique, with proven potential for the fabrication of dissimilar joints. The objective of this work is to investigate the fatigue crack growth behavior of friction stir welded SS304-Al5083 joints. The SS304 and Al5083 sheets (250 mm *x* 80 mm *x* 3 mm) are friction stir welded, using a tungsten carbide tool with 3 mm cylindrical pin diameter, 2.7 mm pin height and 16.5 mm shoulder diameter. The tensile and fatigue crack growth rate tests of the base materials and welded joints are performed. The fatigue crack growth rate of the welded joint is higher than both the base materials. Fractography of fractured specimens revealed a brittle failure of the welded joints and ductile failure for the base materials. Intermetallic compounds at the interface promote the brittle failure of welded specimens, which leads to a higher crack growth rate. To capture the influence of dissimilar material properties on fatigue crack growth behavior, an extended finite element method based numerical method is developed. The numerical simulation well captures the fatigue crack growth behavior of the dissimilar joints.

Emergent core-shifted grain boundaries at free surfaces

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Keywords: grain boundaries, scanning tunneling microscopy, surfaces, emergent grain boundaries, wedge disclination, molecular statics

Emergent grain boundaries at free surface control material properties such as nanomaterial strength, fracture, and corrosion. Using scanning tunneling microscopy, recently we discovered the rotation of whole adjoining grains at the symmetrical tilted small angle boundaries on (111) nanocrystalline copper films [1]. Geometrical analysis shows the preference for boundaries to shift their tilt axis or boundary cores across the (110) plane towards [112] and ultimately to form low energy [112] core shifted boundaries (CSBs), which is confirmed by molecular statics calculation for all fcc metals [2]. We also find the local rotation of the adjoining grains at the high angle boundaries on nanocrystalline copper films and engineered bicrystal [3]. The local rotation of adjoining grains implied the CSB with tilt axis shifted toward to [112] at the free surface and the boundaries with [111] tilt axis deep inside. In contrast to the rotation of whole adjoining grains at small angle grain boundaries, the restructuring of emergent CSBs at large angle grain boundaries are not well understood. The observed geometry of these emergent boundaries needs to be reproduced by atomic calculations. Here, using atomic calculations that involve a methodical shift of the dislocation core, we confirmed the geometry of emergent boundaries observed in experiment and reconciled the atomic calculations with the elastic analysis through the inclusion of a straight wedge disclination at the free surface [4].

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Phase Field Fracture Modelling of Crack Initiation and Propagation in Dual-Phase Microstructures

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Keywords: dual-phase steel, crystal plasticity, phase field modeling, ductile fracture.

Due to their unique composition, dual-phase (DP) steels, which blend the ductile ferrite phase with the hard and brittle martensite phase, exhibit exceptional formability and intriguing material characteristics. However, the mismatched deformation characteristics of the two phases within DP steels leads to intricate failure mechanisms at the micro-scale, such as martensite cracking and interface decohesion between the ferrite-martensite (F/M) and ferrite- ferrite (F/F) phases [1, 2]. To gain insight into the plasticity and failure characteristics of DP steels, it is essential to conduct a thorough analysis of its microstructure through the utilization of a micromechanics-based methodology. This has been addressed before using crystal plasticity and cohesive zone modelling approaches in [3]. Nonetheless, such studies require the implementation of cohesive zone elements in predetermined crack initiation zones. In this work, phase field fracture methodology is coupled with crystal plasticity framework to simulate the initiation and propagation of cracks in DP steels. This numerical framework is capable of simulating the initiation of cracks as well as the intra/inter granular propagation in crystal plasticity finite element (CPFE) simulations without any further damage modelling. The isotropic J2 plasticity model is employed for the brittle martensite phase, while the ductile ferrite phase utilizes a rate-dependent crystal plasticity framework. All the computations are performed with ABAQUS integrating both material and phase field fracture models through user material subroutines. To identify the necessary parameters for each phase, a parameter identification study is carried out. Three-dimensional representative volume elements (RVEs) with various crystallographic orientation sets and morphologies are simulated in order to assess the model's performance with respect to experimental evidence. Further, obtained results are compared with the findings in [3] as well.

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Effect of Static Strain Aging of AISI 4140 steel after Flow Forming

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Keywords: AISI 4140, static strain aging, flowforming

The phenomenon of static strain aging can be described as a process where materials, after being pre-deformed, exhibit a new yield point when held at room temperature or higher temperatures. This process, resulting from the restriction of dislocation movements by solute atoms, can alter the mechanical properties of the material. The efficiency of the aging process is directly related to temperature and time. Adequate time and temperature are required for adequate aging. In this study, the changes in the mechanical properties of AISI 4140 steel due to the mechanism of static strain aging were investigated and analyzed. The AISI 4140 parts were first reduced by 50% using the flowforming process then were aged at 200°C, 250°C, and 300°C for 2 and 4 hours each, respectively. The yield strength of the pre-deformed material before aging is 1200Mpa and the elongation is around 7%. Tensile tests were conducted on the aged specimens to examine their mechanical properties. The yield strengths at 200°C, 250°C and 300°C were measured around 1250 Mpa, 1350 Mpa and 1400 Mpa, and the elongation values were measured as 6.7%, 6.5% and 5.5%, respectively. According to the results, it was observed that yield strengths of aged specimens at which 250 and 300C temperatures increased, but as for aged specimens at which 250C, it did not exhibit yield strength increasing, because of insufficient temperature for activation energy of interstitial atoms which block dislocation motions.

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Effect of Stress Relief Annealing on Stress Corrosion Cracking of CuZn30 Alloy After Flow Forming

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Keywords: CuZn30, flow forming, stress relief annealing, stress corrosion cracking.

Cold work operations often induce residual stresses that can lead to stress-corrosion cracking for Cu-based alloys. Internal stress in alloys can be mitigated by employing stress-relieving annealing [1]. The duration and temperature of the annealing process depend on factors such as the extent of deformation, the alloy composition, and the allowable stress levels post-machining. In this study, CuZn30 material was subjected to flow forming at thickness reduction ratios of 55% and 75%. The flow-forming process introduced residual stresses that increased the susceptibility of copper alloys to stress corrosion cracking. To address this issue, stress relief annealing was applied to the formed parts. Annealing temperatures of 250 °C, 350 °C, 450 °C, and 550 °C were tested, with a 1-hour duration at each specified temperature. To evaluate the effectiveness of stress-relieving annealing in enhancing stress corrosion crack resistance, ammonia vapor test was conducted following the ASTM B858-06 standard [2]. The test was conducted using a test medium with pH values of 9.5 and 10.5, as specified in the standard. The test specimens were suspended in a sealed container for exposure to ammonia vapor and kept there for 24 hours. In the ammonia vapor test, no cracks were observed in any of the specimens at a pH value of 9.5. Cracks were only observed in the specimens which are only formed by flow forming (55% and 75% thickness reduction ratios) and annealed at 250 °C after flow forming (55% thickness reduction ratio) with a pH of 10.5. Additionally, hardness measurements were carried to all specimens in order to see the effect of stress relief annealing. The hardness values of the specimens subjected to stress-relieving annealing at 250 °C after flow forming showed no decrease compared to the untreated specimens. This indicates that stress corrosion resistance can be improved without compromising hardness values. Overall, these findings demonstrate the effectiveness of stress-relieving annealing at 250 °C in reducing stress corrosion cracking in CuZn30 material formed by flow forming processes (%75 thickness reduction ratio) without compromising material hardness.

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Effects of Temperature and Time on Mechanical Properties during Artificial Aging of 6082 Aluminum Alloy

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Keywords: aluminum 6082, flow forming, artificial aging

Aluminum alloys are currently favored in a wide range of industrial applications, because of their low densities and high strength values. Precipitation-hardening heat treatment can further enhance the characteristics of these alloys [1]. The temperature and duration of the precipitation hardening process have a significant role on the performance of the materials for this purpose. This study investigates the effects of artificial aging heat treatment on the mechanical properties of the AA6082 alloy after flow forming process. The influence of artificial aging temperature and time on the mechanical properties of the 6082 aluminum alloy are analyzed. Tensile testing specimens were machined from parts formed by the flow forming. Heat treatments were performed on tensile testing specimens. Solution heat treatment was applied at 530°C/1h with a heating rate of 10°C/min in the open atmosphere and quenched in a 20%vol PAG containing water bath. Artificial aging was then carried out at temperatures of 177°C and 190°C for 4, 6, 8, 10, and 12 hours, respectively [2]. The results demonstrate that the optimum aging temperature and time for 6082 aluminum alloy after flow forming is 190°C/8h.

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Modeling of Coupled Behavior and Microcracking of Multifunctional Composite Structures for Energy Storage

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Keywords: Fracture of Composites, Structural Batteries, Electro-Chemo-Mechanical Coupling, Phase Field Approach, Multifunctional Materials

Energy storage and low thrust-to-weight ratios are major concerns for improving new designs in the aerospace and automotive industries. When these two concerns are considered together, the multifunctionality of structural load-carrying members, especially through adding energy storage capabilities, is a promising approach to realizing lightweight structural members for future transport vehicles. The high specific mechanical and electrical properties of carbon fibers make them ideal for multifunctional applications [1].This work presents a framework for coupled modeling of a multifunctional composite material, structured on the micro-scale, with the ability to function as a battery cell and carry a mechanical load.The microstructure consists of a single carbon fiber surrounded by a very thin solid electrolyte coating and is embedded in a polymer matrix which is a porous material containing active particles able to intercalate lithium. Therefore, the composite structure simulates the electro-chemo-elastic behavior under different electrochemical states (charging-discharging). At these states, a volume swelling caused by lithium-ion movement is observed, which is very similar to heat expansion, where pure volume expansion is produced under thermal load [2].The finite element simulation of monolithically coupled electro-chemo-elastic media is combined with the crack formation in the fiber region. Due to the high concentration gradient at the fiber surface, mechanical stresses are developed, which may lead to the initiation and growth of cracks in the fiber [3]. Crack evolution in the structure causes a decrease in the mechanical properties of fibers and a reduction in the charging properties of the battery by decreasing the diffusivity of lithium ions.The phase field fracture model [4] is implemented into the coupled system for modeling crack propagation and possible damage evolution scenarios. The crack geometry-dependent ion concentration distributions and the elastic stress distributions are investigated using an open-source finite element software FENICS.

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A homogenized constitutive model for the anisotropic plastic deformation of perforated sheets

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Keywords: Perforated sheets, Yield criterion, Anisotropic plastic deformation

Perforated sheets show complex plastic deformation characteristics [1], because of the coupling of deformation characteristics between the matrix and the hole arrangement during plastic deformation. Modelling the macroscopic constitutive is important to providing a theoretical basis for the design of the forming process. Taking the commonly used perforated sheets with hexagonal arrays of circular holes as an example, the deformation characteristics are studied based on the unit cell model simulation under biaxial loading [2,3]. It can be found that the deformation is mainly concentrated in the connection area between the center of the holes. The stress is determined by two parts, which one is the component of the macroscopic stress on the corresponding section, and the other is the increased normal stress component caused by the additional bending moment. Therefore, a homogenized yield criterion which considering the effect of the additional bending moment is proposed. It can well describe the symmetry of the structure, as well as the equivalent performance of uniaxial, biaxial and tension-shear loading. Also, by constructing the parameters related to equivalent plastic strain and the associated flow rule, the anisotropic hardening and plastic flow of the perforated sheets can be quantified respectively. In addition, the proposed model shows good applicability in the square arrays of circular holes.

