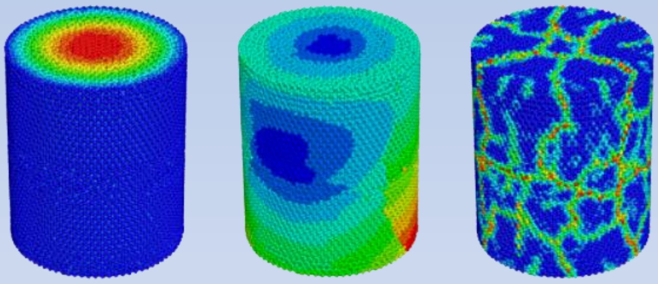

2nd International Workshop on Plasticity, Damage and Fracture of Engineering Materials

18-20 August 2021, Ankara, Turkey

Book of Abstracts

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Turkish Solid Mechanics Group

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The electronic version of this booklet can be found at:
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About

IWPDF 2021

These proceedings contain the abstracts presented virtually at the 2nd International Workshop on Plasticity, Damage and Fracture of Engineering Materials organized by Middle East Technical University in Ankara, Turkey. Participants were given live and pre-recorded options to present their contributions. Due to the challenging conditions caused by the COVID-19 pandemic throughout the world, the workshop is held online to contribute to the dissemination of scientific progress in the field. Subjects of the workshop focused mainly on plasticity-damage and fracture as two main topics. Both computational and experimental studies are presented within the workshop, which focus 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 lectures and the technical session contributors for their live and pre-record presentations. The papers of the workshop will be published in the Procedia Structural Integrity (Open Access). The support from ESIS (European Structural Integrity Society), Middle East Technical University and REPKON Machine and Tool Industry and Trade Inc. is gratefully acknowledged.

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Motohiro Yuasa, Doshisha University (Japan)

Timetable

CT: Contributed Talk, KL: Keynote Lecture, PR: Pre-record

Wednesday, August 18 (Time GMT+3, İstanbul, Turkey)

10:55 – 11:00	**Opening Remarks**		
11:00 – 11:40	KL	**Prof. Dierk Raabe** Düsseldorf, Germany	Multiscale and multi-physics simulations of chemo-mechanical crystal plasticity and phase transformation problems for complex materials using DAMASK
11:40 – 12:20	KL	**Prof. Javier Segurado Escudero** Madrid, Spain	Modeling size effects in metals using FFT homogenization
12:20 – 12:30	**Break**		
12:30 – 12:55	CT	**Lorenzo Bardella** University of Brescia, Italy	Distortion gradient plasticity modelling of the small-scale behaviour of polycrystalline metals under non-proportional loading
12:55 – 13:15	CT	**Stefan Prüger** Technische Universität Bergakademie Freiberg, Germany	Application of a robust, rate-independent crystal plasticity formulation to oligo-crystalline TRIP-/TWIP-steel modeling
13:15 – 13:35	CT	**Lei Liu** Eindhoven University of Technology, The Netherlands	A multi-scale framework towards prediction of the martensite/ferrite interface damage initiation
13:35 – 13:55	CT	**Evgeniya Emelianova** National Research Tomsk State University, Russia	Numerical study of the texture effect on deformation-induced surface roughening in α-titanium
13:55 – 14:15	CT	**Vahid Rezazadeh** Eindhoven University of Technology, The Netherlands	On the deformation behavior of lath martensite in advanced high strength steels

14:15 – 15:00	**Lunch Break**		
15:00 – 15:40	KL	**Prof. Erdogan Madenci** The University of Arizona, USA	Recent Progress in Peridynamic Theory
15:40 – 16:00	CT	**Erkan Oterkus** University of Strathclyde, UK	Comparison of peridynamics and lattice dynamics wave dispersion relationships
16:00 – 16:20	CT	**Selda Oterkus** University of Strathclyde, UK	Peridynamic surface elasticity formulation based on modified core-shell model
16:20 – 16:40	CT	**Aleksandar Sedmak** University of Belgrade, Serbia	Structural integrity assessment of pressure vessels with defects in welded joints
16:40 – 16:50	**Break**		
16:50 – 17:10	CT	**Sandra Baltic** Materials Center Leoben Forschung GmbH, Leoben, Austria	Damage and fracture in aluminum structures
17:10 – 17:30	CT	**Shabnam Konica** Michigan Technological University, USA	A viscoelastic anisotropic phase-field fracture model to predict fatigue fracture in the polymer matrix composites
17:30 – 17:50	CT	**Oleksandr Menshykov** University of Aberdeen, UK	Impact loading of interface cracks: effects of cracks' closure and friction
17:50 – 18:10	CT	**Martin Ferreira Fernandes** Sao Paulo State University, Brazil	Investigation of the damage and fracture of Ti-6Al-4V titanium alloy under dwell-fatigue loadings
18:10 – 18:30	CT	**Jarmil Vlach** VZLU a. s., Czech Aerospace Research Centre, Czech Republic	Impacted area description effect on strength of laminate determined by calculation

Thursday, August 19 (Time GMT+3, İstanbul, Turkey)

10:55 – 11:00	**Opening Remarks**		
11:00 – 11:40	KL	**Prof. Odd Sture Hopperstad** Trondheim, Norway	Plastic flow and fracture in anisotropic aluminium alloys: Experiments, modelling and simulation
11:40 – 12:20	KL	**Prof. Emilio Martínez Pañeda** London, UK	Phase field modelling of corrosion damage and hydrogen embrittlement
12:20 – 12:30	**Break**		
12:30 – 12:50	CT	**Can Erdogan** Middle East Technical University, Turkey	Numerical analysis and extension of a porous plasticity model for ductile failure
12:50 – 13:10	CT	**Sahin Celik** TOBB University of Economics and Technology, Turkey	The role of nucleation conditions for damage under mode-I tearing of ductile plate metals
13:10 – 13:30	CT	**Omar El Khatib** Technische Universität Bergakademie Freiberg, Germany	Investigation of the constraint effects on the ductile fracture resistance using a non-local GTN-model
13:30 – 13:50	CT	**Berkay Kochan** TOBB University of Economics and Technology, Turkey	Voided unit cell simulations with constant stress ratios
13:50 – 14:10	CT	**Artyom Chirkov** National Research Tomsk State University, Russia	Kinetic regularities of the stages of yield plateau and linear strengthening during tension of steel samples: Numerical simulation
14:10 – 15:00	**Lunch Break**		
15:00 – 15:20	CT	**Nils Lange** Technische Universität Bergakademie Freiberg, Germany	Efficient monolithic FE^2-simulation of the creep and ductile deformation behavior of cellular materials
15:20 – 15:40	CT	**Ekaterina Dymnich** Siberian Branch of Russian Academy of Sciences, Russia	Micromechanical analysis for the deformation behavior of additive aluminum alloys

15:40 – 16:00	CT	**Joachim Koelblin** School of Engineering, University of Aberdeen, UK	Deformation of AlSi10Mg parts manufactured by Laser Powder Bed Fusion: In-situ measurements incorporating X-ray micro computed tomography and a micro testing stage
16:00 – 16:20	CT	**Konrad Perzynski** AGH University of Science and Technology, Poland	Prediction of local inhomogeneities in the TiN thin films deposited on the aluminum substrate based on the combination of nanoindentation and numerical modeling
16:20 – 16:40	CT	**Lintao Zhang** Swansea University, UK	Influence of aspect ratio (AR) on the necking angle of tensile specimens for different alloys
16:40 – 16:50	**Break**		
16:50 – 17:30	KL	**Prof. Huseyin Sehitoglu** Illinois, USA	Exploring the Fundamental Issues in Modeling of Twinning In Materials
17:30 – 17:50	CT	**Junhe Lian** Aalto University, Finland	Characterizing and modeling the rate dependency of plastic deformation from single crystal to multiphase steels
17:50 – 18:10	CT	**Yuri Kadin** SKF, The Netherlands	Modeling of plasticity and retained austenite decomposition in bearing steel under cyclic compression
18:10 – 18:30	CT	**David Unger** University of Evansville, USA	Yield criteria representable by elliptic curves and Weierstrass form

Friday, August 20 (Time GMT+3, İstanbul, Turkey)

10:55 – 11:00	**Opening Remarks**		
11:00 – 11:40	KL	**Prof. Timon Rabczuk** Bauhaus-University, Germany	Machine learning based solutions of PDEs
11:40 – 12:20	KL	**Prof. Laura De Lorenzis** ETH Zürich, Switzerland	Two new contributions to phase-field modeling of brittle fracture
12:20 – 12:30	**Break**		
12:30 – 12:50	CT	**Mehmet Dorduncu** Erciyes University, Turkey	A novel ordinary state based peridynamic truss element with uniform/nonuniform discretization
12:50 – 13:10	CT	**Jiayu Sun** Tohoku University, Japan	Epoxy fracture behavior in the metalized CFRP by cold spray
13:10 – 13:30	CT	**Jae Min Sim** Kyung Hee University, Republic of Korea	Evaluation of aging related degradation mechanisms due to neutron irradiation on reactor vessel internals
13:30 – 13:50	CT	**Kenan Cinar** Tekirdag Namik Kemal University, Turkey	Investigation of failure initiation in syntactic foam core L-shaped sandwich structures
13:50 – 14:10	CT	**Kadir Gunaydin** Politecnico Di Milano, Italy	Failure analysis of auxetic lattice structures under crush load
14:10 – 15:20	**Lunch Break**		
15:20 – 15:40	CT	**Linar Akhmetshin** Tomsk State University, Russia	Influence of the unit cell connecting in the metamaterial on its deformation properties
15:40 – 16:00	CT	**Kadir Bilisik** Erciyes University, Turkey	In-plane shear and interlaminar fracture toughness properties of MWCNT stitched para-aramid/phenolic nanocomposites
16:00 – 16:20	CT	**Aleksandr Zemlianov** Tomsk State University, Russia	The influence of bi-layer metal-matrix composite coating on the strength of the coated material
16:20 – 16:40	CT	**Yonca Yasayanlar** Izmir Institute of Technology, Turkey	Modeling of Reinforced Concrete Panels under Blast Loading
16:40 – 16:50	**Closure**		

Pre-recorded Presentations

	PR	**Izzet Tarık Tandoğan** Middle East Technical University, Turkey	Numerical analysis of a micromechanics based cohesive zone model for ductile failure
	PR	**Mohammad Reza Khosravani** University of Siegen, Germany	Effects of fiber on the fracture behavior of 3D-printed fiber reinforced nylon
	PR	**Anatoliy Bovsunovsky** National Technical University of Ukraine, Ukraine	Highly sensitive methods for vibration diagnostics of fatigue damage in structural elements of gas turbine engines
	PR	**Seongwoo Woo** Addis Ababa Science and Technology University, Ethiopia	Reliability design of mechanical systems subject to repetitive stresses
	PR	**Jakub Skoczylas** Lublin University of Technology, Poland	Plane-strain fracture toughness of cured epoxy resins
	PR	**Mohammed Ibrahim Bessaid** University of Tlemcen, Algeria	A poro-fracture approach for numerical modelling of fluid-driven fracture in quasi-brittle materials
	PR	**Apou Martial Kpemou** University of Lorraine, France	Determination of the safety margin on the ductile-fragile transition temperature after introduction of hydrogen into pipelines
	PR	**Varvara Romanova** Institute of Strength Physics and Materials Science, Russia	Multiscale deformation-induced surface roughness in polycrystalline metals and its correlation with plastic strain
	PR	**İbrahim Yelek** Borçelik Çelik Sanayi Ticaret A.Ş, Turkey	Ductile fracture of DX51D material sheet metal panel produced by hemming process
	PR	**Andreas Seupel** TU Bergakademie Freiberg, Germany	Phenomenological modeling of thermomechanical coupling effects of highly alloyed TRIP-steels at different stress states
	PR	**Toros Arda Akşen** University of Sakarya, Turkey	Failure detection in hole expansion test using plastic work citerion
	PR	**Hamed Abdel-Aleem** Central Metallurgical Research and Development Institute, Egypt	Failure analysis of water wall furnace tube

	PR	**Mikhail Perelmuter** Ishlinsky Institute for Problems in Mechanics, Russia	Analysis of interfacial cracks reinforced by nonlinear springs
	PR	**Ülke Şimşek** Middle East Technical University, Turkey	Crystal plasticity analysis of twist extrusion processes
	PR	**Dilek Güzel** Middle East Technical University, Turkey	A two-level homogenization method accounting for particle debonding for polymer nanocomposites
	PR	**Roshan Rajakrishnan** Karlsruhe Institute of Technology, Germany	Modeling the deformation and damage behavior of irradiated Ferritic-Martensitic steel
	PR	**Mert Deniz Alaydin** Brown University, USA	An updated lagrangian multi-layer isogeometric Kirchhoff-Love thin-ahell framework: Application to composite after impact testing of composite laminates
	PR	**Okan Ceylan** Döktaş Dökümcülük Tic. ve San. A.Ş., Turkey	Simulation of 13° wheel impact test using Johnson-Cook failure model
	PR	**Bentejui Medina-Clavijo** CIC nanoGUNE, Spain	In-SEM machining reveals plasticity effects at the cutting edge
	PR	**Onkar Salunkhe** Indian Institute of Technology Bombay, India	Mechanics of deformation and failure of thin film coated Bulk Metallic Glasses
	PR	**Abdelsemi Taibi** RISAM University Tlemcen, Algeria	Numerical modeling of hydration-induced fracture propagation in concrete gravity dams
	PR	**Weidong Wu** Beijing Institute of Technology, China	Dynamic analysis of aluminum containing nano-scale helium bubbles based on molecular dynamics
	PR	**Süleyman Yaşayanlar** Izmir Institute of Technology, Turkey	Localizing implicit gradient damage based treatment of softening in elasto-plasticity
	PR	**Ryota Tamura** Doshisha University, Japan	Texture control of high purity niobium tube by tube channel pressing
	PR	**Sarim Waseem** Middle East Technical University, Turkey	Evaluation of thermomechanical aspects of flow forming process
	PR	**Wei Tong** Southern Methodist University, USA	On the development of macroscopic quadratic plastic potentials for textured FCC crystals with cubic plastic anisotropy

	PR	**Yuta Koike** Doshisha University, Japan	Microstructure and mechanical properties in AZ31 magnesium alloy
	PR	**Vera Friederici** Leibniz-IWT Bremen, Germany	Crack propagation modelling for service life prediction of large slewing bearings
	PR	**Gaston Haidak** Zhejiang Normal University, China	Analysis Damage and Failure mechanism under a lubricated slipper/swashplate interface in Axial Piston Machines
	PR	**Emir Aybars Dizman** İzmir Katip Çelebi University, Turkey	Crystal plasticity based modelling of shear response of carbon fibre reinforced composites
	PR	**Daisuke Hara** Doshisha University, Japan	Microstructure and mechanical properties of AISI4130 steel processed by L-PBF
	PR	**Labinot Topilla** Niğde Ömer Halisdemir University, Turkey	Experimentally and simulations of predefined strengthening and damaged parameters of DP600 and DP800 steels.
	PR	**Andrés Díaz** University of Burgos, Spain	Hydrogen concentration near a crack tip considering plastic strain influence on trapping features
	PR	**Seung-Yong Yang** Korea University of Technology and Education, Korea Republic	Ductile failure criteria for predicting edge crack initiation of an aluminum sheet metal
	PR	**Karthik Srenivasa** Indian Institute of Technology, India	Phase field vs gradient enhanced damage models: A comparative study
	PR	**Vahid Rezazadeh** Technical University of Eindhoven, Holland	On the deformation behavior of lath martensite in advanced high strength steels
	PR	**Surya Shekar Reddy** IIT Hyderabad, India	Study on dynamic crack propagation in brittle materials using phase-field model
	PR	**Mehmet Faruk Yaren** Sakarya University, Turkey	The effect of overload block size on fatigue crack growth life
	PR	**Kemal Arslan** Adana Alparslan Turkes Science and Technology University, Turkey	Computational modeling of strain-rate effects on the low-velocity impact response of sintered Al6061 plates
	PR	**Marcelo Paredes** Texas A&M Univeristy, USA	Ductile fracture and its implication on pressurized transmisison line pipes

	PR	**Deniz Çelikbaş** TOBB University of Economics and Technology, Turkey	Exploring ballistic performance of alumina ceramic tiles with different surface profiles.
	PR	**Igor Smolin** Institute of Strength Physics and Materials Science, Russia	Simulation of residual thermal stress in a layered ceramic composite and estimation of its possible cracking
	PR	**Domen Šeruga** University of Ljubljana, Slovenia	Simulation of elastoplastic response using Prandtl operator approach in a finite element analysis
	PR	**Valentina Zimina** Institute of Strength Physics and Materials Science, Russia	The modeling of the fracture of three-phase ceramic composite
	PR	**Galina Eremina** Institute of Strength Physics and Materials Science, Russia	Verification and validation of numerical models of materials of the lumbar spine
	PR	**Kai Friebertshäuser** Universität Siegen, Germany	Pneumatic fracture computations with peridynamics
	PR	**Tomas Manik** Norwegian University of Science and Technology, Norway	Efficient and robust fully implicit return mapping algorithms for crystal and continuum plasticity
	PR	**Kadir Kaya** Ondokuz Mayis University, Turkey	Mechanical design and optimization of small-scale wind turbine blade
	PR	**Kemal Açıkgöz** Middle East Technical University, Turkey	A phase-field fracture model for combined distortional and dilatational failure in rubber-like materials
	PR	**Izabela Korzec** Lublin University of Technology, Poland	Evaluating the effect of FRP composites on their fracture toughness

Invited Keynote Lectures

Multiscale and multi-physics simulations of chemo-mechanical crystal plasticity and phase transformation problems for complex materials using DAMASK

D. Raabe[1], **M. Diehl**[1,2], **K. Sedighiani**[1,3], **J. Mianroodi**[1], **F. Roters**[1]

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[2] *KU Leuven, Leuven, Belgium*

[3] *Dept. Materials Science and Engineering, Delft University of Technology, Delft, The Netherlands*

The solution of continuum mechanical boundary value problems requires constitutive laws that are based on material physics and that connect deformation, damage, transformation and stress at each material point. These often non-linearly coupled phenomena have been implemented in the free software package DAMASK on the basis of the crystal plasticity and phase field methods using several constitutive laws and homogenization approaches. We present some recent progress made in this multi-physics chemo-mechanical crystal plasticity and phase transformation simulation package and show applications to metallic alloys. Focus is placed on the interplay of alloy thermodynamics and micromechanics of steels and aluminium alloys, implementation of damage models, coupling between damage and deformation, high resolution simulations and coarse graining towards applications for yield surface and forming problems. Some recent ideas on using machine learning in crystal mechanics modeling will be also presented.

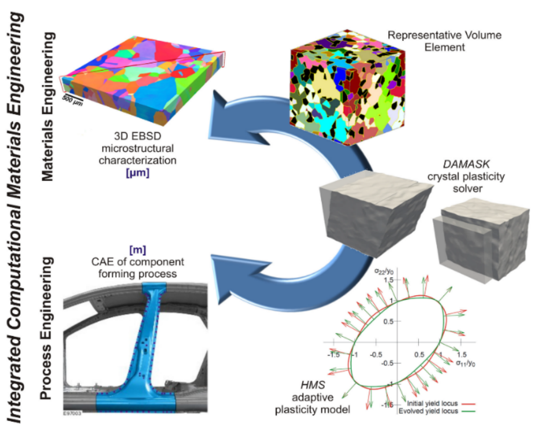
References

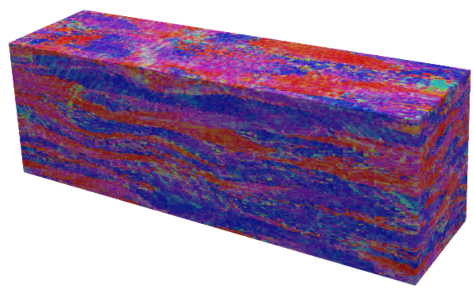
[1] Roters et al. Computational Materials Science, Vol. 158, 2019, Pages 420.

[2] Roters et al. Acta Materialia, Vol. 58, 2010, Pages 1152.

[3] https://damask.mpie.de, https://damask3.mpie.de.

[4] Mianroodi et al. npj Comput Mater 7, 99 (2021). https://doi.org/10.1038/s41524-021-00571-z





Modeling size effects in metals using FFT homogenization

J. Segurado

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The macroscopic response of metallic materials is strongly influenced by their microstructure, including many times the dependence with the characteristic length describing the microstructure. As examples, the plastic response of metallic polycrystals depends on the grain shape and orientation distribution (texture) but also on the absolute grain size, leading to the Hall-Petch effect. Another example are particle reinforced metals, which response, in addition to depend on the volume fraction or particle shapes, depends on the particle size.

In this work, FFT homogenization is combined with non-local constitutive models to obtain this microstructure size dependent behavior. A general staggered FFT framework for solving the mechanical response with lower and higher order constitutive models will be presented [1]. The strategy includes a special treatment of the gradient terms involved and will be first used with strain gradient crystal plasticity to model the grain size dependency of the strength [2]. Secondly, a strain gradient phenomenological plasticity model will be combined with an implicit gradient ductile damage approach in order to obtain the yield, flow stress and ductility as function of the particle size [3].

References
[1] M. Magri, S. Lucarini, G. Lemoine, L. Adam and J. Segurado An FFT framework for simulating non-local ductile failure in heterogeneous materials, Computer Methods in Applied Mechanics and Engineeing 389, 113759, 2021.
[2] S. Haouala, S. Lucarini, J. LLorca, J. Segurado, Simulation of the Hall-Petch effect in FCC polycrystals by means of strain gradient crystal plasticity and FFT homogenization, Journal of the Mechanics and Physics of Solids 134, 103755, 2020.
[3] M. Magri, L. Adam and J.Segurado, Particle size effects in ductile composites: an FFT homogenization study, submitted 2021

Recent progress in peridynamic theory

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Dep. Aerospace and Mechanical Engineering, The University of Arizona, Tucson, Arizona USA

Keywords: Peridynamics, failure, polymers, viscoelasticity, creep, coupling with FEM.
Peridynamic (PD) theory is a non-classical continuum theory based nonlocal interactions between the material points in a body. The interaction occurs between two material points over a finite distance referred to the horizon. The PD equation of motion is an integro-differential equation, and the integrand is free of spatial derivatives of field variables. Therefore, it is applicable in presence of discontinuities in the domain. PD theory is primarily applied to predict crack initiation and propagation in materials. Cracking is achieved through removing the interactions (bond) between the material points.

The PD equations of motion can be broadly classified as Bond-Based (BB), Ordinary State-Based (OSB), and Non-Ordinary State-Based (NOSB) PD. In the BB-PD, the interaction of a pair of material points is independent of the influence of other points in their domain of interaction. However, the OSB- and NOSB-PD is dependent on the influence of other points within their individual domains of interaction. Among the three models, NOSB PD otherwise known as the correspondence model is attractive because of its ability to employ existing constitutive relations for material models.

The force density vectors in PD equilibrium equations are derived both material and geometric nonlinearities. The nonlocal deformation gradient tensor is computed in a bond-associated domain of interaction using the PD differential operator. The PD differential operator enables the construction of the nonlocal form of these equations by introducing an internal length parameter (horizon) that defines association among the points within a finite distance. This study presents recent developments in PD theory such as the direct imposition of local boundary conditions and its coupling with finite element method in ANSYS framework. Also, it presents PD simulations of finite elastic deformation and rupture in rubber like materials, soft polymers, viscoelastic adhesives in bonded lap joints, creep at high temperature and beam structures under quasi static loading conditions.

Plastic flow and fracture in anisotropic aluminium alloys: Experiments, modelling and simulation

O.S. Hopperstad, S. Thomesen, B. H. Frodal, A.J. Tomstad, T. Børvik

Structural Impact Laboratory (SIMLab), Department of Structural Engineering, NTNU – Norwegian University of Science and Technology, NO-7491 Trondheim, Norway

Extruded aluminium profiles are applied in automotive components, such as in frames, crash boxes, bumper beams, and battery protection systems, to save weight while maintaining a high vehicle safety level. Owing to the extrusion process, these materials often exhibit substantial anisotropy in both plastic flow and fracture, which should be accounted for in the design of these safety components. The plastic anisotropy is mainly caused by crystallographic texture, while the main sources for the anisotropy in the fracture strain are, in addition to the plastic anisotropy, the morphological anisotropy (linked to the shape of voids and void-nucleating particles) and the topological anisotropy (linked to the spatial distribution of the voids and void-nucleating particles). Accurate modelling of the anisotropy in plastic flow and fracture requires constitutive models that consider the crystallographic texture and the damage induced by nucleation, growth, and coalescence of voids.

To investigate the anisotropy in plastic flow and fracture of extruded aluminium alloys relevant for automotive components, an extensive experimental study has been conducted. The study includes characterization of grain structure, crystallographic texture and particle structure, and directional tension tests on smooth and notched axisymmetric specimens, where the stress-strain curve at the minimum cross-section is obtained to fracture by use of a laser extensometer. These alloys have different yield strength, work hardening, grain structure, crystallographic texture, and tensile ductility.