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Numerical modeling for shearing of unidirectional carbon fiber reinforced plastic laminates by means of near-net-shape blanking

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Keywords: Near-net-shape blanking, Carbon fiber reinforced plastic, Shearing process model.

Structural components made of carbon fiber reinforced plastic (CFRP) produced using near-net-shape molding processes exhibit a high degree of lightweight suitability. In order to fulfill geometric and functional requirements, a finishing process step of outer and inner contours is necessary for CFRP structural components. Near-net-shape blanking processes with small die clearance and high blank holder force show potential for economical finishing of CFRP structural components with high blanked part quality [1]. For the knowledge-based design of a near-net-shape blanking process comparable to fine blanking with a small die clearance and superimposed blank holder and counter force, an understanding of the separation mechanisms during shearing of CFRP laminates is required. Therefore, this paper deals with the development of a finite element (FE) process model for near-net-shape blanking of unidirectional (UD) CFRP laminates with different fiber volume fraction. Material modeling of the UD CFRP laminates was carried out by means of experimental characterization based on tensile, compression, shear and delamination tests. The formulation of the material model was implemented using a VUMAT user subroutine and includes four damage modes for fiber and matrix under tensile and compressive loading [2]. Regarding the damage initiation condition, the Hashin criterion was used for the fiber and the Puck criterion for the matrix [3]. The application of the blank holder and counter force was realized using a kinematic model based on a VUAMP user subroutine, which is closed loop controlled by the respective reaction force and thus enables an accurate and numerically stable force application. Numerical analysis on near-net-shape blanking of UD CFRP laminates with different fiber volume fraction showed that the blanking force is affected by the fiber-orthogonal longitudinal shear strength. With increasing fiber volume fraction, an increase in blanking force is to be expected. A validation based on experimental near-net-shape blanking tests, which will be conducted in the next step, enables an analysis to understand the separation mechanisms by means of the damage criteria of fiber and matrix in UD CFRP laminates.

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Thermomechanical analysis of the shear zone during fine blanking of quenched and tempered steel

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Keywords: Fine blanking, Thermoviscoplastic modeling, Thermographic measurement.

In order to design deformation mechanism-based sheet materials as well as tribologically stressed tool elements, knowledge of the thermal load is required for fine blanking. The characteristic of fine blanking leads to a thermomechanically induced heat dissipation in the shear zone, which is influenced by the process parameters. Depending on the load spectrum, the dissipated heat accumulates in the shear zone and causes heating along the sheared path. The shear zone heating has an influence on the activation of the deformation mechanisms during fine blanking of high manganese steel and thus on the realization of a high sheared surface hardening [1]. In addition, the thermomechanically induced heating influences the wear behavior of the tool elements actively involved in fine blanking. Numerical modeling of plastic flow for analyzing the temperature in the die edge area and its influence on the shear zone requires a thermoviscoplastic material model [2], temperature-dependent physical parameters as well as consideration of the stress- and temperature-dependent contact heat transfer [3]. Therefore, this paper deals with the development of a methodology for numerical analysis of the thermomechanical influence of the process parameters on the shear zone heating. The methodology was derived by means of an experimental investigation of the sheared surface temperature based on thermographic measurements during fine blanking of quenched and tempered steel 42CrMo4 (AISI 4140). For this purpose, a thermomechanically coupled finite element (FE) model was designed, taking into account thermoviscoplasticity, temperature-dependent physical parameters as well as a steady-state calibrated contact heat transfer and validated by means of experimental fine blanking tests. The validation was carried out using force, die roll and thermography measurements based on varied blanking velocity and blank holder force. The thermomechanically coupled FE modeling showed a sufficiently accurate correspondence regarding the experimentally determined blanking force, die roll as well as sheared surface temperature. An increasing blanking velocity resulted in a reduction of blanking work. Numerical analysis in terms of reduced blanking work revealed a significant heat accumulation in the shear zone, indicating thermal softening at higher blanking velocity.

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Progressive Failure Analysis of Composite Open-Hole Tension Tests Based on Schapery and Crack Band Theories

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Keywords: Schapery Theory, Progressive Failure Analysis, Composites

Due to their high strength, stiffness, and low density, the use of fiber-reinforced composites (FRP) has accelerated tremendously during the last half-century. The formed FRP laminae are innately orthotropic and can theoretically be modified in an infinite variety of configurations. For such complex structures, progressive failure analysis (PFA) methodologies that can predict failure initiation and progression are required. The fundamental source of nonlinearity in the stress-strain response of many polymer matrix composites is matrix microdamage. The pre-peak softening phase that transpires due to matrix microdamaging is often neglected in PFA methods. Schapery theory (ST), a thermodynamically based work potential theory, was designed for simulating matrix microdamage in FRPs [1][2]. The ST manages the evolution of damage inside the material by diagnosing the correlations between transverse/shear response and the dissipated potential induced by matrix microdamage. In Enhanced Schapery Theory (EST), an extended version of ST, it is presumed that matrix microdamage confines into more pronounced damage modes and failure initiates in which the element domain is no more viewed as a continuum, and the embedded discontinuities are characterized using crack band.

This work proposes a failure analysis tool modeled and employed in readily available explicit finite element analysis software ABAQUS as user-defined material model subroutine (VUMAT) which comprises nonlinear microdamage as well as mesh objective failure evolution. The developed tool uses mechanical properties of the composite obtained from the characterization tests. Nonlinearity of the transverse & shear moduli are taken into account with empirical polynomial functions acquired from tests of coupons with varying stacking sequences. Crack Band Theory (CBT), a nonlinear mesh objective failure evolution method, is used in the post-peak phase [3].

This study aims to compare failure predictions using the developed method with experimental results and ABAQUS built-in failure criteria. Experimental and numerical studies are conducted on unidirectional (UD) composite open-hole tension (OHT) specimens. Preliminary analyses indicated that the developed EST-integrated method outperforms the ABAQUS built-in failure model for plane stress problems. Moreover, as additional work to be conducted, strain contours of the specimens will be acquired using Digital Image Correlation (DIC) and compared with the numerical results. The validity of the user-defined material model subroutine will also be assessed.

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A Stochastic Phase-Field Approach for Ductile-Like Fracture of Rubber-Like Materials

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Keywords: phase-field fracture, stochastic failure, ductile-like failure

The classical phase-field approach [1] assumes a homogenized distribution of the critical energy release rate over the material, which inevitably triggers catastrophic failure, leading to a brittle-failure in the simulations. The experimental studies show, on the other hand, a ductile-like failure for rubber-like materials [2]. This behavior is extremely important for phase-field modeling of fatigue crack growth. In this work, a stochastic distribution of the critical energy release-rate, in the form of critical entropic energy distribution, governed by fuzzy rules is analyzed. The stochastic properties of the unfilled SBR in a series of fracture experiments on die-cut v-shape double edge notched specimens are demonstrated first over their characteristic ductile-like behavior on load-displacement curves and by comparison with laser-cut specimens where we see sharp brittle fracture. The work is validated over experiments from literature and in-house experiments on double edge v-notched unfilled SBR specimens. It is shown that the ductile-like fracture is intermittent as in experiments, following non-straight complex fracture paths over otherwise completely symmetric specimens.

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Short Fiber-Reinforced Acrylonitrile Butadiene Styrene for Additive Manufacturing: Process-Structure-Property Analysis

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Keywords: Additive manufacturing, short carbon fiber, mechanical properties.

Additive manufacturing (3D-printing) based on layer-by-layer material deposition is currently used for manufacturing of parts with complex geometry. One of the most accessible methods of 3D-printing is fused filament fabrication (FFF), which works with polymeric materials in the form of a filament. Among the variety of thermoplastic polymers, that were adapted for this method, one of the most widely used is acrylonitrile butadiene styrene (ABS). Composites with ABS matrix and natural or synthetic microscale additives were developed to improve stiffness, elastic modulus and strength of 3D-printed structures.

Although additive composites with short fiber have been successfully fabricated and are commercially available, understanding of their deformation and fracture mechanisms is a challenging problem because of complexities of the microstructural morphology. In particular, the presence of microscale defects in the form of matrix voids, fiber damage and irregular fiber orientation can alter the targeted properties of these materials after manufacturing process.

The aim of this work is to investigate the effect of manufacturing parameters and resulting microstructural characteristics on the elastic and fracture properties of 3D-printed short fiber-reinforced ABS samples by comparing results of both experimental and numerical studies. Mechanical properties of samples were evaluated in the series of tensile and bending tests. The samples were printed with different infill angle and using various diameter nozzles. The internal microstructure of samples was examined using micro computed tomography and scanning electronic microscopy.

Finite element simulations were performed to assess effective response of materials. Representative volumes used in these numerical models were created based on real samples microstructure. In addition, analytical estimation of the effective elastic properties was performed using Mori-Tanaka homogenization scheme. New results on stiffness and strength properties of short fiber-reinforced 3D-printed samples were obtained and compared with those made of standard ABS material.

Modeling of Al-Cu solid solution compression with accounting of phase transitions and dislocation plasticity

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Keywords: molecular dynamic, phase transition, plasticity.

The problem of studying plastic deformation in metals under complex dynamic loading and the associated change in their defect structure is still relevant. The plastic deformation process in pure metals is often accompanied by the formation and interaction of dislocations. In some situations, the contribution of phase transitions exceeds the dislocation plasticity contribution to stress relaxation under dynamic tests.

In our work, we developed a stress relaxation model using machine learning methods and applied it to simulate uniaxial compression of the material. Molecular dynamics (MD) simulations using the LAMMPS software package [1] and the ADP potential [2] of Al-CU solid solution compression showed the nucleation and movement of dislocations as well as the phase transition of the crystal structure. These processes lead to a significant relaxation of shear stresses. The parameter fitting procedure for the developed phase structure evolution model and the dislocation plasticity model from the previous literature [3] was carried out by the Bayesian method, which allows us to calculate a quasi-probability characterizing the degree of coincidence of the calculated curves with the reference data. An artificial neural network trained on the results of MD calculations was used as the equation of state of Al-Cu solid solution at varied concentrations of components.