To model the complex directional stress-strain behaviour and ductility of these anisotropic alloys, a coupled damage and single crystal plasticity model is adopted. Using this material model, explicit crystal plasticity finite element analyses of the tension tests on smooth and notched specimens are carried out, using models with one element per grain, and compared with the experimental results. The agreement between the experimental and numerical results is found to be satisfactory with respect to anisotropy in yield strength, plastic flow, hardening and failure, and the various shapes of the fractured specimens, induced by the crystallographic texture and its evolution for the different stress states, are well predicted by the crystal plasticity finite element analyses. The study demonstrates the importance of an accurate plasticity model, which represents the key microstructural features of the material, in simulations of large strain plasticity and ductile fracture of these materials.

References

[1] S. Thomesen, O.S. Hopperstad, T. Børvik. Anisotropic plasticity and fracture of three 6000-series aluminum alloys. Metals 11 (2021) 557.

[2] A.J. Tomstad, S. Thomesen, T. Børvik, O.S. Hopperstad. Effects of constituent particle content on ductile fracture in isotropic and anisotropic 6000-series aluminium alloys. Materials Science & Engineering A 820 (2021) 141420.

[3] B. H. Frodal, S. Thomesen, T. Børvik, O.S. Hopperstad. On the coupling of damage and single crystal plasticity for ductile polycrystalline materials. International Journal of Plasticity 142 (2021) 102996.

Phase field modelling of corrosion damage and hydrogen embrittlement

E. Martínez-Pañeda

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Electro-chemo-mechanical phenomena such as stress corrosion cracking, corrosion fatigue and hydrogen embrittlement are widespread across the energy, transport and construction sectors and can compromise future low-carbon technologies, from nuclear fusion to hydrogen-based energy systems. However, predicting the evolution of damage due to the combined action of mechanical fields and the environment has long been considered an elusive goal.

In this talk, I will show how the phase field paradigm can open new horizons in the modelling of hydrogen embrittlement, pitting corrosion and stress corrosion cracking. The phase field can play a dual role; it can describe the growth of cracks, based on a suitable energy balance, and it can characterise how the corroding surface of a metal (solid-electrolyte interface) evolves, as dictated by thermodynamics and local kinetics. The opportunities enabled by the confluence of phase field methods and multi-physics modelling will also be discussed. Phase field models can easily be coupled with differential equations describing various chemical phenomena such as local reactions, ionic transport and hydrogen uptake and diffusion. These elements will be coupled in a mechanistic framework that can predict the early fracture of hydrogen-embrittled alloys [1,2] and the pitting and subsequent cracking of metals in corrosive environments [3]. Localised corrosion and damage can be predicted as a function of the material, the loading conditions and the environment, for arbitrary geometries and dimensions.

The predictive capabilities of the phase field-based multi-physics modelling framework developed will be showcased through numerical experiments. The sensitivity of crack growth resistance to material strength, loading rate and hydrogen concentration is appropriately captured. The shape and size of corrosion pits are compared to those observed experimentally, revealing an excellent agreement. In addition, the capabilities of the modelling framework in enabling Virtual Testing are showcased. Large-scale multi-physics predictions are obtained for technologically relevant applications, from the cracking of bolts to the failure of pipelines [4]. Phase field approaches easily enable capturing damage evolution from an initial distribution of defects, as measured from in-line inspection or other non-destructive techniques. More recent extensions, such as the consideration of multiple hydrogen traps [5] or the modelling of fatigue damage will also be discussed.

Acknowledgements
I would like to acknowledge financial support from the Engineering and Physical Sciences

Research Council (EPSRC) through grant EP/V009680/1 and from the Royal Commission for the 1851 Exhibition (RF496/2018).

References

[1] E. Martínez-Pañeda, A. Golahmar, C.F. Niordson. A phase field formulation for hydrogen assisted cracking. Comput. Methods Appl. Mech. Eng. 342, pp. 742-761 (2018).
[2] P.K. Kristensen, C.F. Niordson, E. Martínez-Pañeda. A phase field model for elastic-gradient-plastic solids undergoing hydrogen embrittlement. J. Mech. Phys. Solids 143, 104093 (2020).
[3] C. Cui, R. Ma, E. Martínez-Pañeda. A phase field formulation for dissolution-driven stress corrosion cracking. J. Mech. Phys. Solids 147, 104254 (2021).
[4] P.K. Kristensen, C.F. Niordson, E. Martínez-Pañeda. Applications of phase field fracture in modelling hydrogen assisted failures. Theor. Appl. Fract. Mech. 110, 102837 (2020).
[5] M. Isfandbod, E. Martínez-Pañeda. A mechanism-based multi-trap phase field model for hydrogen assisted fracture. Int. J. Plast. (in press) 103044.

Exploring the fundamental issues in modeling of twinning in materials

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There has been considerable recent interest in twinning deformation in metals. In this presentation, some of the previous observations and models on twinning are reviewed. Then, we present advanced models for twinning utilizing a combination of atomistic and meso-scale descriptions. We consider cubic (fcc and bcc), ordered (B2 and B19') and hcp crystals in our calculations. Some of the new developments in modeling of twinning (the role of shears, shuffles and offsets) will be reviewed and the importance of twinning in monotonic deformation and fatigue studies will be also highlighted. We show theoretically the description of the twin plane in shape memory alloys and precisely how twin migrates. We discuss how the twin-slip interactions result in strengthening of metals such as in high entropy alloys due to complex dislocation core evolution at slip-twin intersections. Current state-of-the-art models follow a case-by-case analysis of each possible intersection, requiring expensive atomistic or dislocation-dynamics simulations. Furthermore, the existing models are not truly predictive in that they employ some form of empiricism. We propose for the first time, the non-planar core structures of sessile dislocations of the reactions. We uncover the sensitivity of twin interaction stresses on planar fault energies, aimed to inform exploration of the compositional design space for superior nanotwinned alloys.

References

[1] S. Kibey. J.B. Liu, D.D. Johnson, H. Sehitoglu , Predicting twinning stress in fcc metals: linking twin-energy pathways to twin nucleation, 55,20,6843-6851, Acta Materialia , 2007.
[2] S. Alkan, A. Ojha, H. Sehitoglu, Determination of latent hardening response for FeNiCoCrMn for twin-twin interactions, Acta Materialia, 147,149-164, 2018.
[3] A.S.K. Mohammed, H. Sehitoglu, Strain-sensitive Topological Evolution of Twin Interfaces, Acta Materialia,208 116716, 2021.
[4] G. Gengor, ASKMohammed, H.Sehitoglu, 1012 Twin interface structure and energetics in HCP materials, to appear in Acta Materialia, 2021

Machine learning based solutions of PDEs

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Partial Differential Equations (PDEs) are fundamental to model different phenomena in science and engineering mathematically. Solving them is a crucial step towards a precise knowledge of the behavior of natural and engineered systems. In general, in order to solve PDEs that represent real systems to an acceptable degree, analytical methods are usually not enough. One has to resort to discretization methods. For engineering problems, probably the best-known option is the finite element method (FEM). However, powerful alternatives such as mesh-free methods and Isogeometric Analysis (IGA) are also available. The fundamental idea is to approximate the solution of the PDE by means of functions specifically built to have some desirable properties. In this contribution, we explore Deep Neural Networks (DNNs) as an option for approximation. They have shown impressive results in areas such as visual recognition. DNNs are regarded here as function approximation machines. There is great flexibility to define their structure and important advances in the architecture and the efficiency of the algorithms to implement them make DNNs a very interesting alternative to approximate the solution of a PDE. We concentrate on applications that have an interest for Computational Mechanics. The focus will be on two strategies: Deep collocation methods and deep energy methods. While deep collocation methods employ the PDE (and BCs) as loss function, the energy of a mechanical system seems to be the natural loss function for DEM. In order to prove the concepts, we deal with several problems and explore the capabilities of the method for applications in engineering.

Two new contributions to phase-field modeling of brittle fracture

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The phase-field modeling approach to fracture has recently attracted a great deal of attention due to its remarkable capability to naturally handle fracture phenomena with arbitrarily complex crack topologies in three dimensions. On one side, the approach can be obtained through the regularization of the variational approach to fracture introduced by Francfort and Marigo in 1998, which is conceptually related to Griffith's view of fracture; on the other side, it can be constructed as a gradient damage model with some specific properties.

In this talk, the speaker highlights two very recent contributions to phase-field modeling of brittle fracture. The first part of the talk focuses on crack nucleation under multiaxial stress states. It is shown that the available energy decompositions, introduced to avoid crack interpenetration and to allow for asymmetric fracture behavior in tension and compression, lead to multiaxial strength surfaces of different but fixed shapes. Thus, once the intrinsic length scale of the phase-field model is tailored to recover the experimental tensile strength, it is not possible to match the experimental compressive or shear strength. The talk introduces a newly proposed energy decomposition that enables the straightforward calibration of a multi-axial failure surface of the Drucker-Prager type. The new decomposition, preserving the variational structure of the model, includes an additional free parameter that can be calibrated based on the experimental ratio of the compressive to the tensile strength (or, if possible, of the shear to the tensile strength), as successfully demonstrated on two data sets taken from the literature.

The second part of the talk deals with brittle fracture in anisotropic materials featuring two-fold and four-fold symmetric fracture toughness. For these two classes, the talk introduces two newly proposed variational phase-field models based on the family of regularizations proposed by Focardi, for which Gamma-convergence results hold. Since both models are of second order, as opposed to the previously available fourth-order models for four-fold symmetric fracture toughness, they do not require basis functions of C1-continuity nor mixed variational principles for finite element discretization. For the four-fold symmetric formulation we show that the standard quadratic degradation function is unsuitable and devise a procedure to derive a suitable one. The performance of the new models is assessed via several numerical examples that simulate anisotropic fracture under anti-plane shear loading.

Evaluation of thermomechanical aspects of flow forming process

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Flow forming is an incremental cold forming process, where a rotating, axisymmetric workpiece is elongated by the relative axial motion of rollers which simultaneously reduces the wall thickness. Even though flow forming has been prevalent in the industry, the complex nature of the localized deformation involved in flow forming has made it difficult to design analytical methods to accurately predict results, leading to process design incorporating an abundance of trial and error. Despite the recent surge in studies using the finite element method to study specific flow forming applications, there is a gap in the literature on the thermal aspects of this process. There have been studies focusing on the effects of prior heat treatment on the final flow forming product (see e.g. [1]), however there is limited insight offered on the heat discharged during the process itself. Moreover, the studies employing thermomechanical models to study flow forming parameters, tend not to take convective effects into account [2]. Within this scope, a thermomechanical, dynamic and explicit finite element model is developed in ABAQUS. The validity of the model is confirmed by evaluating and comparing reaction forces induced in the rollers, which were known from experimental data. Coolant convection effects were modeled in conjunction with roller and mandrel conduction cooling to study the thermal variations in the deformation zone during the process. The methodology detailed in this study facilitates a deeper understanding of the evolution of heat during the process, as well as laying the groundwork for further exploration into the possible role of a material's thermal properties in the definition of formability. This in turn, could push the current boundaries of flow forming to allow us to work with materials that are harder to form.

Acknowledgements
Authors gratefully acknowledge the support by Repkon Machine and Tool Industry and Trade Inc.

References
[1] A. Karakaş, T.O. Fenercioğlu, T. Yalçinkaya, The influence of flow forming on the precipitation characteristics of Al2024 alloys, Materials Letters 299 (2021) 130066.
[2] H. Shinde, P. Mahajan, A.K. Singh, R. Singh, K. Narasimhan, Process modeling and optimization of the staggered backward flow forming process of maraging steel via finite element simulations, The International Journal of Advanced Manufacturing Technology 87 (2016) 1851–1864.

Reliability design of mechanical systems subject to repetitive stresses

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The basic reliability concepts - parametric ALT plan, failure mechanism and design, acceleration factor, and sample size equation were used in the development of a parametric accelerated life testing method to assess the reliability quantitative test specifications (RQ) of mechanical systems subjected to repetitive stresses. To calculate the acceleration factor of the mechanical system, a generalized life-stress failure model with a new effort concept was derived and recommended. The new sample size equation with the acceleration factor also enabled the parametric ALT to quickly evaluate the expected lifetime. This new parametric ALT should help an engineer uncover the design parameters affecting reliability during the design process of the mechanical system. Consequently, it should help companies improve product reliability and avoid recalls due to the product failures in the field. As the improper design parameters in the design phase are experimentally identified by this new reliability design method, the mechanical system should improve in reliability as measured by the increase in lifetime and the reduction in failure rate.

Plane-strain fracture toughness of cured epoxy resins

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Cured epoxy resins are well known as quite brittle materials which have relatively low fracture toughness at room temperature or lower. Beside that, they have excellent adhesion properties as well as very good corrosion and chemical resistance. Therefore, cured epoxy resins are attractive materials which are widely applied in such branches of industry as automotive or aerospace. They are not only used as adhesives but also as coatings and especially as fiber reinforced (FRP) composites' matrices. High range of applications and variety of both epoxy resins and curing agents cause that it is truly significant to deeply analyze mechanical/strength properties of cured epoxy resins before use. Thus, it is very important to provide results of mechanical/strength tests for selected materials of this kind.In the study experimental examination on cured epoxy resins were presented. Various types of epoxies were subjected to Compact Tension (CT) test, which is a strength test based on mode I fracture, conducted in accordance with the ASTM D5045-14 Standard. Furthermore, a novel solution was provided by the authors to easily determine the Pq parameter needed for calculation of the plane-strain fracture toughness. Then, the results of plane-strain fracture toughness were set together with basic mechanical/strength properties, such as tensile modulus and stress-strain characteristics, as well as with static and dynamic fracture toughness, obtained in quasi-static three-point bending tests and Charpy dynamic impact tests, respectively. Moreover, the mean values of peak forces were taken into consideration in the case of different mechanical strength tests, including additionally the Double Cantilever Beam (DCB) test. Moreover, the acoustic emission (AE) equipment was used to register elastic waves parameters during CT test. Subsequently, the obtained AE data was analyzed with the Fast Fourier Transform (FFT) method and the Wavelet Transform (WT) and discussed in comparison to the strength tests' results.

Acknowledgements

This paper was financially supported by the Ministerial Research Project No. DEC-2016/21/B/ST8/03160 financed by the National Science Centre, Poland.

Ductile failure prediction during the flow forming process

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Flow forming is an incremental metal-forming technique used for manufacturing thin-walled seamless tubes where a hollow metal material flows axially along the mandrel by a rotating mandrel and multiple cylinders (see e.g. [1]). Flow formed materials are frequently used in the aviation and defense industry and it is crucial to examine the influence of the process on the material in terms of ductile fracture. There have been certain attempts to predict failure during flow forming with continuum damage models (see e.g. [2] for a recent example). However, the process requires in-depth failure analysis considering different process parameters and materials. The current study is concerned with investigating the ductile fracture behavior during a flow forming process which includes complex stress states in terms of stress triaxiality and Lode parameter. Ductile fracture is simulated through the modified Mohr-Coulomb model whose parameters are obtained from [3], for a preliminary analysis. A user material subroutine (VUMAT) has been developed to implement the plasticity behavior and the damage accumulation rule. The model is validated through finite element (FE) simulations performed in Abaqus/Explicit and using the experimental data in [3]. Fracture process is simulated with element deletion in explicit FE analysis. The validated framework is applied to a finite element model of a flow forming process. The initial results show a highly damaged region outside the specimen after 70% thickness reduction for the aluminum alloy. The modeling framework is planned to be applied using various process parameter for different materials.

Acknowledgements
The authors gratefully acknowledge the support by Repkon Machine and Tool Industry and Trade Inc.

References
[1] A. Karakaş, T.O. Fenercioğlu, T. Yalçinkaya, The influence of flow forming on the precipitation characteristics of Al2024 alloys, Materials Letters 299 (2021) 130066.
[2] A.K. Singh, A. Kumar, K. Narasimhan, R. Singh, Understanding the deformation and fracture mechanisms in backward flow-forming process of Ti-6Al-4V alloy via a shear modified continuous damage model, Journal of Materials Processing Technology 292 (2021) 117060.
[3] H. Granum, D. Morin, T. Børvik, O.S. Hopperstad, Calibration of the modified Mohr-Coulomb fracture model by use of localization analyses for three tempers of an AA6016 aluminium alloy, International Journal of Mechanical Sciences 192 (2021) 106122.

Structural integrity assessment of pressure vessel s with defects in welded joints

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Fracture mechanics approach for structural integrity assessment is described in the case of two pressure vessels for compressed air in reversible hydropower plant Bajina Basta in Serbia. The results of non-destructive testing indicated unacceptable defects on both vessels and set a base for application of FAD diagrams and risk based analysis. Risk matrix are applied with the aim of assessment and analysis of the integrity of the vessels. Installation and maintenance of pressure equipment to meet basic customer requirements involves a range of activities, starting from the project phase to the exploitation of the equipment until reaching a prescribed or expected working life, while at the same time taking into account all aspects: the structure, materials selection, quality of performance, manufacturing and testing, operating conditions and the monitoring and maintenance of the equipment. User requests that the equipment is functioning reliably, and that it maintains integrity during the expected life. In the case of damage as a result of load and working conditions, performed inspections and quality maintenance need to be assessed for their impact on the integrity of the working life. This paper analyses the integrity of a pressure vessel, made of NIOVAL 50, in the presence of defects in welded joints, found by non-destructive testing (NDT), mainly ultrasonic testing (UT). The presence of defects in welded joints and their effects of pressure vessels performance were analysed by using stress intensity factor, and structural integrity was assessed using Failure Assessment diagram (FAD) and risk matrix.

Acknowledgements
We acknowledge the support of Serbian Ministry for Education, science and technological development.

Numerical analysis of a micromechanics based cohesive zone model for ductile failure

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The micromechanism of ductile fracture phenomenon, i.e. nucleation, growth and coalescence of pores, is well established in the literature. One of the popular approaches to model ductile fracture numerically is cohesive zone modelling. However, its constitutive relations, or traction-separation laws, are mostly derived phenomenologically without considering the physical mechanism of crack initiation and propagation. In this context, the objective of this work is to develop and implement a physically motivated cohesive zone modelling framework for ductile fracture in metallic materials. In order to accomplish this, a micromechanics based traction-separation relation which considers the growth of a physical pore is developed based on the previous works [1-3]. Tractions are directly represented as a function of pore fraction, while its evolution is driven by separations. The model is implemented as an intrinsic cohesive zone model in a two-dimensional (2D) setting for mode-I, mode-II and mixed-mode fracture cases. The derivation of the mixed-mode case leads to a yield function representation of tractions and separations, instead of an explicit expression. Hence, an incremental implicit elasto-plastic numerical integration scheme is employed to solve mixed-mode system of equations. The framework is implemented as a user element subroutine in Abaqus (UEL) and the numerical simulations are conducted with compact tension (CT) and single edge notch (SEN) specimens to show the capability of the model and the influence of the micromechanical parameters such as pore size, shape and spacing on the ductile crack initiation and propagation. The work is concluded by presenting an outlook for the capability of the model to predict crack path (see [4]).

Acknowledgements

Tuncay Yalçinkaya gratefully acknowledges the support by the Scientific and Technological Research Council of Turkey (TÜBİTAK) under the 3501 Programme (Grant No. 117M106).

References

[1] T. Yalcinkaya, A. Cocks, Physics based formulation of a cohesive zone model for ductile fracture, in: Key engineering materials, volume 651, Trans Tech Publ, pp. 993–999.

[2] T. Yalçinkaya, A. Cocks, Micromechanical cohesive zone relations for ductile fracture, Procedia Structural Integrity 2 (2016) 1716–1723.

[3] T. Yalçinkaya, I. T. Tandogan, A. Cocks, Development of a micromechanics based cohesive zone model and application for ductile fracture, Procedia Structural Integrity 21 (2019) 52–60.

[4] İ. T. Tandoğan, Ductile fracture of metallic materials through micromechanics based cohesive zone elements, Master's thesis, Middle East Technical University, 2020.

Effects of fiber on the fracture behavior of 3D-printed fiber reinforced nylon

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Considering capabilities of additive manufacturing (AM), its application has been increased in numerous industrial and research projects. The three-dimensional (3D) printing techniques have been used for fabrication of prototypes and functional end-used products with complex geometries. 3D printing of continuous fiber reinforced compo-nents is a promising composite fabrication process which can be utilized in different industries. This paper evaluates the mechanical performance and fracture behavior of reinforced and non-reinforced parts fabricated by 3D printing technology. To this aim, nylon and glass fiber materials were used to print specimens based on material extrusion technique. The test coupons were designed with different raster directions and saved in ".stl" format, and later molten material was used to print the specimens in layers. Since there is a possibility to improve the strength of 3D-printed parts by incorporation of fi-bers, here we used glass fiber to increase the mechanical behavior of additively manu-factured parts. Based on a series of experimental practices, mechanical properties of reinforced and non-reinforced parts were determined. In detail, tensile strength, elastic modulus, and toughness were documented. In addition, effects of raster direction on the fracture resistance of the parts were determined and compared with that of non-reinforced parts. The outcome of this study can be used for design of 3D-printed fiber reinforced composite with superior fracture resistance.

Mechanical design and optimization of small-scale wind turbine blade

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The use of wind energy, one of the most important renewable energy resources, is increasing day by day. Due to the fact that the kinetic energy of the wind is taken by the blade and transmitted to the generator through mechanical elements, The first ring of the energy production chain in wind turbines is the blade. Nowadays, it is desired to design blades with the necessary strength, light weight and low production cost. Thus, the mechanical design and mechanical behavior of the blade have become much more important. In this study, the design and optimization of a small-scale wind turbine blade with a length of 1 m has been performed.For this purpose, Qblade and ANSYS Workbench software were used for the design and optimization of the blade. Analyzes have been made using the Qblade software and the preliminary mechanical design of the blade has been carried out by taking into account the mass, deformations and equivalent stresses on the blade. Fluid Structure Interaction (FSI) analysis of ANSYS Workbench software has been used to analyze the mechanical behavior (deformations, Stresses, failure analysis according to the theories namely Tsai-Wu.) of the blade in extreme working condition. Afterwards, an optimization has been made in the Response Surface Optimization module of the ANSYS Workbench software, taking into account the mechanical behavior analysis. As a result of the optimization process, the blade design with the necessary strength and light weight made of E-Glass epoxy material have been performed.

Phase field vs Gradient enhanced damage models: A comparative study

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A comparison of the two different approaches for modelling damage in material in an infinitesimal strain setting is studied. The first approach is the phase field damage model where a Helmholtz free energy density function is considered that incorporates a new energy degradation function along with a phase field non-conservative order parameter. The variational derivative of this free energy functional with respect to the non-conserved order parameter field must reach a stationarity value resulting in the Allen-Cahn equation. The relation between the order parameter and the damage variable defines this Allen-Cahn equation as the evolution equation for damage. The second approach is the nonlocal gradient enhanced damage model where the damage variable is taken as an independent variable which will be determined based on the local strain measure. Here, the nonlocal integral form is approximated to an implicit or explicit differential form using the Taylor's series expansion for simpler numerical implementation. A 1D bar example is considered for commenting on the similarities and differences of the two approaches to damage based on the mesh convergence studies based on h-refinement, length scale parameter studies and the damage profile.

Study on dynamic crack propagation in brittle materials using phase-field model

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Keywords: Phase-field method, Dynamic brittle fracture, Hybrid formulation, Staggered scheme.

The dynamic crack propagation and branching in a brittle material are studied using the phase-field method. The phase-field method uses a length scale parameter to regularize the discrete crack to a diffuse crack and can also be interpreted as a damage-gradient model. The displacement field is coupled with the phase-field, and both are solved as sequentially coupled systems using the staggered method. The scalar phase-field varies between zero and unity (zero for the intact region and unity for the fully broken region). In this study, a new way of implementation is done using ABAQUS software to solve for the two fields. Some benchmark examples of dynamic brittle fracture are solved and verified with the existing numerical results. Numerical results show that when a crack accelerates, the damaged band tends to widen perpendicular to the propagation direction before forming two distinct macroscopic branches.

The influence of thickness / grain size ratio in micron sized sheet specimens through CPFEM calculations

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Microscale forming operations have become quite popular due to miniaturisation which focuses on micro scale design and manufacturing of devices, components and parts, e.g. in RF-MEMS. In such processes when the component dimension becomes comparable with the grain size, considerable size effect is observed. Recent experimental studies on micron sized sheet specimens have shown that the ratio between thickness (t) and grain size (d) has a significant influence on the mechanical behavior of materials which cannot be explained merely with the intrinsic (grain) size effect. Even though the grain sizes are similar, remarkable differences in mechanical response is obtained for different cases with different thicknesses. In this context, the aim of the current study is to address this extrinsic type size effect through crystal plasticity simulations (see e.g. [1]). A series of local crystal plasticity finite element simulations are conducted for different values of t/d ratio in tensile specimens. Different granular morphologies of polycrystalline samples are generated using Voronoi tessellation and tested axial loading conditions (see e.g. [2]). The effect of varying t/d ratio, the grain morphology and the texture on stress-strain response are examined for the micron sized sheet specimens to address the influence of the t/d on microstructure evolution and macroscopic constitutive response.