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Peridynamics as a simulation method for dynamic fracture

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Keywords: continuum-kinematics-based peridynamics, dynamic fracture, damage models

Fracture problems have been addressed by various computational methods, such as damage models, discontinuous finite element discretizations, and phase-field fracture simulations. However, Peridynamics allows an alternative approach to fracture because it models the material in a non-local form. Our contribution presents a concept of dynamic fracture with continuum-kinematics-based peridynamics. The chosen continuum-kinematics-based peridynamic model extends the current peridynamic models by introducing surface and volume-based interactions. The surfaces and volumes considered for these non-local interactions are constructed using the point families derived from the material points' horizon. The new continuum-based peridynamic approach necessitates a new understanding of damage and fracture. It is no longer sufficient to think of material damage and brittle fracture as bond-based events because of the three different interactions. Thus, we extend the force density of the material by kinematic variables that account for the loss of load-carrying capability. Furthermore, the surface effect within continuum-based peridynamics is discussed. By numerical examples, it is shown that the presented approach can correctly handle crack growth and spontaneous crack initiation under dynamic loading conditions with large deformations.

Phase-field simulation of self-healing AlMg alloy

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Keywords: Phase-field model, Self-healing material, Diffusion healing heat treatment

The AlMg alloys are widely used in different transportation industries due to their excellent strength-to-weight ratio [1]. In these industries, the components must withstand overloads and a high number of loading cycles [2], which, over time, can generate damage in the materials and in the worst-case failure [3]. To increase the lifetime of these parts, one innovative solution is to use self-healing materials. There exist different types of self-healing methods, one of them is the diffusion self-healing mechanism. In this mechanism, the alloy microstructure is composed of a healing agent in solid solution [4]. After damage, a healing heat treatment triggers the diffusion of this healing agent towards the voids and heals the material. An in-situ Diffusion Healing Heat Treatment at 400 °C was applied to heal a damaged AlMg alloy at the European Synchrotron Radiation Facility (ESRF) [5], where nano-holotomographies (nano-CT) of the damaged and healed microstructure evidenced the healing capacity of the alloy by diffusion mechanism with a voxel size of 35 nm. A diffusion phase-field model based on Kim-Kim-Suzuki [6] was applied to predict the microstructure evolution of the material during this healing heat treatment. The results obtained with the phase-field model are compared with the experimental measurements to corroborate their accuracy.

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Evolution of cathode surface morphology and distribution of oxides during TIG welding

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Keywords: TIG, electrode, tungsten, cathode.

The high quality of TIG welds as well as their good appearance, is owing to non-consumable tungsten electrode which allows to precisely direct the arc. The succession of welding operations leads to a change in the morphology of the electrode tip [1,2] which affects the stability of the arc plasma and consequently the welded product quality. In this work, the effect of the type of current arc on the oxides behavior inside of the electrode and its impact on the morphology of its surface was analyzed. Following the experimental results obtained, it was found that the DC generates a considerable degradation of the electrode while it is better preserved by applying a pulsed current.

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A Continuous-discontinuous Constitutive Model for High-Fidelity Analysis of Bondline Failure in Polymeric Matrix Composites

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Keywords: Bondline failure, non-local regularization, XFEM

Adhesively bonded Polymeric Matrix Composite (PMC) structures could offer significant cost savings and increase production rates in the fabrication and assembly of future composite airframes. In particular, bonded PMCs may eliminate the use of thousands of mechanical fasteners and allow incorporation of multiple aircraft composite primary structures into a unitized structural design. However, increased susceptibility to defects and manufacturing irregularities, including voids, disbonds, and geometry variations, as well as complex interacting failure mechanisms hinder a widespread use of bonded PMCs. High-fidelity computational materials-based analysis methods that can capture the effect of defects and improve the understanding of failure mechanisms that govern bondline failure are needed to support qualification and certification of next-generation bonded PMCs and safely reduce redundant fasteners. The objective of this work is to contribute to such development. A constitutive model is developed for finite element (FE) analysis of bondline failure in polymeric matrix composites where the adhesive material is modeled as a continuum. A continuous-discontinuous framework is considered for capturing quasi-brittle failure within epoxy adhesives and arbitrary solution-dependent crack paths in presence of bondline defects. In this approach, an elasto-plastic constitutive model with isotropic damage is enhanced with the introduction of extended finite element method (XFEM) enrichments that incorporate non-local features. The implementation of the approach in commercial FE software Abaqus using built-in XFEM capabilities in combination with a set of user-defined subroutines is presented and illustrated in two-dimensional FE models representative of adhesively-bonded double-cantilever beam (DCB) specimens. Constitutive properties, including plasticity characteristics, are obtained using test coupons machined from plaques made from epoxy-based film adhesive material.

Phase-field crack propagation in viscoelastic elastomers

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Keywords: phase-field fracture, visco-elaticity, elastomers.

Recent studies on fracture dynamics in elastomer membranes has shown that velocity of crack propagation is proportional to the pre-stretching imposed to the membrane [1], and that crack evolution is related the viscoelastic properties of the material [2]. In this communication, we present a mechanical model for the description of crack evolution in elastomers able to capture the main features of the fracture dynamics observed in experiments [1,2]. We formulate a theory for finite visco-elasticity that includes smeared phase-field fracture. Two viscous contributions are introduced in the model. In a fracture evolution process, they account for the rate-dependency of the strains and for the motion of the crack tip. As a results, two different characteristic times affect the advance of the crack and the strain relaxation of the material surrounding the crack tip. The rule played by these two characteristic times on the crack evolution is studied by performing analytical estimates and numerical simulations.

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Laser and Spectral Diagnostics for Structural Materials: a Review

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Keywords: laser, diagnostics, spectroscopy.

Laser and spectral diagnostics are state of the art characterization methods for structural materials [1]. Due to the nature of optics and photonics processes, these diagnostic methods can be applied to the structures in the laboratory, in-situ, or remotely. The application can be passive spectroscopy e.g., emission spectroscopy, such as thermography [2], or active spectroscopy such as laser excited fluorescence [3]. The light delivery system can be free space optics [4] or guided wave optics, e.g., fiber optics [5]. We plan to review current optical spectroscopy methods applied to structural materials for material characterization and structural health diagnostics.

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Fatigue crack nucleation modelling for macroscopic defects

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Keywords: Weld defects, Crack Nucleation, Fatigue

Engineering steel structures often contain macroscopic fabrication defects, such as weld imperfections. During service, cracks can emanate from such defects under cyclic loading. The crack nucleation from such defects is not only governed by the geometrical characteristics of the defects but also by the underlying microstructure, which results in a distribution of crack nucleation life. Once a defect is detected during the service of a structure, the prediction of the crack nucleation life and the associated uncertainty is important not only to ensure the safe usage of the structure but also to avoid over-conservative corrective measures. With this motivation, the current work aims to develop a methodology for the prediction of crack nucleation from macroscopic defects using a two-scale modelling approach. For this purpose, two models at different scales are used. At the macroscopic scale, a continuum elasto-plastic finite element model (FEM) of the structure with the defect is used to model the geometrical characteristic of the defect and the local stress field. At the mesoscopic scale, a crystal plasticity FEM of the material in the vicinity of the defect is used, wherein the microstructure is captured. The two models are coupled, such that the boundary conditions of the mesoscopic model are obtained from the macroscopic model. To characterize the crack nucleation in the grains of the microstructure, a plastic slip-based fatigue indicator parameter is used. With the modelling set-up, a comparison of defects of different shapes is made in terms of the crack nucleation life and the associated scatter. The prediction of the modelling approach is found to be in qualitative agreement with empirical equations.

Evaluating the Delamination Resistance on Metal Sandwich Panel under Four Points Bending Condition

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Keywords: Delamination effect, Dimple geometry, Damage, Sandwich Panel, Bonding capability.

The purpose of this work is to investigate the delamination effect on the sandwich panel due to the different dimple geometry using four points bending under 50% and 70% of cyclic loading condition. The geometry of core panel with cavity and less dense properties has a significant affect towards the failure mechanism of delamination. The influence of core geometry plays significant roles in contributing the delamination failure. In many engineering applications, sandwich panel were developed to fulfil the certain requirement such as lightness, high bending stiffness, and capability to absorb high energy in order to sustain an optimum performance [1]. Based on the previous studies, the core geometry with cavity and less dense give significant affect in contributing the delamination effect [2]. Therefore, it is vital to understand the mechanism of delamination failure by investigating the relationship between core geometry and the type of loading conditions in order to enhanced the delamination resistance and improved the capability of sandwich panel. The specimens were prepared using high strength steel, AR500 as outer panel and magnesium alloy as core panel, and they have been tested using four points bending setup with 10 Hz frequency under 50% and 70% of constant cyclic loading condition. The delamination effect on the bonding region in crosssectional view were recorded. It has been found that sandwich panel with smaller dimple geometry has significantly improved the delamination resistance by 30% compared to larger dimple geometry. The delamination effect of cross section in vertical direction at the affected region. It indicates that there was a matrix cracking on the bonding region, which led to the significant delamination effects on the sandwich panel for larger dimple geometry. This study revealed the potential of dimple geometry on core surface enhanced the delamination resistance and contributed to the optimum bonding capability especially in the cyclic loading environment.

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Microstructure- and damage-nucleation-based crystal plasticity finite element modeling for the nucleation of multi-type voids during plastic deformation of Al alloys

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Keywords: Alumnium alloy; Void nucleation; Damage-nucleation-based CPFE modeling

During deformation of aluminum (Al) alloys, there are three kinds of voids being formed by distinct mechanisms, i.e., matrix-cracking voids (MCVs), particle-cracking voids (PCVs), and interface-debonding voids (IDVs), due to mesoscale heterogeneous deformation. The three kinds of void nucleation have different effects on the subsequent void growth, void coalescence, and ductile fracture of Al alloys. To determine the complex nucleation behavior of the three kinds of voids under mesoscale heterogeneous deformation, a microstructure- and damage-nucleation based crystal plasticity finite element (MDN–CPFE) model considering different nucleation mechanisms was established. To realize the MDN-CPFE modeling, the deformation and void nucleation of the matrix, particle, and their interface in Al alloys were described by a non-local dislocation density CP constitutive model and a local stored energy density criterion, an elastic constitutive model and a maximum principal stress criterion, and a cohesive zone model and fracture energy criterion, respectively. The developed MDN-CPFE model was validated by the nucleation locations and quantitative variations of the three kinds of voids in an in-situ tensile test. Using the developed model, the nucleation characteristics of the three kinds of voids during the small deformation of Al alloys were analyzed. It is found that PCVs are likely to nucleate within particles that are located at the deformation bands and with greater shape irregularity; IDVs are prone to nucleate at the interfaces around smaller particles in the deformation bands; MCVs tend to nucleate within grains with a higher Schmid factor and aspect ratio. The void area fractions (VAFs) of the three kinds of voids all evolve with an incubation stage and then followed by an exponentially increasing stage during deformation. The duration of the incubation stage for the three kinds of voids, designated by the nucleation strain, presents the following sequence: PCV < IDV < MCV; while, their VAFs and quantities present the opposite sequence. Additionally, the effects of the particle volume fraction and grain size on the nucleation strain, total VAF, and proportion of VAFs of the three kinds of voids were unraveled.

Simulation of cranial damage and fracture and validation with a head model

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Keywords: finite element method; skull; trabecular bone; cortical bone; biomechanics; head injury; sutures; skull fractures.