References

[1] T. Yalcinkaya, W.A.M. Brekelmans, M.G.D. Geers, BCC single crystal plasticity modeling and its experimental identification, Modelling and Simulation in Materials Science and Engineering 16 (8) (2008) 085007.

[2] T. Yalcinkaya, S.O. Çakmak, C. Tekoğlu, A crystal plasticity based finite element framework for RVE calculations of two-phase materials: Void nucleation in dual-phase steels, Finite Elements in Analysis and Design 187 (2021) 103510.

Weak form of peridynamics for modeling composite materials

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Composites exhibit distinct strength properties along different orientations. Therefore, their properties can be tailored as necessary in order to achieve desirable strength-to-weight ratio and light weights. However, their numerical modeling for failure prediction is still a challenging task due to their complex damage patterns and heterogeneous nature. The damage in composite structures may take place in different forms such as fiber breakage and delamination depending on the fiber orientation, loading, and boundary conditions. Hence, understanding the damage behavior composite structures under loads is very crucial for their structural integrity. The prediction of the failure modes of the composite structures is a challenge for the classical computational methods such as finite element method (FEM). Peridynamic (PD) theory introduced by Silling [1] is extremely suitable for failure prediction. The PD equilibrium equations are expressed in the form of integral of spatial derivatives incorporating the interaction of material points within a finite distance. The damage in PD analysis is introduced through the removal of interactions. Therefore, the crack nucleation and propagation can be investigated at multiple sites with arbitrary paths in the structure. Madenci et al. [1,2] introduced weak form of PD equations of motion for failure analysis of materials. The weak form of PD equation of motions provides computational efficiency and enables the direct imposition of natural and essential boundary condition. This study concerns the failure analysis of composite materials by using the weak form of PD equations of motion. The capability of the present approach is demonstrated by considering a composite lamina having different fiber orientations with and without a defect in the form of a crack under tensile loading. Crack nucleation and growth are based on the maximum principal stress and visibility criteria.

References

[1] E. Madenci, M. Dorduncu, A. Barut, and N. Phan, Weak form of peridynamics for nonlocal essential and natural boundary conditions. Comput Method Appl M, Vol. 337, pp. 598-631, 2018.
[2] E. Madenci, A. Barut, and M. Dorduncu. Peridynamic differential operator for numerical analysis, 1st Edition, Springer, 2019.

Impacted area description effect on strength of laminate determined by calculation

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All machine parts go through a number of processes during their lifetime. This is independent on the material which they are made of. The service life factor is influenced by production technology, the method of assembly, surface treatment, operating conditions and the whole range of planned or less expected load cases. During the period of use, a large or small number of damages can occur and the influence must be considered in terms of the impact on the further safe use. The group of expected damage of a smaller extent with relationships to service life also includes poorly identifiable damage caused by a collision with fast moving objects. Numerical simulation helps to rate the severity of the next situation. The main goal of this work was to assess the influence of case idealization of the impacted area on the result of the laminate test specimen strength, which was acquired from calculation. The article is focused on simulation of composite specimen impact test in accordance with ASTM D7136 standard. The specimen size was 250 mm long and 100 mm wide with the thickness 1.584 mm. It consisted from12 plies of unidirectional carbon fibre in polymer matrix. Samples were impacted to the unsupported plate centre by hemispheric impactor with dimeter 12.7 mm in range of energy from 1 to 10 Joules. After that, the initial stiffness and strength was compared with properties of damaged samples and influence of damaged area model description was studied. The calculations performed with ABAQUS software were part of a broader set of analyses, that preceded the demonstrated experiments. The effects of the presented simplifications were investigated mainly due to possible calculations with the help of linear solvers, which could be useful in post-impact analysis.

In-plane shear and interlaminar fracture toughness properties of MWCNT stitched para-aramid/phenolic nanocomposites

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In-plane shear and mode–II interlaminar fracture toughness properties of three-dimensional nanostitched para-aramid/phenolic composites were experimentally investigated. Introducing the nanostitched fiber into nanocomposites slightly enhanced their shear strengths and the interlaminar fracture toughness (GIIC) due to the through-the-thickness reinforcement which was provided by micro filament TOWs and nanotubes.In-plane shear failure mode was predominantly micro shear hackles in the matrix; debonding and later stage fiber pull-out between filament TOWs and matrix in the interface; fibrillar peeling and stripping on the filaments due to angular deformation. However, the failure mode of interlaminar fracture toughness was mainly shear hackles in the interlayer region of the nanostitched composite. Cracks grew in the inter and intra TOWs boundaries where the resin was fractured half way around each yarn cross-section and micro cracks moved to the through-the-thickness of the composite. At the blunt crack tip, carbon nanotubes in the phenolic resin and filament TOWs probably reduced the stress clustering via friction/debonding/pull-out/sliding as a form of stick-slip. These failure mechanisms probably arrested the crack growth and suppressed delamination in the through-the-thickness fiber reinforced zone. As a result, nanostitched para-aramid/phenolic composite structures showed damage tolerance behavior compared to the pristine composite.KeywordsMultiwall carbon nanotubes, para-aramid fabric, nanoprepreg, nanostitching, in-plane shear, mode-II fracture toughness.

Acknowledgements
This work was supported by Roketsan Industries with Grant No. RS/ERCİYES DSM-76301-14-01N/R. The authors would like to thank this valuable grant. In addition, the authors would like to thank Prof. Dr. M. Tanoglu and Research assistant Serkan Kangal for the In-plane shear and ENF tests. In addition, they would like to thank the Erciyes University Technology Research and Implementation Center (TAUM) for the SEM photos.

A multi-scale framework towards prediction of the martensite/ferrite interface damage initiation

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Martensite/ferrite (M/F) interface damage largely governs failure of dual-phase (DP) steels. In order to predict the failure and access the ductility of DP steels, appropriate models for the M/F interfacial zones are in demand. Several M/F interface models have been proposed in the literature, which however do not employ consistent descriptions for the interfaces at different scale levels. Moreover, it has been recently suggested that the martensite substructure boundary sliding dominates the M/F interface damage initiation and therefore should be taken into account. Towards addressing these aspects, a multi-scale modelling framework for the M/F interfacial zones is developed in this work. Two scales are considered: the DP steel mesostructure consisting of multiple martensite islands (martensite/austenite laminates) embedded in a ferrite matrix and the microscopic M/F interfacial zone resolving the martensite substructure. Within the damage initiation regime, a deformation jump across the M/F interface is introduced besides the homogeneous deformation gradient, enabling to describe the complete mesoscopic interfacial zone kinematics. By accounting for the interface microstructure, applying the meso-to-micro scale transition yields customized interface periodic boundary conditions (IFPBC), used to complement the microscopic boundary value problem (BVP). The effective stress and deformation jump are obtained by upscaling the microscopic BVP solution, to provide a consistent coupling to the mesoscopic kinematics. To enable prediction of the mesoscopic M/F interface damage, a set of effective interface damage indicators are additionally defined. Making use of the substructure boundary sliding mechanism and assuming that before the interface damage initiates, the M/F interface response has limited contribution to the DP steel mesostructure overall response, allow to reduce the multi-scale framework towards a microphysics-based M/F interface damage indicator formulation, which quantitatively correlates the interface damage initiation and the sliding activity. The main features of the homogenization framework (without reduction) are demonstrated using numerical examples of a representative microscopic M/F interfacial zone unit cell, followed by model reduction unified for the smooth interfacial morphology with different interface orientations. This formulated interface damage indicator is applied to a DP steel mesostructure with multiple martensite islands, exhibiting considerable advantages for predicting the mesoscopic M/F interface damage initiation.

Acknowledgements

This research was carried out under project number T17019d in the framework of the research program of the Materials Innovation Institute (M2i) (www.m2i.nl) supported by the Dutch government.

Multiscale deformation-induced surface roughness in polycrystalline metals and its correlation with plastic strain

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The key challenge for materials science and mechanical engineering is to predict plastic strain localization and fracture long before these processes become evident on the macro scale. Many efforts have been made to identify early precursors of plastic strain localization preceding fracture. In this paper we present an approach to early prediction of macroscale plastic strain localization from observations of deformation-induced surface roughening. Experimental and numerical investigations are performed to reveal a correlation between multiscale surface roughness and local plastic strains in uniaxial tension. The analyses show that roughening intensifies on a larger scale when smaller length scale deformation mechanisms are exhausted. A particular attention is given to the mesoscale where grains are united into clusters to form surface undulations. A dimensionless parameter is introduced to quantify mesoscale roughness patterns, which appears to be fairly sensitive to and well correlated with the local strain values. Particularly, it begins to increase nonlinearly in the place of necking well ahead of the visible plastic strain localization.

Acknowledgements
This work is supported by Russian Science Foundation (Project No. 20-19-00600).

Ductile fracture and its implication on pressurized transmisison line pipes

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The efficient and effective movement of natural gas from producing regions to consumption regions requires an extensive and elaborate transportation system. The transportation system for natural gas consists of a complex network of pipelines, designed to quickly and efficiently transport natural gas from its origin, to areas of high natural gas demand. Defective pipes might reduce safety and reliability of the system during operation. The occurrence of crack-like defects on the pipe surface (inner or outer) as a result of manufacturing process or operating conditions represent one of the main cause of accidents which not only brings environmental catastrophic consequences but also human life losses. Therefore, the ductile fracture propagation control is an essential element of the pipeline design. In this seminar, a coupled fluid-structure interaction modelling is presented to simulate the dynamic ductile fracture in steel pipelines. The proposed model couples a fluid dynamics model describing the pipeline decompression and the fracture mechanics of the deforming pipeline exposed to internal and back-fill pressures. The coupled Euler-Lagrange (CEL) method is used to link the fluid and structure models. In a Lagrange formulation, the modified Mohr-Coulomb (MMC) model describes the plastic deformation and ductile fracture as a function of the underlying stress/strain conditions. The effect of plastic anisotropy on fracture mechanics parameter CTOA is also investigate. The proposed methodology has successfully been applied to simulate full-scale pipeline burst tests on API X65 steels available in the open literature.

Hydrogen concentration near a crack tip considering plastic strain influence on trapping features

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Modelling hydrogen assisted cracking is one of the most prominent challenges in predicting hydrogen embrittlement phenomena. Prognosis and mitigation of these common failures are crucial for many industries where hydrogen is handled or is formed as a by-product. In order to assess crack initiation and propagation, damage models accounting for hydrogen effects must reproduce the transient effects that uptake and diffusion involve. Here, the relationship between plasticity and trapping phenomena is revisited from two approaches: trapping characterisation and crack tip modelling. The plastic influence on trap densities and binding energies is usually calibrated with electro-permeation tests on pre-strained thin samples, finding an average trapping value that fits permeation delay. However, the representativity of this value is discussed assuming non-homogeneous plastic strain in membranes and the likely presence of residual stresses, especially for sheets that have been cold-rolled in order to achieve large plastic deformation values. A 1D permeation model with stress and strain distributions is simulated to delimit the range of validity of the averaging approach. Then, the implications of inaccurate trap density fitting are illustrated by simulating hydrogen concentration near a crack tip, where hydrogen trapped in dislocations is assumed to be diffusible and to contribute to the embrittlement micro-mechanism. Additionally, a coupled framework is implemented following hydrogen-enhanced localised plasticity theories where softening-induced laws depend on hydrogen concentration.

Acknowledgements
The authors gratefully acknowledge financial support from the Ministry of Economy and Competitiveness of Spain through grant RTI2018-096070-B-C33.

Simulation of 13° wheel impact test using Johnson-Cook failure model

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Keywords: Wheel, Impact Test, Johnson Cook.

In this study, It was examined that the physical results of the wheel impact test can be validated in simulation environment using the finite element method (FEM) and Johnson Cook failure model. Wheels play critical role for a vehicles.Wheel is safety equipment beside being aesthetic part that works under different dynamic and static cyclic loads. For this reason, wheels are tested in challenging conditions. Many failures occur in wheel impact tests that cause design changes and wasting time. Therefore, prediction of the wheel impact test failures within simulation at design stage, have many advantages such as shorter project time, lower production cost, less trials. Wheel impact tests are done in accordance with ISO 7141 standart[1]. Wheel samples with negative (fail) and positive (pass) results in 13° impact test were considered. Wheel material is AlSi7Mg (A356). Johnson-Cook failure model is used to predict possible fractures[2]. A356 Johnson-Cook material parameters taken from literature [3]. Simulation model created and performed with explicit solver LS-Dyna in ANSYS 2021 R1 version[4]. When the simulation results compared with physical results, all fractures and damaged areas on the wheels with negative results were seen at exactly same areas. Similarly, no plastic deformation was seen on wheels with positive results. Finally, 13° wheel impact test model was validated with simulation also by using the finite element method and Johnson-Cook failure model.