The human head is an intricate arrangement of solid and soft tissues, governed by complex principles of materials and interactions. Computational simulations of the human head have been developed over time, achieving significant levels of detailing, complexity and accuracy. However, the majority of focus has been directed towards the brain and other internal structures. The importance of the skull, which plays a crucial role in direct head impacts, is frequently disregarded and oversimplified. In this study, a novel skull model is devised for the authors' head model, known as YEAHM. This model preserves the original external geometry but incorporates sutures, diploë, and cortical bone, which exhibit varying thickness in different head regions based on medical craniometric data. These structures are represented using constitutive models that account for the nonlinear behavior of skull bones and their failure characteristics. The skull model is thoroughly validated by comparing simulation outcomes with experimental findings reported in existing literature, encompassing various aspects: (i) local material validation, (ii) blunt trauma resulting from direct impact on a stationary skull, (iii) three impacts at different velocities to simulate falls, and (iv) blunt ballistic temporoparietal head impacts. Accelerations, impact forces, and fracture patterns are utilized as validation metrics for the skull model.

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A Crystal Plasticity Study of the Effect of the Initial Misorientation on Nanoindentation Response

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Keywords: Nanoindentation, Mechanics of Materials, Crystal Plasticity Finite Element Method

The application areas of nanoindentation to quantify mechanical behavior of materials on different scales are expanding rapidly (see e.g. [1]). Examination of elasto-plastic behavior, anisotropy and time/rate dependent deformation characteristics for different temperatures with only a nano-scale indent on the sample surface offers significant potential for future developments. Nanoindentation also provides an opportunity to study size effects during the plastic deformation and the associated formation of defect structures. A comprehensive understanding of the effect of the testing setup and its imperfections on the measured data presents significant potential to improve the estimation of elastic and inelastic material properties from the experimental results. In this study, a systematic analysis for the effect of small initial misorientation between nanoindentation instrument and single crystal tungsten test sample is carried out using crystal plasticity finite element simulations. Crystal plasticity finite element analysis is widely used to investigate the deformation behavior of crystalline materials at mesoscale. Conventional and mechanism-based strain gradient crystal plasticity finite element analysis (CPFEA) are used to model plane strain wedge nanoindentation of single crystal tungsten. Numerical and experimental results are correlated to determine the misorientation axes and range between test samples and nanoindentation instrument. Results show that initial misorientation varies the lattice rotations and leads to their antisymmetric distribution under the indenter.

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Micropolar crystal plasticity and orientation phase field for evolution of grain microstructure

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Keywords: Cosserat Crystal Plasticity, Grain boundary migration, Orientation Phase Field

The challenge of predicting changes in the microstructure of metals undermechanical loading at temperatures above 300°C remains complex due to the involvement ofmultiple mechanisms. The change in crystal orientation at a point within the material canoccur as a result of both plastic deformation and migration of grain boundaries. To addressthis issue, researchers have previously combined the Kobayashi-Warren-Carter (KWC)orientation phase field with crystal plasticity [1]. It was later recognized that the micropolartheory provides a more suitable framework for this problem, leading to the coupling of theKWC orientation phase field with Cosserat crystal plasticity [2]. However, the KWCformulation includes a singular diffusion equation and is limited to grain boundary energiesof the Read-Shockley type. In recent developments, an alternative model for the orientationphase field has been proposed, which allows for anisotropic grain boundary energies [3]. Inthis study, we extend this model by coupling it with Cosserat crystal plasticity and compareits predictive capabilities and numerical performance to the KWC-Cosserat crystal plasticitycoupling within a two-dimensional finite element framework.

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Effects of Print Orientation on Mode-I Fracture Toughness of Additively Manufactured PLA: Simulation by XFEM

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Keywords: Mode-I, Fracture Toughness, Print Orientation, XFEM.

In this study, Mode-I fracture toughness of the PLA material was to be determined through three-point bending fracture test so as to extract the critical value for the crack propagation. The raster angle utilized to fabricate the single edge notch bending (SENB) specimens with three repetitions was chosen as ±45°. Three different print orientations (P-Os) were utilized to investigate the effects of printing direction (i.e., horizontal, lateral, and vertical) on the fracture properties. Extraction of the fracture properties was conducted as per the standard ASTM D5045-14 on the specimens fabricated in different print orientations. The values of Mode-I fracture toughness of PLA were respectively obtained as 4.19, 4.15, and 3.73 MPa$\sqrt{m}$ with horizontal, lateral, and vertical print orientation. A commercial finite element package ABAQUS was utilized in order to employ the extracted values into extended finite element method (XFEM) and to investigate the crack propagation in the specimens.

Damage detection in marine propeller in service

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Keywords: Marine Propeller, Impact Fault, Finite Element Medialization, Damage detection.

The damage of marine propellers blades is usually caused by an impact with a foreign object, erosion from cavitation or impurity of the material. The impact of the marine propeller with foreign objects in the water causes small chips on the edge of the blade that are often unnoticed by the user of the boat. This leading edge damage, if not detected and treated, can lead to fatigue cracks. This paper focuses on the detection of this structural defect by vibration analysis of a healthy propeller and a propeller whose leading edge is damaged. A 3D model of marine propeller was developed on a mechanical design software. Damage to the leading edge of the blade was modelled by extrusion material removal in two geometric shapes "V" and "I" of well-defined sizes. A modal analysis was performed on Ansys Workbench for a propeller modelled by a single blade for healthy and damaged configurations. In the first part of the study, the effect of the size, position, and geometric shape of the defects on the modal parameters of the helix was analyzed and discussed. In addition, the influence of this lack of impact on the dynamic response of the blade was analyzed by comparing the dynamic response of a healthy blade with that of a damaged blade. This can be used as a defect detection procedure in marine propellers in service indicating the position and the severity of the defect.

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Recent Advances in Modelling and Experimental Evaluation of Plasticity-Induced Fatigue Crack Closure

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Keywords: crack closure, fatigue life evaluation, variable amplitude loading.

Loading cycles of variable amplitude are typical in aerospace, wind turbine, transport, pipeline and many other industrial applications. The evaluation of fatigue life of structural components working under variable amplitude loading is very challenging. There is a broad consensus amongst the international fracture community regarding the significant problems and deficiencies of the existing fatigue life evaluation procedures [1].

At the core of any of advanced fatigue life evaluation methods and computer programs is a crack tip load opening (and closure) model that aims to simulate the crack closure phenomena [2]. Crack closure implies that a fatigue crack remains closed for some portion of a tensile load cycle due to the formation of a plastic wake behind the crack tip, which can significantly reduce the fatigue crack driving force. This paper discusses the latest advances on analytical modelling and experimental evaluation of fatigue crack opening loads under variable amplitude loading conditions. In particular, we present the exact solution obtained by the distributed dislocation technique for a finite fatigue crack propagating under constant amplitude of cyclic stresses as well as a new experimental method [3, 4], which is capable to evaluate cycle-by-cycle crack tip opening load values for large numbers of fatigue cycles. Further, we discuss the applications of these new developments to development and validation of more adequate fatigue life evaluation procedures.

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Dwell fatigue fracture in Ti microstructures through crystal plasticity and phase field fracture frameworks

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Keywords: Dwell fatigue, Crystal Plasticity, Phase field fracture

Titanium alloys, with their superior strength-to-weight ratios, corrosion resistance, and fatigue performance, are integral to aerospace applications, notably in aero-engines. However, their vulnerability to dwell fatigue significantly reduces their operational life which requires an in-depth analysis of micro-mechanisms [1,2]. These alloys largely consist of alpha and beta phases, with the latter becoming dominant at high temperatures. The pronounced plastic anisotropy of the HCP-structured alpha phase underscores the importance of studying cold dwell loadings [3]. This research delves into the "rogue" grain combination concept, a potential major factor behind the early failure of Ti alloys. This unique combination comprises a c-axis oriented hard grain juxtaposed with soft grains leading to evolution of local high stresses which can be analyzed through an anisotropic plasticity model at the grain scale. For this purpose, a rate-dependent crystal plasticity model is employed and coupled with a phase field fracture framework for the prediction of crack nucleation and subsequent propagation. Three-dimensional polycrystalline representative volume elements are generated and loaded under both quasi-static and dwell fatigue conditions. Additionally, a lower order strain gradient crystal plasticity model is employed enabling modeling of size effects. With this model, a failure criterion based on GND densities and stresses is introduced through the phase field.

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Fracture characteristics of 3D-printed polymer parts: role of manufacturing process

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Keywords: Additive manufacturing, fracture behavior, crack path

Although additive manufacturing (AM) was first developed to produce prototypes, in recent years it has also utilized used for fabrication of end-use products. As a result, the mechanical strength of additively manufactured parts has gained considerable significance. AM also known as three-dimensional (3D) printing has proved its capabilities in fabrication of customizable parts with complex geometries. However, a profound knowledge about the structural integrity of 3D-printed part is still required. In the current study, effects of manufacturing parameters on the mechanical strength and the fracture behavior of 3D-printed components have been investigated. To this aim, we fabricated specimens using polyethylene terephthalate glycol (PETG) and fused deposition modeling (FDM) process. Particularly, the dumbbell-shaped and single edge notched bend (SENB) specimens were fabricated and examined to determine their tensile and fracture behaviors. In this context, the notch in SENB specimens were introduced by two different techniques to investigate influence of manufacturing process on the mechanical performance of 3D-printed PETG parts. The outcomes of this study can be used for future designs of FDM 3D-printed parts with a better structural performance.

Machine Learning and Data Mining for Enhanced Efficiency of Dislocation Simulations and Microstructure-Property Relations

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Keywords: dislocation, discrete dislocation dynamics, plasticity, machine learning

Discrete Dislocation Dynamics (DDD) simulations are highly precise methods used to determine the plastic deformation of materials at the micro level. These simulations directly quantify dislocation movements and interactions, which are the fundamental physical processes involved in the plastic deformation of crystalline materials. The complex and dataintensive nature of DDD simulations requires multiple steps to post-process and analyze data to understand the material behavior. Data mining and machine learning methods can significantly aid in the analysis of the extensive data generated by these simulations. For instance, these techniques can provide valuable insights into dislocation mechanisms, such as the cross-slip mechanism, which are not readily observable through experiments. Furthermore, surrogate models and hybrid simulations can remedy the computational burden of DDD simulations by identifying and utilizing the relationships between microstructure and properties in solving forward problems. Our study primarily focuses on identifying these relationships within microstructures through data mining and machine learning techniques and explores the key descriptors that outline the behaviors and evolved microstructures in dislocation simulations. We also present our initial promising attempts at using physics-based Deep Learning methods as a replacement for certain aspects of DDD simulations.

Application of Adelaide University Snapback Indirect Tensile test (AUSBIT) on 3D Printed Cement-based Materials

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Keywords: 3D printing, Brazilian disc, indirect tension; fracture; snap-back, interlayer bond strength, layer orientation.

Additive manufacturing (AM), known as three-dimensional (3D) printing, is an innovative technology that has found applications in the construction industry [1-2]. Due to the intrinsic layer-by-layer manufacturing process, interlayer bond strength is a key that needs to be investigated and improved, to ensure the reliability and suitability of the technology. In fracture tests, the orientation of the layers and their interfaces strongly affect the responses and hence stability of the tests. Fracture can happen very abruptly and hence can be out of control due to weak interfaces between layers, particularly in indirect tensile tests on disc specimens. In this study, the use of AUSBIT (Adelaide University Snapback Indirect Tensile test [4-6]) facilitates the investigation of pre- and post-peak behaviour of the 3D printed disc specimens thanks to its ability to stabilize the cracking process in Brazilian disc testing. This prevents abrupt or instant failure of disc specimens and hence can allow more time for the use of advanced image-based instrumentation. In combination with AUSBIT, Digital Image Correlation (DIC, [7, 8]) enables observation of full-field strain distributions and their evolutions during fracturing process.

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An adaptive acceleration scheme for phase-field fatigue

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Keywords: phase-field fatigue, acceleration scheme, crack tip tracking

Phase-field models for fatigue fracture, e.g. [1,2], represent a versatile approach capable of reproducing the main characteristics of fatigue behavior. However, the associated computational effort makes the cycle-by-cycle analysis of components in the high cycle fatigue (HCF) regime with cycle counts $n > 10^4 ... 10^5$ practically unfeasible. To overcome this, a cycle-jump acceleration scheme can be adopted, where the explicit cycle-by-cycle resolution of a certain number of cycles Δn is skipped by instead extrapolating selected state variables based on their evolution during only some explicitly computed cycles in between the cycle jumps.

To exploit the full potential of this strategy, an adaptive cycle-jump algorithm is proposed in [3] for the model presented in [1] which degrades the fracture toughness of the material as a representative fatigue history variable accumulates above a certain threshold. In the proposed scheme, the core idea lies in deciding when and how many cycles can be skipped based on the cycle-wise rate of a scalar variable Λ which is representative of the fatigue lifetime advancement. For this, the fatigue life of a component is divided into three stages: (1) an initial stage before fatigue effects are triggered, (2) the crack nucleation stage, and (3) crack propagation (including the Paris regime) ending with failure of the component. During the first stage, the system behaves linearly, which can be exploited to calculate how many cycles are needed such that the fatigue history variable hits the threshold to trigger the fatigue effects and thus directly jump to that point. Within the second stage, Δn is computed such to elicit a target increment of the maximum of the phase field variable within the domain. Analogously, in the third stage, the number of cycles to skip is determined such to provoke a certain crack growth which is related to the phase-field regularization length. For this final stage, where the crack growth rate determines the cycle jump size, a novel, numerically efficient and precise crack tip tracking algorithm is presented which overcomes issues of conventional approaches [3].

The behavior and reliability of the proposed cycle-jump scheme is first demonstrated by comparing cycle-by-cycle with accelerated results. Then, the adaptive cycle-jump scheme is used to analyze the fatigue life of various virtual specimens. Finally, the obtained accuracy and speedup are compared with those from other available cycle-jump approaches.

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Finite Element Simulation and Experimental Study on Defects in CuZn40Pb2 Brass Alloy Water Valve Covers During Hot Forging

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Keywords: hot forging, brass, simulation

This study aimed to analyze the numerical simulation of the closed die hot forging process of a CuZn40Pb2 brass alloy water valve cover. The hot forging process of the brass alloy water valve cover, carried out in a conventional single stroke forging press, was found to result in various defects in the material geometry. The primary factors influencing these defects were identified as the temperature of the cylindrical billet and the die[1].

To investigate and optimize these factors, finite element simulations were conducted utilizing Deform 3D software, encompassing considerations such as geometry and force. [2].

Observations revealed that lubricant application reduced the coefficient of friction, improving material flow and minimizing defects in the valve cover during the hot forging process[3].

Thorough analysis of experimental processes and finite element simulations identified the causes of defects in the die and valve cover. Results showed the significant influence of temperature and friction coefficient on forging defects, enabling optimization of forging parameters.

The experimental findings were consistent with the simulation results, enhancing understanding of the hot forging process for the CuZn40Pb2 brass alloy water valve cover and providing insights for process optimization and defect prevention.

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A comparative study on fatigue behavior of recycled Aluminum alloys and their welded joints

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Keywords: Recycling, HCF, Al-alloys

Recycling of Al-alloys is crucial to avoid the high energy requirement for production of primary Al. However, one of the major concerns in using recycled Al in load bearing engineering components is how the fatigue properties get affected. This calls for a thorough and systematic investigation on fatigue behaviour of recycled Al-alloys. Towards this, different alloy variants are designed with enhanced impurity content (Fe, Si, Cu, Zn etc. systematically increased from variants GA1 to GA3) which is commensurate with that found in post-consumer scrap Al. High cycle fatigue (HCF) tests under stress-controlled mode are conducted both in base alloy as well as friction-stir-welded butt joints (FSW joints) for these alloy variants. The test results show that fatigue life is higher in the base metal compared to FSW joints for both the alloy variants GA1 and GA3, with a higher fatigue limit observed for the base material. This indicates better fatigue properties in the base material compared to the FSW joints. To understand this variation in fatigue properties between the base and weld, and among the alloy variants, detailed fractographic investigation on tested specimens are carried out. The investigation revealed that the failure primarily occurs through transgranular crack initiation from the surface in the case of base material and FSW joints. However, multiple crack initiation sites are observed in case of FSW joints, as opposed to one or two crack initiation sites for the base material. This accentuated the crack initiation process in FSW joint, thereby curtailing the fatigue life. This behavior is attributed to presence of defects (surface and sub-surface) in case of the FSW joint which prompted early crack initiation from several sites. Failure location in the FSW joints is found to change in some cases from the weld-toe to the base metal, especially in alloy GA3. This is caused due to the presence of large volumetric defects in GA3 wherein the impurity content (like Fe, Cu and Zn) is higher compared to GA1.

Effect of Pressure Sensitivity on Hypervelocity Impact Damage

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Keywords: Hypervelocity impact damage, Drucker-Prager plasticity, pressure sensitivity.

This study focuses on the influence of pressure sensitivity (β) in the context of Drucker-Prager (DP) [1] plasticity model on the hypervelocity impact (HVI) performance of a spacecraft shield. The Johnson-Cook (JC) material parameters for pressure insensitive case ($\beta = 0^o$) were chosen to be that of Al6061-T6 Aluminium alloy taken from literature [2]. For the pressure sensitive cases ($\beta > 0^o$), the DP hardening data was generated in tabular form under pure shear from single element tests conducted at various strain rates and temperatures employing the JC hardening parameters of Al6061-T6 alloy mentioned previously. Thus, the DP model coincides with the JC model under pure shear but differs from the JC model only in terms of pressure sensitivity of yielding. Using the calibrated DP model, single element tests under uniaxial tension and compression were also conducted at various strain rates and temperatures. These tests highlighted the significance of finite pressure sensitivity in terms of tension-compression asymmetry in yield stress across all strain rates and temperatures. Effect of β was not observed in pure shear tests at the same strain rate. HVI simulations were then conducted using the above DP model in ABAQUS/Explicit to investigate the effect of β. An Al6061-T6 spherical projectile was used to strike a target plate, both modeled with three dimensional continuum temperature displacement finite elements of the type C3D8RT in ABAQUS. The impact velocity was taken as 7 km/s perpendicular to the target plate. Simulations were conducted for various values of $\beta = 0^o - 30^o$. The same Mie-Gruneisen Equation of State, JC ductile failure criterion, and simple tensile cutoff spall failure criterion were employed in all simulations to exclusively investigate the effect of pressure sensitivity parameter.

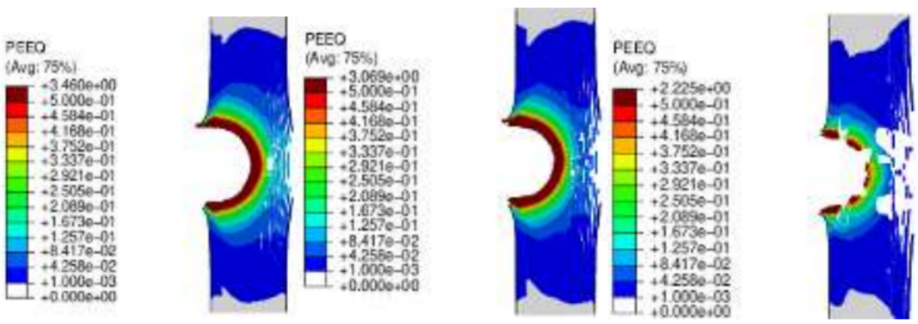

Figure 1: Contour plots of equivalent plastic strain in the central through-the-thickness cut view of the target for $\beta = 0^o, \beta = 10^o, \beta = 30^o$.

Results indicate that the damage in the target plate comprises of cratering and spallation. The equivalent plastic strain (PEEQ) decreases in the crater region with increasing β, resulting in smaller crater diameter and crater depth as shown in the Figure 1. However, the spall diameter increases with higher β values. Mass loss decreases in the crater region but increases in the spall region as β increases. This parametric study shows that increasing the β value can enhance the cratering resistance of the target plate under hypervelocity impact but may diminish the spall resistance, highlighting the importance of considering pressure sensitivity in such HVI simulations.

Keywords: Financial support from IITB-ISRO Space Technology Cell through a sponsored project with code RD/0119-ISROC00-010 is thankfully acknowledged.

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Field-Split Preconditioning via Schur Complement for Phase-Field Fracture Mechanics with Finite Element Method

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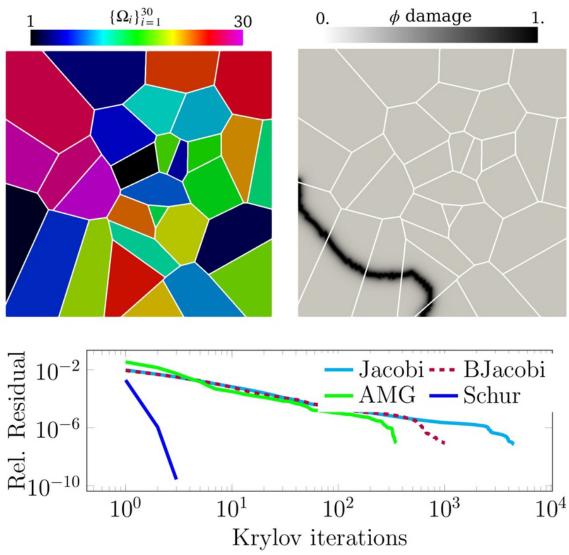
Keywords: phase-field method, HPC, field-split preconditioning

The phase-field method is a useful tool for simulating fractures, crack propagation, and studying complex fracture phenomena. However, solving certain phase-field fracture problems numerically with FEM involves tackling large systems of linear equations, which can be computationally demanding. To address this issue, parallel computing through the domain decomposition method can be employed. However, to achieve scalable parallel simulations, an optimal preconditioner is required. In this work, we explore the application of field-split preconditioning via the Schur complement [1] to enhance the efficiency of solving phase-field fracture problems in parallel. We utilize vectorial finite elements [2], which facilitate an overall monolithic approach.