References

[1] TSE. (2017). Turkish Standard. Türk Standartlar Enstitüsü, 15189(112).
[2] Wang, X., & Shi, J. (2013). Validation of Johnson-Cook plasticity and damage model using impact experiment. International Journal of Impact Engineering, 60(October), 67–75.
[3] Gupta, S., Abotula, S., & Shukla, A. (2014). Determination of johnson-cook parameters for cast aluminum alloys. Journal of Engineering Materials and Technology, Transactions of the ASME, 136(3).
[4] LS-DYNA Keywords User's Manual

Comparison of peridynamics and lattice dynamics wave dispersion relationships

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Peridynamics [1-6] is a new continuum mechanics formulation. Peridynamic equations of motion are integro-differential equations and they do not contain spatial derivatives as opposed to classical continuum mechanics which uses partial differential equations. This brings a significant advantage to predict crack initiation and propagation since the displacement field is discontinuous if cracks exist in the structure and spatial derivatives are not defined along the crack surfaces. Moreover, peridynamics is a non-local continuum formulation so that material points inside an influence domain, named horizon, can interact with each other. Horizon is a length scale parameter which doesn't exist in classical continuum mechanics. Finally, peridynamics has a capability to represent wave dispersion which is observed in real materials especially at shorter wave lengths. Therefore, wave frequency and wave number has a non-linear relationship in peridynamics. In this study, we present wave dispersion characteristics of peridynamics and compare with lattice dynamics.

Acknowledgements
This material is based upon work supported by the Air Force Office of Scientific Research under award number FA9550-18-1-7004.

References
[1] Silling, S.A., 2000. Reformulation of elasticity theory for discontinuities and long-range forces. Journal of the Mechanics and Physics of Solids, 48(1), pp.175-209.
[2] E. Madenci and E. Oterkus, Peridynamic theory and its applications, New York: Springer, 2014.
[3] Madenci, E., Barut, A. and Dorduncu, M., 2019. Peridynamic differential operator for numerical analysis. Springer International Publishing.
[4] Imachi, M., Tanaka, S., Bui, T.Q., Oterkus, S. and Oterkus, E., 2019. A computational approach based on ordinary state-based peridynamics with new transition bond for dynamic fracture analysis. Engineering Fracture Mechanics, 206, pp.359-374.
[5] Basoglu, M.F., Zerin, Z., Kefal, A. and Oterkus, E., 2019. A computational model of peridynamic theory for deflecting behavior of crack propagation with micro-cracks. Computational Materials Science, 162, pp.33-46.
[6] Zhu, N., De Meo, D. and Oterkus, E., 2016. Modelling of granular fracture in polycrystalline materials using ordinary state-based peridynamics. Materials, 9(12), p.977.

Influence of the unit cell connecting in the metamaterial on its deformation properties

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Metamaterials are materials whose properties are determined not so much by their chemical composition as by their structure. There is a difference between material and metamaterial. The material is based on a strictly ordered arrangement of atoms in a lattice, whereas in a metamaterial the unit cells consist of larger structural elements. Mathematical finite element modeling is appropriate for predicting the deformation behavior of a mechanical metamaterial sample. The purpose of this paper is to investigate the knowledge gap on the effect of the way how the unit cells of the mechanical metamaterial are connected in a three-dimensional sample on its deformation behavior using numerical simulations.We examined the static loading of a set of the metamaterial unit cells within the framework of the linear theory elasticity for the case of three-dimensional homogeneous chiral cell structures, which have been the subject of recently published numerical studies on mechanical metamaterials. We found that strains are localized in the ring elements of chiral structures and are not localized in the ligaments. Two methods of connecting unit cells are considered («joining» and «overlapping»). The advantages and disadvantages of each of the connecting methods in the system consisting of two cells were described. It was shown that equivalent stresses occur when two cells influence each other in the «joining» method. Strain and stress analysis make it possible to estimate dangerous places of potential fracture in mechanical metamaterial samples.In a general sense, the dream of materials science is to design materials rationally to avoid tedious trial and error experiments.In this paper, a new type of metamaterial cell connection is developed by eliminating anti-twisting edges and understanding the direction of motion of the constituent structures. When the metamaterial is subjected to uniaxial loading directed along the rod, cell deformation will cause the chiral structures to rotate. We believe that this technological advancement will allow the required mechanical behavior to be achieved in the future according to customer requirements.This work is a step in the challenge of optimizing the microstructure of metamaterials. It will be interesting to see full-scale experiments in the future.

Acknowledgements
The work was performed according to the Government research assignment for ISPMS SB RAS, project FWRW-2019-0035.

Numerical study of the texture effect on deformation-induced surface roughening in α-titanium

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The effects which the texture severity has on the micro- and mesoscale deformation behavior of titanium specimens subjected to uniaxial tension are investigated numerically. For this purpose, three-dimensional models taking an explicit account of the grain morphology and crystallographic orientations of grains are developed in terms of the crystal plasticity theory. Four sets of Euler angles simulating the basal texture of different severity are assigned to the model microstructures generated by the method of step-by-step packing. The prismatic axes of hexagonal grains deviate within $\pm 10^o$, $\pm 20^o$, $\pm 40^o$ and $\pm 60^o$ from the direction normal to the free surface. The boundary-value problems are solved within a dynamic approach using the ABAQUS / Explicit finite-element package. To validate the model developed, the stress-strain curve calculated for the model where the prismatic axes of hexagonal grains deviate within $\pm 40^o$ from the direction normal to the free surface is compared with the experimental curve obtained for the specimen with the same texture. The difference between these curves does not exceed 3%. Based on the calculation results, conclusions are drawn about the effect of the severity of a basal texture on the stress-strain evolution and deformation-induced surface roughening in α-titanium specimens under loading.

Acknowledgements
This work is supported by Russian Science Foundation (Project No. 20-19-00600).

Crack propagation modelling for service life prediction of large slewing bearings

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Slewing bearings in wind turbines are meant to last 20 years or longer. But wind turbine accidents (structural failure) occur nevertheless. Is the climate change and the more extreme weather phenomena a risk? Or do the bearings have a weak spot due to design or material defects? Minimising the risk and with this enhancing the public acceptance of those turbines is of great importance. For a more accurate prediction of the service life of slewing bearings XFEM calculations with crack initiation and crack propagation are investigated. Using Abaqus XFEM a simulation model for crack propagation was developed. The material parameters such as Paris coefficients for crack propagation and fracture toughness values (KIC) were measured in advance on samples in different heat treatment conditions, corresponding to different regions of the bearing, namely core, induction hardened raceway, and a transition region.With the linear elastic fracture mechanics approach the local stress intensity factor range Delta K for a given starting crack front is calculated. Coupling this information with the Paris-law and a maximum crack propagation interval of 0.1-0.3 mm, the number of cycles is determined. The crack is then extended stepwise until Delta K reaches the limiting fracture toughness of the material, when violent rupture of the material takes place. The crack propagation model was first checked on different test specimen geometries. Correlating these first test results with experimental data helped to adjust the model and verifying the simulation provides correct data. In addition the crack initiation phase can be estimated. For example, by simulating the load cycle number during the crack propagation phase of the rotating bending specimens, the load cycle number required for crack initiation can be derived on the basis of the experimentally determined S-N-curves.The simulation of real components, such as bearings, will be developed subsequently, using calculated stress distributions provided by other project partners as input parameters (sub-structure approach). Possible crack initiation locations are defined 1) on the basis of detected damage that occurred on older bearings in service, 2) on the basis of calculated local excess stresses in the bearing.The results suggest that for the investigated wind loads and considering the design specifications regarding fabrication and material properties, no early fatigue failure of the bearings is expected. Bearing failure is most likely promoted by an unfavorable combination of overloads and corrosion damage.

Acknowledgements
Supported by Federal Ministry for Econimc Affairs and Energy on the basis of a decision by the German Bundestag. Funding reference number: 0324303E.

Determination of the safety margin on the ductile-fragile transition temperature after introduction of hydrogen into pipelines

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Hydrogen embrittlement is a phenomenon that affects the mechanical properties of steels intended for hydrogen transport. One affected by this embrittlement is the ductile brittle transition temperature, which characterise failure mode modification for a steel from ductile to brittle. This temperature is conventionally defined and compares to service temperature as acceptability criterion for codes. Transition temperature does not depend only on material, but also on specimen geometry particularly the thickness. This phenomenon is attributed to plasticity constrain described by several parameters as the effective stress T, the out-of-plane stress Tz and the parameter Ap related to the surface covered by plastic deformation iso-lines. Generally, the transition temperature is defined for conservative reason by Charpy impact test. Standard Charpy specimens are straight beams with a thickness of 10 mm. For thin pipes, it is impossible to extract this type of standard specimens. One uses in this case Mini-Charpy specimens with a reduced thickness due to pipe curvature. The use of Roman tiles, curved specimens extracted directly from the pipes allows to obtain specimens with the plain pipe thickness and reduces machining time and cost. This paper aims to quantify the effect of hydrogen embrittlement on the transition temperature of a pipe steel (API 5L X65) as well the effect of Charpy specimen thickness. Three plastic constrain parameters (Teff, Rp and AP) are computed in order to get a linear correlation between plastic constrain and the shift of the transition temperature. Interest of roman tile specimens is unlight by comparison with standard and mini Charpy specimens.

Micromechanical analysis for the deformation behavior of additive aluminum alloys

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Additive manufacturing (AM) as one of the most promising technique for metal part producing has been experiencing a powerful development over the last decade. Among AM techniques, selective laser melting (SLM) is one of the most used in producing complex-shaped aluminum alloy components which are characterized by a microstructure with a various type of grain geometry and crystallographic orientations. Despite a great potential of the additively produced parts in a various range of fields, their industrial application is still limited due to many unsolved R&D problems. One of the limitations involves the poorly understood microstructure-to-property linkage of additive aluminum alloys. The present contribution aims to numerically investigate the micromechanical response of an SLM AlSi10Mg alloy under uniaxial tension along three different axes. The microstructural model is simulated by the cellular automata finite-difference (CAFD) method based on the numerical solution of the heat transfer problem coupled with cellular automata to model solidification. This approach allows describing the microstructural features associated with the technological parameters of SLM. The constitutive equations of the grain behavior are formulated within the crystal plasticity framework. The boundary value problem is solved in the finite element package ABAQUS / Explicit using the VUMAT procedure. The stress and plastic strain fields analyzed at the grain scale demonstrate significant anisotropy. Statistical analysis of the stress-strain states reveals two dominant stress levels associated with the presence of a cube texture in the melt pool centers and randomly oriented grains in the hatch overlap regions. The uniaxial tension is shown to lead to a complex stress-strain state at the grain scale where the stress tensor components acting perpendicular to the loading axis make a significant contribution to the overall material response.

Acknowledgements
This study was performed in accordance to the Government research assignment for ISPMS SB RAS and under financial support of Deutsche Forschungsgemeinschaft PL 584/4-1.

A viscoelastic anisotropic phase-field fracture model to predict fatigue fracture in the polymer matrix composites

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Polymer matrix composites are suitable candidates for replacing traditional metals and their alloys in the automotive and aerospace industries due to their lightweight, tunable properties and reduced emission characteristics. However, due to the inherent nature of the application, these materials often find themselves working under varying temperatures, pressure, and cyclic loading setting, such as inside of an engine. Therefore, fatigue studies of these materials are crucial to predict their lifetime accurately prior to the application stage. In this work, we present a thermodynamically consistent, coupled viscoelastic phase-field fracture theory to model fatigue-induced damage in the fiber-reinforced polymer matrix composites. The composite RVE is taken as a mixture of fibers and matrix, represented by the fiber volume fractions and their respective orientations. We use a homogenized constitutive theory to treat the composite as a highly anisotropic material to capture its rate-dependent behavior under large deformation. Based on the theory of anisotropic hyperelastic material, we use an invariant-based approach to account for the anisotropic constitutive response. In what follows, we model the progressive cracking in the composite material using an anisotropic phase-field fracture theory, building upon an energy-based anisotropic failure criterion. We obtain the model parameters by fitting the available experimental data from the existing literature. We implement our model by writing a user element subroutine (UEL) in the commercial FE software ABAQUS/Standard and show some representative numerical simulations relevant to the composite fatigue study. The model can predict typical fatigue behavior of composites such as loss in stiffness, crack initiation and growth under Mode-I, Mode-II, and mixed-mode loading tests under different fiber orientations and volume fractions cases.