The field-split preconditioning technique aims to decompose the original monolithic linear system into smaller sub-problems that can be solved more efficiently. By exploiting the underlying physics, the linear system is split based on two involved fields: displacement and phase-field variables. The Schur complement matrix is derived from the original system matrix by eliminating the unknowns associated with the displacement field, providing a smaller and more favorable precondition.



The effectiveness of the field-split preconditioning with Schur complement for phase-field fracture is demonstrated via numerical experiments. As an example, a heterogeneous problem with thirty randomly place polygonal-shaped materials is used. The accompanying figure clearly depicts rapid convergence achieved by field-split preconditioning, with convergence attained in less than five Krylov iterations. This represents a substantial reduction in the number of iterations and CPU time compared to other well-known preconditioners.

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Influence of the Calibration Test on the Fracture Initiation Prediction in Rectangular Cup Drawing Process

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Keywords: Rectangular cup drawing, Plasticity, Polynomial yield criterion.

In the cup drawing process, it is aimed for the sheet metal to be formed into the desired shape without going through failure. Tearing is one of the failure types observed in the cup drawing processes and leads to material loss. Tearing failure is mainly relevant to the geometry of the die tools, mechanical properties of the material, lubrication conditions, and blank holder force. Among these parameters, mechanical features and the yield criterion are essential for tearing performance.

In the present study, the tearing failure in a rectangular cup drawing process was assessed for the AISI304 austenitic stainless steel that is prevalently employed in the automotive industry. A plasticity model, including the fourth-order complete polynomial-based yield criterion and a fracture model regarding the plastic work concentration, was implemented to predict the tearing failure. Furthermore, the fracture model was calibrated through the physical uniaxial tensile test and a bulge test in order to distinguish the difference in plastic work damage indicator acquired by different loading paths.

It was observed that the prediction performance was noticeably increased when the damage indicator from the bulge test was employed. Moreover, the material model involving the complete polynomial yield criterion and the fracture model could accurately estimate the crack initiation location and the propagation path.

Fracture Forming Limit Curve Prediction by Ductile Fracture Models

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Keywords: Ductile fracture model, Fracture locus, Forming limit curve.

The fracture forming limit curve is an essential tool giving information about fracture initiation in metal forming applications. In order to obtain a fracture-forming limit curve, the Nakajima test should be carried out. However, these tests are costly and time-consuming processes. Therefore, companies in the automotive industry tended to use non-expensive numerical approaches to determine the material's formability limits.

In this work, an anisotropic polynomial yield criterion was implemented to calibrate the different ductile fracture models, including only or both the stress triaxiality and the Lode parameter's effect. Analyses of different uniaxial tensile test geometries were carried out, and the two-dimensional fracture loci were constructed by different ductile fracture models. Correspondingly, the fracture-forming limit curves were predicted by the two-dimensional fracture loci.

The results showed that the ductile fracture models, including only the stress triaxiality effect, provide an acceptable performance covering the range from uniaxial tension and the plane strain tension lines, while the models, including the stress triaxiality and Lode parameter, provide a plausible prediction performance throughout the whole range for forming limit diagram.

On multi-scale strain localization in twinning Magnesium

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Keywords: magnesium, twinning, strain patterning, digital image correlation

Magnesium alloys are the lightest structural metals, but their structural application is hampered by the complexity of their crystallite-scale deformation that operates with multiple slip and twin mechanisms. They are hence prime candidates to benefit from advanced polycrystalline models, and an extensive literature formed to address their anisotropic and load-path-dependent behavior. While these attempts typically seek validity in an aggregate-average sense, there is also a recent physics-based drive towards higher-fidelity modeling that can represent strain fields at some microstructural length scale.

Over time, we have amassed spatially resolved in situ data that can counterpart such models, detailing the intergranular strain localization signature of wrought Magnesium AZ31 polycrystals. The method is an advanced in situ implementation of digital image correlation with optical microscopy that can employ high resolution objectives thanks to automated corrective measures. Further, full-field area scanning is utilized to reveal long range strain localization that is a huge issue for Magnesium alloys (e.g. Lüders-like twinning bands [1]). The presented studies will cover crystallographic texture dependence [2,5], cyclic loading and its effect on twin-based Lüders banding [3], inherited strain localization structures (via texture scars that form with renucleation in the previous forming process) [3,4], and interaction with stress raisers [5].

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A thermo-mechanical investigation of textured Magnesium in an effort to validate crystal plasticity simulations

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Keywords: magnesium, twinning, plastic dissipation, thermo-mechanical behavior

Magnesium is among the lightest structural metals with a high strength-to-weight ratio. A widespread adoption of magnesium alloys in the industry, however, is impeded by its unorthodox mechanical behavior. The vast differences between activation energies of the slip systems in HCP magnesium, combined with profuse (and abrupt) activity of tensile twinning leads to an extreme plastic anisotropy. On top, there is intense strain heterogeneity, primarily, linked to the spatial coordination of twinning (e.g., [1]) that also shows a strong dependence on crystallographic texture. The recent experimental efforts that target a better understanding of magnesium (and validate polycrystal simulations) include investigation of its mechanical response by measuring strain and texture for different starting textures, load paths, deformation rates, and temperatures. In contrast, this work aims to incorporate temperature measurements of dissipative response of Magnesium during deformation as well as the usual stress-strain measurements in order to obtain a high-fidelity thermo-mechanical description of its plastic deformation. To this end, the temperature of textured magnesium AZ31 samples under cyclic loading are recorded under an IR camera. The obtained deformation-history dependent curves of stress and temperature are then used to validate a coupled thermomechanical crystal plasticity model, posed in the variational framework devised by Ortiz and Stainier for viscoplastic constitutive relations [2] and later revised to incorporate thermomechanical coupling [3].

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Impact of Cure Temperature and suspension viscosity on the Mechanical Properties of Carbon Nanofiber-Reinforced Epoxy Resin Nanocomposites

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Keywords: Carbon nanofibers, Nanocomposites, Cure temperature, Mechanical properties.

The use of nanocomposite materials in many industrial applications has been increasing in recent years due to their improved mechanical performance and lower weight. Among the nanoparticles available for use in this type of new materials, carbon-based nanoparticles such as carbon nanofibers appeared as one of the more promising due to their good mechanical, electrical, and thermal properties [1, 2]. In epoxy resins with added carbon-based nanoparticles for use in various industrial fields (especially in railways, aircraft, or process industries) it is necessary to understand how they interact during the manufacturing process [3, 4]. Therefore, the main goal of this study is to analyze the properties of an epoxy resin enhanced with carbon nanofibers, with special emphasis on the effect of suspension viscosity on mechanical properties. Resin viscosity tests, measurement of the contact angle between the carbon nanofiber particles and the resin as well as shrinkage tests will be carried out. The effect of pre-cure temperature, between 7°C and 40°C, on the mechanical response of the nanocomposite was also evaluated. The results obtained showed that the presence of carbon nanofibers increased the viscosity between 45% and 74% and the shrinkage effect decreased from 3.18 to 0.70%. The mechanical properties were maximized for a temperature of 5°C, representing an increase in maximum bending stress between 13% and 32% depending on the resin used.

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Investigation of Cross-ply Curved Composite Laminates under Pure Transverse Loading

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Keywords: curved composite laminates, matrix crack-induced delamination, fractography

Curved composite laminates have been utilized in the primary structures such as ribs and spars of airplane wings and wind turbine blades. These structures are exposed to high loads which creates high interlaminar stresses in the curved area leading to the delamination failure mode. Delamination results in a significant loss in the load-carrying capacity of these structures and eventually catastrophic failures [1,2]. This study presents an experimental and numerical investigation of cross-ply curved composite laminates, having a stacking sequence of $[(90/0)_4,\overline{90}]_s$ subjected to pure transverse loading. The experiments are conducted with an electromechanical testing machine. The load-displacement data of specimens are recorded, which reveals that the specimens lose their load-carrying capacity with single or multiple load drops accompanied by 4-5 delaminations in total. In the experiments, a high-speed camera is utilized to observe the failure sequence of specimens and the digital image correlation method is used to obtain in-situ strain field over the curved region. High-speed camera observations show that specimens have the same failure sequence though having different load drop schemes; first delamination initiates at the inner side of the curved region and subsequent failure occurs at the next neighboring interfaces. In-situ strain field reveals the strain concentration regions occur at the inner side of the curved region where the first failure is observed Post-mortem specimens are investigated with a digital microscope, and in the micrographs, radial & transverse matrix cracks, delamination migration and meandering crack path are observed. Explicit finite element analyses are conducted using interlaminar and intralaminar damage models to simulate the delamination and matrix failure modes, respectively. LaRC04 failure criterion is implemented to ABAQUS via user subroutine. The effect of matrix crack on the failure load are investigated by using LaRC04 failure criterion. The results of analysis reveal that matrix cracks induce delamination at lower loads, which leads to a better agreement with experimental data. The matrix damage pattern observed in the finite element analyses are matched with the experimental one well.

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Ductile crack path prediction through phase field and uncoupled damage models

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Keywords: ductile failure, phase field fracture, finite element method, non-local modeling.

Simulation of ductile fracture is commonly performed with uncoupled ductile damage modeling techniques using finite element. In this approach, damage is defined by a failure criterion, and the failure itself is simulated by deleting elements. The local nature of the failure modeling process results in significant mesh dependency in both crack initiation and propagation phases as demonstrated in [1]. Non-local or gradient methods have been proposed as a solution to such issues in failure simulations through the introduction of a length scale. Phase-field fracture method, where cracks are defined as non-local diffuse entities, is used in this work to address mesh dependency problems in the ductile failure simulations of Inconel 718. The Johnson-Cook and modified Mohr-Coulomb damage criteria calibrated in [2] for Inconel 718 are utilized in both uncoupled approach and phase field fracture model. Coupling of these damage criteria with the phase field framework has already been demonstrated in [3]. Finite elements simulations are performed with varying element sizes and orientations in the crack propagation region, and the results are compared with the experimental observations. Uncoupled ductile failure simulations are performed with Abaqus/Explicit solver while the phase field fracture simulations utilize Abaqus/Standard, and the models are implemented through user subroutines for both methods.

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Investigation of Roughness Effect on Dynamic Behaviour of Frictional Interfaces

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Keywords: Sliding friction, Stick-slip, Roughness, Maxwell-slip model

Performance and reliability of the engineering materials are highly affected by the frictional sliding as the stick-slip behavior causes vibration and noise, unstable motion, wear and tear, and a reduction in the control accuracy [1-3]. Stick-slip and the steady sliding are the two sliding mechanisms observed in the friction tests. This study aims to investigate the roughness effect on the dynamic behavior of frictional interfaces. We model a rough elastic body using the Maxwell-slip model (MSM) by introducing a randomness to the initial positions of the blocks of MSM by using beta probability distribution function (PDF). Surfaces with various roughness values are imitated by changing the shape parameter of beta PDF. Sliding of the blocks on a rigid substrate occurs by a constant speed driver that is connected to all blocks by the springs carrying only tangential load. Coulomb friction law is assumed at the interface. We have conducted frictional sliding experiments on PMMA blocks with various roughness values using an in-house friction experimental setup. Our simulation results showed that rougher surfaces are prone to exhibit steady sliding behavior whereas smoother surfaces are prone to exhibit stick-slip behavior. The results are compared with the experimental results.