Crystal plasticity finite element analysis of twist extrusion processes

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Keywords: CPFEM, Twist extrusion process, Texture Analysis.

In order to produce ultrafine-grained materials various types of severe plastic deformation (SPD) processes depend on simple shear deformation mode which has a deep impact on the texture evolution inducing pronounced influence on the plasticity behavior of metallic alloys. Twist extrusion (TE) is a non-uniform and non-monotonic severe plastic deformation method, which leads to major microstructural changes. Previous studies show that TE process can be used for producing uniform weak textures in pre-textured copper. Besides that, commercialization for industrial usage has been limited because of production efficiency and non-uniform distribution of grain refinements. In the meanwhile, the technique has been improved to have better performance in the microstructure evolution e.g. a recently developed nonlinear twist extrusion procedure (NLTE) [1]. NLTE method is designed by modifying the channel design of the mold in twist section to restrain strain reversal and rigid body rotation of workpiece which are known as disadvantages of twist extrusion. In the current work, the texture evolution during nonlinear twist extrusion (NLTE) and conventional, linear twist extrusion (LTE) are investigated through local crystal plasticity fine element computations (see e.g. [2,3]). Single copper crystal which has a billet form is fully extruded through the TE and NLTE mold models separately. In addition to spatial stress and strain evolution, the orientation differences and texture evolution of extruded billets are examined with respect to two different initial orientations i.e. (<111> and <100>). Moreover, the deformation histories of certain surface and inner elements are analyzed to compare the performance of TE and NLTE SPD processes.

References

[1] T. Yalçinkaya, Ü. Şimşek, H. Miyamoto, M. Yuasa, Numerical Analysis of a New Nonlinear Twist Extrusion Process, Metals 9(5) (2019) 513.

[2] B. Güler, Ü. Şimşek, T. Yalçinkaya, M. Efe, Grain-scale investigations of deformation heterogeneities in aluminum alloys, AIP Conference Proceedings 1960 (2018) 170005.

[3] T. Yalcinkaya, S.O. Çakmak, C. Tekoğlu, A crystal plasticity based finite element framework for RVE calculations of two-phase materials: Void nucleation in dual-phase steels, Finite Elements in Analysis and Design 187 (2021) 103510.

Evaluation of aging related degradation mechanisms due to neutron irradiation on reactor vessel internals

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Since ASS (Austenitic Stainless Steel) and associated weld materials have been mainly used to RVIs (Reactor Vessel Internals), they experience harsh environment including neutron irradiation. If the effects accumulate after prolonged exposure to such an environment, ASS materials may undergo changes in micro and macroscopic behaviors due to irradiation induced ARDMs(Age-Related Degradation Mechanisms) [1, 2]. In this regard, many researches on variety of mechanical and fracture properties have been carried out [3]. Also, constitutive models for ASS materials taking into account ARDMs such as IE(Irradiation Embrittlement), VS(Void Swelling) and IC(Irradiation enhanced Creep) have been proposed and revised based on experimental data for management and assessment [4-6]. In this study, analytical evaluations were performed considering the mechanical property changes and ARDMs for the ASS weld part. In the evaluation, loading conditions such as WRS (Weld Residual Stress), operating conditions and gamma heating were considered, and user subroutine was incorporated with FE analysis to reflect IE, VS and IC. The detailed simulations were conducted, and, not only variations of von Mises stress and strain but also VS distributions were also examined sequentially. Furthermore, fatigue crack growth evaluation was carried out based on ASME B&PV code section XI[7] considering stress distribution at a location of postulated crack from the FE analysis.

Acknowledgements
This research was supported by the project "Evaluation of structural integrity of reactor vessel internals considering irradiation damage and seismic load" of the Korea Hydro & Nuclear Power Co., Ltd, Central Research Institute.

References

[1] Rao, A. S. 2014. Degradation of austenitic stainless steel (SS) light water reactor (LWR) core internals due to neutron irradiation, Nuclear Engineering and Design, 269, 78-82.
[2] NUREG/CR-7027, 2010. Degradation of LWR core internal materials due to neutron irradiation.
[3] NUREG/CR-4513 Rev. 2. 2016. Estimation of fracture toughness of cast stainless steels during thermal aging in LWR systems.
[4] Materials Reliability Program-135, Rev.2. 2019. Development of material constitutive model for irradiated austenitic stainless steels.

[5] Materials Reliability Program-230, Rev. 2. 2012. Functionality analysis for westinghouse and combustion engineering representative PWR internals.
[6] Materials Reliability Program-211, Rev. 1. 2017. PWR internals aged-related material properties, degradation mechanisms, models, and basis data-state of knowledge.
[7] ASME Section XI, 2015. Rules for inservice inspection of nuclear power plant components, ASME Boiler and Pressure Vessel Code.

Damage and fracture in aluminum structures

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This research introduces a numerical model for describing damage processes and fracture in a severely strain-hardened aluminum alloy. The macroscopic phenomenology and fracture mechanisms of sheet-metal specimens as well as thin-walled structures have been studied experimentally and numerically for various loading conditions. The model's essential feature is capturing different fracture mechanisms under various stress states. This has been accomplished by introducing a stress state dependent damage variable in the elasto-plastic constitutive behavior. A custom material model with nonlocal regularization has been implemented into commercial finite element software. The model has not only been applied to modeling uncracked and pre-cracked alloy specimens, but has also been put at test in a complex loading scenario occurring in a real world mechanical component. The model's true predictive ability has been assessed thereby. The model predictions for various geometrical as well as loading scenarios are found to be in very good agreement with experimental findings. This has been accomplished even for fundamentally different damage and fracture processes without any changes of the material model. Furthermore, a simplified method for determination of material constants has been introduced that assists traditional inverse identification of parameters by artificial intelligence based on machine learning methods. All research findings together encourage the general use of the constitutive model for the design of aluminum and other sheet-metal structures.

Acknowledgements
The authors gratefully acknowledge the financial support under the scope of the COMET program within the K2 Center "Integrated Computational Material, Process and Product Engineering (IC-MPPE)" (Project No 859480). This program is supported by the Austrian Federal Ministries for Climate Action, Environment, Energy, Mobility, Innovation and Technology (BMK) and for Digital and Economic Affairs (BMDW), represented by the Austrian research funding association (FFG), and the federal states of Styria, Upper Austria and Tyrol.

Influence of aspect ratio (AR) on the necking angle of tensile specimens for different alloys

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Tensile testing is a mechanical test used to determine the uniaxial mechanical properties of materials under tensile loading with different strain rates. The results obtained from tensile tests can provide basic material properties such as, yield strength (YS), ultimate tensile strength (UTS) and elongation information. In the late stages of a tensile test, the process of necking – fracture is needed to understand the material's fundamental behaviour. For a tensile bar with a rectangular cross-section, there are two necking modes: diffused necking and localized necking [1]. The necking mode can possibly be predicted using the necking angle. The transition between them is depends on the aspect ratio (AR) of the bar. This work aims at determining the influence of aspect ratio (AR), the ratio of the specimen width to thickness, on the necking angle of a tensile specimen. The outcome of this research can help us to further understand the different modes of necking: diffused necking and localized necking. This becomes more important tensile specimen dimensions are miniaturised. The necking angle θ is defined as the angle between the fracture surface and the pulling direction: $\cos 2\theta = -3/(1+2k)$, where k is the ratio of strain in the thickness and width directions and is a good indicator of specimen size effects on mechanical properties [2]. This work was conducted through both experiments and numerical simulations. Three steels were selected: DP800, DP600 and 316L stainless steel. For DP800 and DP600 tensile specimens were manufactured by Electrical Discharge Machining (EMD) and for the 316L stainless steel tensile specimens were made by Additive Manufacturing (AM) using a Renishaw AM400 machine. The experimental results were used to calculate parameters used in a damage model. Digital Image Correlation (DIC) was adopted and the results were used to compare with simulation results as a validation. For simulation, different aspect ratio values were selected and the necking behaviour is discussed in detail. Some initial results were obtained as shown in Fig.1 and 2. The results show that necking increases with decreasing AR values, in agreement with previous publications, [1,2]. The equivalent plastic strain distribution prior to fracture in FEM results is similar to that in the experiments measured using the DIC method. These give confidence in the method and further results are being collected.

Acknowledgements

The authors would like to thank EPSRC for funding the Rapid Alloy Prototyping Prosperity Partnership project (EP/S005218/1 - ACCELERATING ALLOY DEVELOPMENT THROUGH DELIVERING NOVEL PROTOTYPING SOLUTIONS) which made this work possible. The authors would also like to thank the Welsh Government, European Regional Development Fund (ERDF) and SMART Expertise Wales for funding Materials Advanced Characterisation Centre (MACH1) where the work was carried out.

Failure detection in hole expansion test using plastic work citerion

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Although the uniaxial tensile test gives information about the formability limits of the material, for certain materials showing a considerable amount of strain localization, sophisticated formability tests are required to obtain the stretch formability limit of the material. Hole expansion test is a process performed to obtain the formability limit considering the stretching conditions of a sheet with a hole. For automotive industry, this feature has a crucial role in the reliability of the engineering parts exposed to the several stretching modes. In the present study, the hole expansion process of twinning induced plasticity (TWIP940) and transformation induced plasticity (TRIP540) steel sheets were simulated using finite element method. Implicit Msc. Marc software in conjunction with the Hypela2 user subroutine file, was used for the numeric solutions. The plastic work-based failure criterion was incorporated into the subroutine and the homogeneous fourth-order polynomial-based yield function (HomPol4), which predicts both r value and yield stress ratio directionalities, was considered to define the bound of the yield loci. Hole expansion ratio and the failure strain predicted from simulations were compared with the experimental results to assess the capability of the HomPol4 criterion. It was seen that the numerical results were in good agreement with the experimental results for both steel sheets. Moreover, failure stroke values were predicted using failure criterion based on plastic work. Stroke value was successfully captured for the TWIP940 steel, which does not exhibit a significant amount of strain localization. On the other hand, a difference between the numerical and experimental results was observed for TRIP540 steel sheet.

Modeling of plasticity and retained austenite decomposition in bearing steel under cyclic compression

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This paper presents a study on the evolution of plasticity and retained austenite of a martensitic bearing steel under cyclic compression, a phenomenon relevant for rolling contact fatigue of bearing steels. The decomposition of retained austinite is associated with two mechanisms: stress assisted and strain induced decomposition. These two mechanisms are incorporated in the current Finite Elements (FE) simulations, being combined with an advanced cyclic plasticity model. Cyclic compressive tests were run to estimate the plastic material parameters governing the complex hardening behavior. Using a genetic (optimization) algorithm, these parameters were computed in such way that the difference between the experimentally measured stress-strain curves and the numerical predicted ones is minimized. The retained austenite content was measured by X-ray diffraction before and after the completion of the cyclic compression tests. The initial content was used in the FE simulations as the input parameter, and the decomposed content of retained austenite was computed by FE and compared against the experimental data.

Distortion gradient plasticity modelling of the small-scale behaviour of polycrystalline metals under non-proportional loading

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Towards the reliable modelling of the irreversible behaviour of micron-scale metals under general loading histories, we build on the Mixed energetic-dissipative Potential (MP) proposed in [Panteghini et al. (2019) Proc. R. Soc. A 475, 20190258] in the context of higher-order strain gradient plasticity (SGP). Such MP follows earlier contributions by Chaboche, Ohno, and co-workers for nonlinear kinematic hardening within size-independent metal plasticity. The MP is given by M quadratic terms that each transitions, at a distinct threshold value, into a linear dissipative contribution. Therefore, the MP involves 2M positive material parameters, consisting of the M threshold values and M moduli weighing each quadratic recoverable term. Our analysis [Bardella (2021) Proc. R. Soc. A 477, 20200940] demonstrates that, under proportional loading, the MP limit for M toward infinity converges to a less-than-quadratic potential with specific properties. This is a key result to identify the material parameters of models adopting the MP. Moreover, we provide a formula for the characterisation of the recoverable and dissipative contributions of any possible MP limit, showing that, in relation to the predicted size effects with diminishing size, one can select the MP such as its contribution to the strengthening (that is, increase in yield point) is mostly dissipative, while its contribution to the strain hardening increase is mostly energetic. On this basis, we demonstrate that combining the MP with distortion gradient plasticity (that is, SGP relying on Nye's dislocation density tensor [Gurtin (2004) J. Mech. Phys. Solids 52, 2545-2568]) allows accurate fitting the experimental data of [Liu et al. (2013) Phys. Rev. Lett. 110, 244301] on the cyclic torsion of copper wires of diameter spanning from 18 to 42 micrometres. To this purpose, we implement the MP in the finite element model that we have previously developed for the torsion problem [Panteghini, Bardella (2015) J. Mech. Phys. Solids 78, 467-492] and identify its parameters by resorting to the Coliny evolutionary algorithm coded in Dakota [https://dakota.sandia.gov/sites/default/files/docs/6.0/html-ref/topic-package coliny.html]. The results show unprecedented good agreement between experimental data and model predictions [Panteghini, Bardella (2020) Philos. Mag. 100, 2352-2364].