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Delamination behaviour of elastic surface coatings subjected to thermal shock

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Keywords: Elastic coating delamination, Hot shock, Cold shock, Displacement Correlation Technique, Finite Element Method.

Elastic surface coatings, especially, Thermal barrier coatings (TBCs) are recognized as essential key materials for high-performance aero-engine and heavy-duty gas turbine blades due to their excellent thermal protection properties [1-3]. When the surface of the metallic substrate is deposited by these coatings with a thickness of 100-400 μm, it was reported that the substrate temperature could effectively be reduced by 100-200 °C [4-7]. Moreover, they protect metallic substrate from severe chemical corrosion and high temperature oxidation. Thus, utilization of these coatings leads to increase in the efficiency of engines and gas turbine blades. This papers examines the effect of transient thermal loading and the thermal shock on delamination behavior of the thermal barrier coatings (TBCs). The coating-substrate system is considered to consist of three layers which are ceramic coating, bond coating and the metallic substrate. In order to analyze the problem, finite element method (FEM) is used. Boundary conditions and loads are determined in thermal and mechanical fields. Delamination behavior of TBCs is investigated based on two different crack configurations, which are crack at the interface of the surface coating and crack at the interface of the bond coating. Cracks are modeled using singular finite elements and mixed mode I/II stress intensity factors (SIFs) are calculated through the use displacement correlation technique (DCT). Energy release rate and dimensional phase angle values are also determined for different conditions. Parametric analyses are carried out to reveal the influences of crack configuration, material properties, thermal shock time and its type either hot or cold, thickness of coating materials and crack length. Fracture analysis of TBC delamination under cold thermal shock loading was examined by Ping-wei [8]. However, authors examined coating system subjected to cold shock, crack at the bond coating was not analyzed and presented results were limited since effects of aforementioned parameters on delamination were not thoroughly presented. Hence, results presented in this study fill this gap and it is found that the crack tip stress field is shear dominant, energy release rate and SIFs for crack configurations are different from each other due to the utilized materials. Possible delamination due to unstable propagation of the crack is also presented for different parameters.

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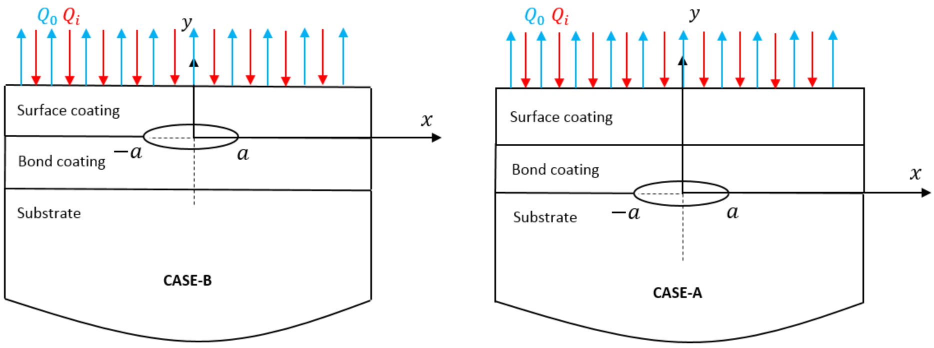

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Numerical Simulation of Low-Velocity Impact on $[0_5/90_3]$s CFRP BeamConsidering Accurate Experimental Conditions

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Keywords: Polymer-matrix composites, Low-velocity impact, Finite element method

Composite materials are extensively employed in aerospace, renewable energy, and transportation industries due to their exceptional strength-to-weight ratios. However, their weak interfacial characteristics make them vulnerable to out-of-plane loadings, including lowvelocity impact (LVI) events, which can result in internal failures like matrix cracking and delamination. While experiments can determine the failure behaviour and resistance of composites to LVI, there is a growing interest in replacing a significant portion of experimental efforts with physically accurate numerical simulations. To validate these simulations and their associated damage models, direct observation of the dynamic evolution of damage becomes important. In a recent experimental study by Bozkurt and Coker [1], $[0_5/90_3]$s CFRP beam specimens subjected to transverse impact loadings were analysed with full-field digital image correlation method, and in-situ progression of matrix cracking followed by dynamic progression of delamination were captured. In this study, we constructed the finite element (FE) model of the LVI experiments presented in [1]. Our objectives are to reproduce the observed damage accurately and to investigate its dynamic progression beyond the limitations of experimental observations. The numerical model is constructed in the commercial FE package ABAQUS/Explicit and incorporates the following features. For modeling ply damage, we employed a three-dimensional continuum damage mechanics approach, utilizing the LaRC05 damage initiation criterion implemented through a user-defined subroutine (VUMAT) with an explicit integration scheme. To simulate delamination damage, we employed the cohesive zone method and inserted built-in cohesive elements at the 0°/90° interfaces. To replicate the experimental boundaries, we proposed a heuristic approach for modeling boundary conditions (BCs) by assembling spring elements at the corresponding boundary nodes. The stiffness of these springs was determined based on minimizing the differences between the full-field displacements and strains obtained from both the experiment and simulation. The numerical simulations showed good agreement with the experimental results in terms of failure load, sequence, and initiation location. The influence of experimental boundaries on the dynamic damage characteristics is illuminated by utilizing the proposed BCs approach. By comparing the numerical findings with the experiments, we gained further insights into the damage growth in composite beams under LVI loading.

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Finite element analysis of JCO-E fabrication process and its influence on the material properties and collapse capacity of offshore pipelines

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Keywords: cold-forming process, offshore pipeline, collapse

The JCO-E process is a commonly used process for fabricating large diameter thick-walled line pipes through cold forming/expanding processes. In particular, the initial flat configuration (plate) is deformed significantly in the inelastic range to obtain the circular configuration (line pipe) of the final product through a sequence of steps which involve: (a) crimping of plate edges, (b) "J", C" and "O" steps where a punch is used to deform the plate and obtain a minimum distance (gap) between the plate edges (c) welding of plate ends to obtain a semi-circular geometry and (d) expansion to improve the geometry of the final product. The cold forming steps of the process (JCO steps) and the final expansion step affect the geometric (i.e., cross-sectional ovality, wall-thickness) and material properties of the final product. The effect on the geometric and the material properties are important for the resistance to collapse of the fabricated pipe in the presence of extreme external pressurization, compared to seamless pipes [1], [2]. In the present work, the JCO-E fabrication process is numerically simulated using advanced finite element tools for the case of a thick-walled 30-inch-diameter pipe, which is candidate for deep water installation. Subsequently, the structural performance of the line pipe is investigated under external pressure in a unified approach. Uniaxial tests are performed to obtain the material properties used in the finite element model, which are representative of the loading history that the plate is subjected during the process. The effects of the forming parameters on the properties of the final product are investigated through extensive parametric studies. The results have shown that there exists an optimum expansion range for achieving the minimization of the geometric imperfections of the final product and the maximization of the collapse capacity of the pipe. The numerical predictions on the material properties and the collapse performance of the fabricated pipe are also compared with analytical-simplified methodologies.

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Effect of Prooxidants on LDPE and LDPE/Thermoplastic Starch Blends Properties

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Keywords: Prooxidants, Polyethylene degradation, Mechanical tests, Thermoplastic starch.

Low density polyethylene, while commonly used, contributes significantly to the exacerbation of ecological concerns owing to its slow environmental degradation and lack of biodegradability [1]. In order to address this pressing concern, the incorporation of prooxidants in small quantities can be a transformative solution. By introducing these substances, hydrophilic functional groups can be formed along the macromolecular chains, rendering them more vulnerable to microbial attack and degradation [2].
By adopting this approach, our research attempts to combine low-density polyethylene with stearate-based prooxidants to initiate the thermal degradation of the polymer backbone. Subsequently, the resulting Ox-PE mixtures are blended with thermoplastic starch (TPS) to yield a novel material that claims improved biodegradability and superior performance characteristics. The prepared LDPE/prooxidant and Ox-LDPE/TPS blends are characterized by FTIR spectroscopy, contact angle and mechanical tests. The FTIR of Ox-LDPE shows that the metal ions Mn2+ can act as thermal catalysts while Fe3+ was not effective in accelerating thermal degradation. Contact angle results of Ox-LDPE indicate a lowering in the PE hydrophobicity while the tensile test revealed that Mn2+ is the most efficient prooxidant. This interpretation results from the largest performance loss observed in the PE-Mn mixture. Moreover, the analysis of Ox-LDPE/TPS blends highlights the accumulation of carbonyl groups following the initial phase of thermo-oxidation, suggesting a rise in the degradation of the polymer chains.

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Influence of ply thickness in the $[0/90_n]_s$ CFRP laminate under quasi-static in-plane compression loading: Experimental and finite element modeling study

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Keywords: Carbon fiber reinforced polymer, Quasi-static compression, Laminate thickness, Intralaminar and interlaminar damage, Finite element modeling.

This work studies the correlation between the 90° ply thickness in a $[0/90_n]_s$ carbonfiber reinforced polymer (CFRP) lay-up and its in-plane compressive strength. In literature, studies have shown that lamina thickness have a significant effect on the mechanical response and damage inheritance in the structure [1], [2]. In this study, a quasi-static in-plane compression experiments coupled with digital image correlation (DIC) were performed on laminated composite [MTC510-UD300-HS-33%] with three different thickness of 2.2, 3.2, and 4.2 mm. The thickness increases with increase in the n^{th} ply of 90° while keeping 0° ply constant in all the laminates. Then, an LS-Dyna based finite element model (FEM) was developed using a progressive damage model (MAT 55) to investigate the intralaminar and interlaminar damage propagation in the composite. The calibrated FEM model showed good agreement with the experimental results, in terms of qualitative and quantitative damage assessment. The results demonstrate that reducing the 90° lamina thickness can influences the mechanism of damage propagation and inhibits matrix cracking. Overall, this study provides insights towards designing and optimization of composite laminate for impact resistance in structural application.

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Optimized Neural Networks for Structural Damage Prediction Based on Modal Analysis

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Keywords: Neural Networks, Optimization, Damage prediction.

Damage detection and localization play a pivotal role in structural health monitoring endeavors. While the application of Artificial Neural Networks (ANNs) has yielded success in identifying damage within civil and mechanical infrastructures, it's worth noting that these ANNs come with certain inherent limitations. However, a promising avenue for enhancing the efficacy of ANNs lies in the modification of their architecture and refining their training strategies.

In this study, the authors introduce a novel approach that leverages a metaheuristic algorithm known as the Butterfly Optimization Algorithm (BOA) to craft an optimized ANN tailored for the task of predicting multiple types of damage in aluminum bars. The input parameters for this ANN are drawn from the natural frequencies of the structure, while the output is focused on predicting the depths of cracks within the material. To generate the necessary dataset, an advanced Finite Element Model (FEM) is employed, which is adapted to accommodate various crack depths. This data collection is facilitated through the utilization of a simulation tool.

To ascertain the robustness of this proposed technique, real-world experimental data derived from the analysis of cracked beams is gathered, encompassing a range of distinct crack depths. The performance of this newly introduced approach is subsequently benchmarked against alternative methods that also harness metaheuristic algorithms, specifically the Artificial Bee Colony Algorithm (ABC) and the Genetic Algorithm (GA).

Remarkably, the results showcase that the innovative methodology put forth by the authors exhibits a high level of predictive accuracy in the realm of damage prognosis. This underscores the potential of the Butterfly Optimization Algorithm in optimizing the architecture of ANNs to effectively forecast various forms of damage in structural components

Effect of Ferromagnetic Materials Composition on Magnetic Flux Leakage Signals during Fatigue Crack Growth in Steel

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Keywords: fatigue, crack growth, magnetic flux leakage

Fatigue cracks in steel structures can have catastrophic consequences if undetected or not properly managed. The Metal Magnetic Memory (MMM) testing, utilising changes in the self-magnetic-leakage field (SMFL), is a widely used non-destructive evaluation technique for detecting and monitoring cracks. However, the lack of an accurate description of the SMFL changing mechanism under elastic and plastic cyclic loads [1,2] makes it crucial to understand this relationship in order to enhance the accuracy of MMM testing for identifying and characterising fatigue cracks in steel structures. Therefore, there is a need to investigate the effect of varying ferromagnetic materials composition on MMM signals to improve crack detection and monitoring techniques and ensure the structural integrity and safety of steel components [3]. This study aims to investigate the effect the percentage of ferromagnetic material composition in steel on MMM signals during fatigue crack growth and to analyse the relationship between the percentage of ferromagnetic materials in steel and the MMM signals, specifically focusing on the material constant parameter in the Paris law. To achieve this objective, a constant cyclic loading method was employed, and an MMM scanning device was used to scan the SMFL signals. The study utilised three different types of pre-cracked CT steel specimens, namely ASSAB 705, ASSAB 709 and ASSAB 760, with stress ratios, R set at 0.1 and 0.3. Through the experimental setup, the MFL signals were captured and analysed, correlating them with the percentage of ferromagnetic materials composition in the steel samples. The Paris law was then used to determine the material constant parameter. Based on the results obtained, it is concluded that the material constant parameter in the Paris law increases as the percentage of ferromagnetic material composition in the steel increases.

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Investigation of Failure Mechanisms in Dual-Phase Steels through Micromechanics-Based Frameworks

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Keywords: dual-phase steel, crystal plasticity, cohesive zone modeling, ductile fracture.

Due to their special composition, which combines the ductile ferrite phase with the hard and brittle martensite phase, dual-phase (DP) steels have excellent formability and intriguing material properties. However, this incompatible deformation behavior of two phases within DP steels results with complicated failure mechanisms in micro-scale. These include martensite cracking and interface decohesion between the ferrite-martensite (F/M) and ferriteferrite (F/F) phases [1, 2]. A detailed analysis of DP steel microstructure using a micromechanics-based methodology is required in order to understand their plastic and failure behavior. To capture the impact of microstructure evolution on macroscopic response, a crystal plasticity and cohesive zone modeling based failure framework for three-dimensional Representative Volume Element (RVE) calculations is used. For the brittle martensite phase, the isotropic J2 plasticity model is used, whereas the rate-dependent crystal plasticity framework is used for the ductile ferrite phase. To study intergranular cracking, cohesive zone elements are inserted at the F/M and F/F interfaces. Additionally, an uncoupled damage model is used to model intragranular failure in the martensite phase. To calibrate the aforementioned failure models, a comprehensive parameter identification study is carried out. The ability of the framework to predict the failure and plastic responses in comparison to the findings in the literature is assessed [3]. This is achieved through analyzing and discussing a variety of threedimensional polycrystalline RVEs with diverse microstructural properties including the effect of addition of simulated cohesive interfaces, crystallographic orientation, martensite morphology, stress triaxiality and martensite volume fraction. Critical factors determining the failure mechanisms in dual-phase steels have been identified as the morphology of the martensite phase and the triaxial stress state that the material experiences.

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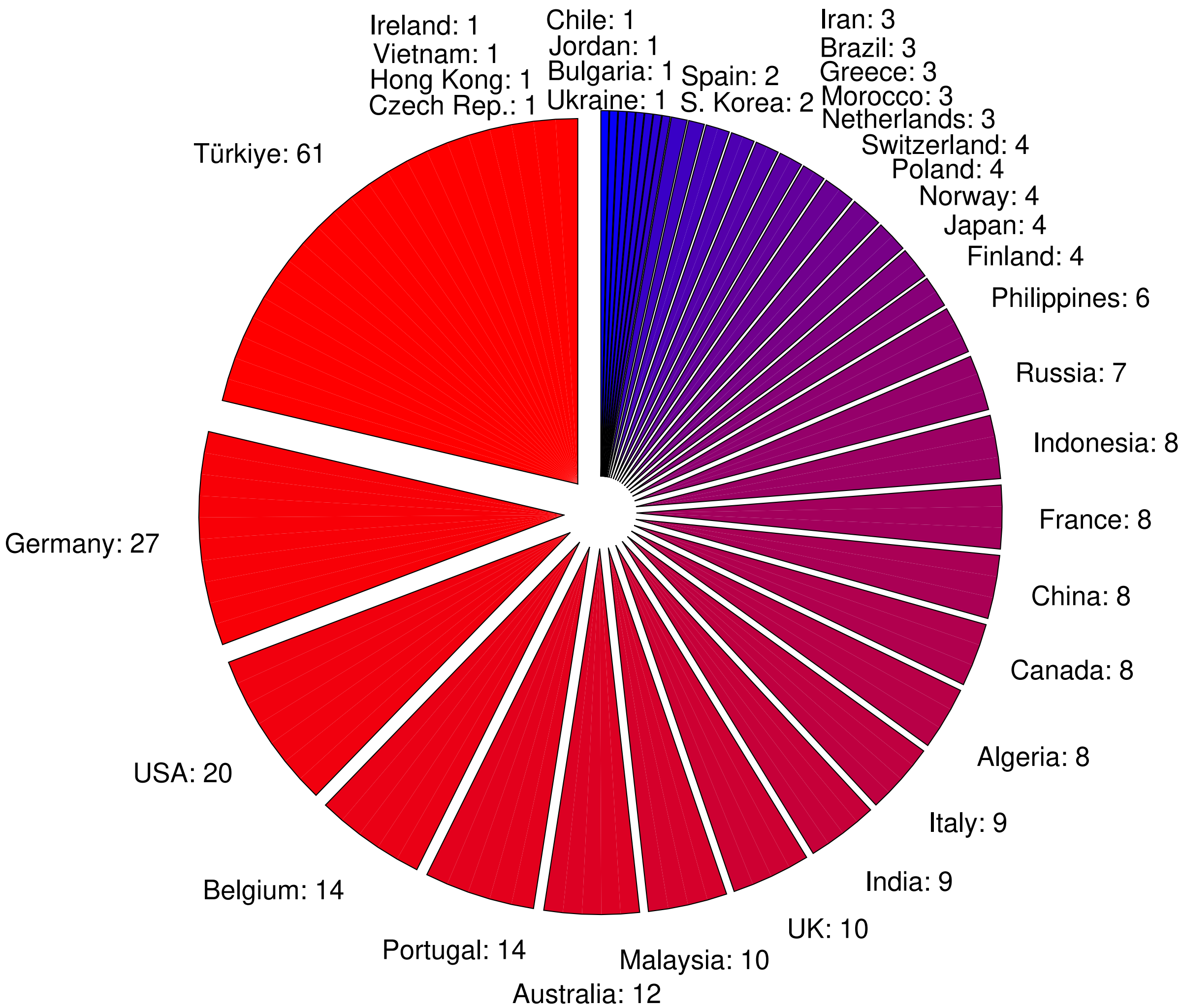

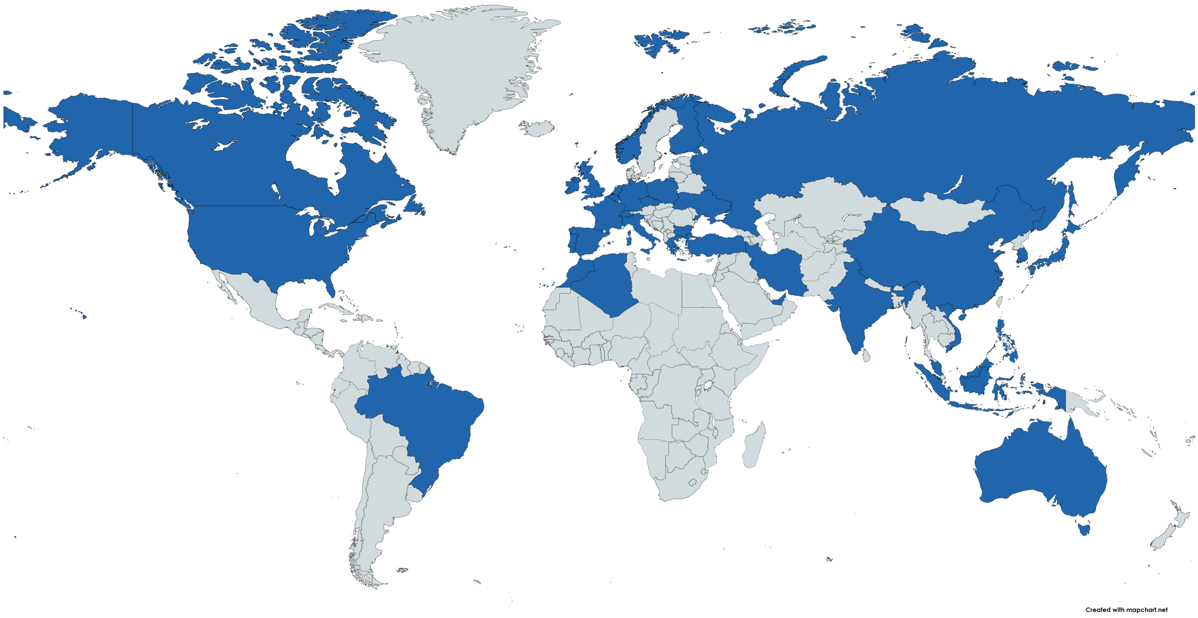

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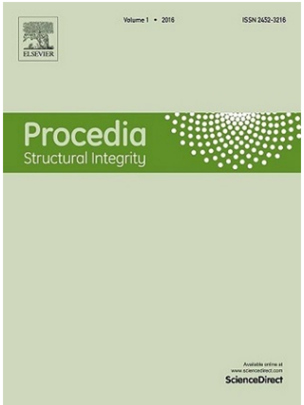

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