An updated lagrangian multi-layer isogeometric Kirchhoff-Love thin-shell framework: Application to composite after impact testing of composite laminates

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Carbon-fiber reinforced epoxies are extensively used in the aerospace industry due to their advantageous properties such as high strength to weight ratio, high stiffness and, enhanced fatigue resilience. Despite these desirable engineering properties, laminated composites are notorious for their low tolerance to certain loading conditions. Quite often aerospace structures are exposed to low-velocity impacts due to tool drop during routine maintenance or unfortunate events like a bird strike, causing structural damage. These combined modes of structural damage, typically manifesting in fiber failure, matrix cracking/plasticity as well as delamination, highly undermine the residual strength of the composite structure under compression and reduce the pristine failure load significantly [1].Motivated by this problem and the ever-increasing presence of laminated composites in aerospace structures, we propose a multi-layer thin-shell analysis framework in the Isogeometric Analysis (IGA) context. Central to this development, we reformulate the governing thin-shell equations in terms of the mid-surface velocity degrees of freedom, accommodating the material response in the time-rate form while ensuring objectivity. Each ply in the laminated composite structure is represented as a surface that can be built of multiple Non-uniform rational B-spline (NURBS) patches. On the laminate level, adjacent plies are connected via penalty-based cohesive interfaces to account for possible interlaminar damage or delamination. To accurately model the intralaminar progressive failure modes on the ply level, we combine a transversely isotropic plasticity model with Continuum Damage Mechanics (CDM) and devise a three-step elastic-predictor-plastic/damage corrector stress-update algorithm. On the computational geometry end, to handle complex multi-patch geometries, we propose a consistent penalty coupling technique for enforcing the continuity conditions at patch interfaces. The same penalty technique is also employed to weakly enforce symmetry boundary conditions if necessary. A recently proposed non-local penalty contact is adopted as part of the formulation to handle complex dynamic crushing and low-velocity impact scenarios. Examples of various complexity ranging from Open Hole Test (OHT) to Compression After Impact (CAI) testing of damaged specimens validate the accuracy, efficiency, and robustness of the proposed framework.

References

[1] Tan, W., Falzon, B. G., Chiu, L. N., & Price, M. (2015). Predicting low velocity impact damage and Compression-After-Impact (CAI) behaviour of composite laminates. Composites Part A: Applied Science and Manufacturing, 71, 212-226.

Failure analysis of auxetic lattice structures under crush load

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Lattice structures are promising materials in the terms of energy absorption, acoustic and vibrational damping, high strength-to-weight ratios and thermal management capabilities. In particular, auxetic lattice structures, among others, show high energy absorption performances due to their characteristic negative Poisson's ratio. In this study, chiral auxetic units, manufactured from Ti6Al4V powder using Electron Beam Melting (EBM), were tested in compression mode for energy absorption investigation until the failure of the structure. Moreover, a constitutive equation for the material was derived according to tensile and bending test results on ASTM specimens. The obtained data were used to generate and validate non-linear computational models including ductile failure analysis for optimum topology design and mechanical performance forecast of different auxetic cells, including the chiral one, experimentally tested and anti-tetrachiral and re-entrant auxetic lattice structures that are prone to prematurely fail under crush loading conditions.

Modeling the deformation and damage behavior of irradiated Ferritic-Martensitic steel

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For future fusion reactors, the Reduced Activation Ferritic-Martensitic (RAFM) steels have been chosen to be the reference structural material for breeding blanket and first wall applications due to their promising irradiation swelling resistance and thermomechanical properties. However, their material properties are strongly influenced by neutron irradiation at low operating temperatures (<340°C), resulting in loss of uniform elongation, non-linear hardening, embrittlement, and premature damage. Plastic flow localization and related channeling are identified in numerous studies as the primary deformation mechanisms along with accelerated void nucleation and coalescence as the primary ductile damage mechanism. Since the loss of uniform elongation is a safety concern as per current reactor design codes, modeling this material behavior on component scale supports the efficient development of blanket components by demonstrating their safe operation beyond the limits given by the current design codes.Coupled deformation damage models like the viscoplasticity model by Aktaa and Petersen, 2011 describe these effects for small deformations. But to tackle the geometrical nonlinearities in addition to material nonlinearities that arise after localized deformation and diffused necking, a finite strain framework must be applied. Additionally, the GTN model is used to model the ductile damage and is extended to viscoplasticity. A thermodynamic framework is proposed for an irradiated material by considering change of the material's internal energy through an irradiation-related power term based on defect density. Using the framework and the Dual variables approach by Haupt and Tsakmakis, 1989, a thermodynamically consistent finite strain formulation of the deformation and damage model is proposed. The model is derived in a corotational form and implemented in ABAQUS as UMAT subroutine including a suitable integration procedure (Weber and Anand, 1990) to handle finite rotations. Calibration is done simulating tensile tests and fitting calculated true stress - true strain curve to the experimental one. The results are encouraging as the material behavior until failure is fairly well captured. The model and the relevant results are presented and discussed.

Finite similitude for cyclic cohesive zone models

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The root cause of a high percentage of engineering structural failures can be attributed to fatigue and fracture. Thorough testing to mitigate failure due to fatigue and fracture can be expensive to perform particularly for large or complex components or when expensive materials are involved. A possible solution is scaled experimentation using scaling relationships to evaluate the fatigue strength of a full-scale structure using a smaller model. The most widely used technique in scaling is dimensional analysis, which suffers from numerous limitations, and predominant amongst these is its inability to deal with scale effects and thus accurately represent the behaviour of a full-scale structure. This paper introduces a novel scaling theory termed first-order finite similitude applied to fatigue testing. The new theory is trialled on a 2D compact tension (CT) specimen conforming to ASTM E647 standards and assessed using the commercial finite element package Abaqus. Cohesive elements are employed in the CT models placed along the expected crack path to evaluate the crack growth under a cyclic load of 35 cycles. Different scaled models are simulated corresponding to 80%, 60%, 50% and 25% of the size of the full scale CT specimen. The material used for all models is artificial tooth and both linear elastic and plastic responses are evaluated. Graphs for reaction force vs. displacement are obtained to reveal that the theory can predict the behaviour of the full-scale model to within 2% error for a linear elastic bulk material and 4% for a plastic bulk material. Similarly, a clear improvement is shown using an extra scaled experiment in contrast to the one scaled experiment used traditionally in dimensional analysis. Further work would need to be performed using different numerical case studies and physical experiments to further validate the new theory.

The role of nucleation conditions for damage under mode I tearing of ductile plate metals

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Keywords: Ductile Fracture, Mode I Crack Propagation, Shear Band, Intermetallic Particles.

The energy dissipation related to ductile plate tearing is highly dependent on the origin of the damage development. The analysis of mode I loading plates containing pre-existing and uniformly distributed damage has yielded the first insight into how the main part of the tearing energy goes into the diffuse plate thinning that initiates the tearing process [1]. Upon further loading, the plastic flow subsequently localizes into a shear band within the diffuse region, governing plate separation. The energy going into through-thickness shear localization is only a fraction of the total tearing energy but depends heavily on the rate and account of nucleating damage. However, the reality is that plate tearing experiments display several fracture surface morphologies, and not all can be attributed to through-thickness shear localization. The primary reason for the absent through-thickness shear localization is the heterogeneity in the damage-related microstructure. Voids are not uniformly distributed in real materials, nor are they equal-sized or spherical. Initial studies have demonstrated a significant change in both the tearing energy and the fracture surface morphology when accounting for the size, shape, and (random) distribution of the void nucleation sites [2]. In essence, a low number of small (compared to the plate thickness) randomly distributed nucleation sites link up in a void-by-void-type failure. In contrast, bigger particles, or a large number of small particles, facilitate multiple void interactions. This shift in the micro-mechanics governing failure also ties to the macroscopically observed fracture surface morphology. However, the initial studies include only one distribution of equal-sized voids (ellipsoidal) and only consider strain-based void nucleation. The present work aims to achieve a better representation of the damage-related microstructure by accounting for co-existing strain and stress-based nucleation. That is, a distribution of small second phase particles will nucleate damage by plastic strain-controlled nucleation, supplemented by a distribution of large particles governed by stress-based nucleation. The role of nucleation condition and the intrinsic material length scales (set by the size, shape, and number of nucleation sites) will be subject to investigation.

Acknowledgements
The authors gratefully acknowledge the financial support by TÜBİTAK (Project No:

315M133). Kim Lau Nielsen and Vishal Vishwarkarma is financially supported by the Danish Council for Independent Research in project "Advanced Damage Models with Intrinsic Size Effects" (Grant no: DFF-7017-00121).

References

[1] K. Nielsen, J. Hutchinson, Cohesive traction-separation laws for tearing of ductile metal plates, Int. J. Imp. Eng. 48 (2012) 15-23.
[2] Ş. Çelik, R. G. Andersen, C. Tekoğlu, K. L. Nielsen, On the dependence of crack surface morphology and energy dissipation on microstructure in ductile plate tearing, Int. J. Fract. (2021). https://doi.org/10.1007/s10704-020-00513-8.

Mechanics of deformation and failure of thin film coated bulk metallic glasses

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Bulk Metallic Glasses (BMGs) show superior mechanical properties such as high strength ($\sim$2 GPa), high yield strain of about $\sim$2% and high corrosion resistance. But, they lack ductility which prevents them from being used as structural materials. Much of research is going on to increase their ductility by intrinsic and extrinsic methods via experiments and they are also backed up by simulations. In this work, we numerically investigate the mechanical behaviour of thin film coated BMGs through Finite Element Method (FEM) Simulations. We simulate the effect of an extrinsic copper coating on the deformation and failure of monolithic BMG cylinders under compression. We employ the Anand and Su (2005) constitutive model for BMGs implemented by us in ABAQUS FEM software via user material subroutines: UMAT and VUMAT. An isotropic, elastoplastic material model is used for representing the Copper coating with properties of pure copper. Uniaxial compression simulations at quasi-static strain-rate are performed using the Explicit/Dynamics formulation in ABAQUS. The simulations take into consideration a ductile damage and failure mechanism involving cracking inside the shear bands in the BMG matrix. We observe the formation of shear bands which transform into cracks in the BMG matrix. The simulations were able to correctly predict the deformation and fracture mechanism of the BMG matrix and copper coating under uniaxial compression. Results show that a thin copper coating of about 5% of the diametrical thickness of the cylinder increases the strain to failure of the coated BMG by 2% which is in agreement with experiments reported in literature. The present results have implications for designing coated BMGs with improved malleability or strain to failure enabling their deployment in structural applications.

Acknowledgements
Onkar Salunkhe would like to acknowledge the financial support received for this research from IIT Bombay through IRCC Research Internship Awards at IIT Bombay with project code RI/0317-10001227-001 (2018).

Investigation of the damage and fracture of Ti-6Al-4V titanium alloy under dwell-fatigue loadings

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Keywords: Dwell-fatigue, fatigue, titanium alloys, Ti-6Al-4V, turbine engines.

Ti-6Al-4V titanium alloy gas turbine engine components for aeronautical applications operate at a steady state after reaching the maximum stress during each duty cycle. The load holds combined with the fatigue process causes a phenomenon called dwell effect. The dwell periods reduce the fatigue life of titanium alloy components, such as blades and disks in turbine engines. In this work, trapezoidal dwell-fatigue and triangular fatigue tests were performed at room temperature with a fatigue ratio of 0.1. The trapezoidal waveforms (dwell-fatigue tests) had a 10-second dwell period and 1-second loading and unloading rates for each fatigue cycle. The triangular waveforms (fatigue tests) were equivalent to trapezoidal waveforms with zero seconds at the maximum stress. The Weibull distribution statistical analysis verified the dwell-fatigue data reliability. The experimental results showed that the dwell-fatigue life debits for dwell periods of 10 seconds at stress levels of 1.0, 0.975, and 0.95 of the material yield strength were 10.2, 10.0, and 4.5, respectively. The results suggest that the dwell sensitivity of Ti-6Al-4V alloy increases at high-stress levels. The fracture of dwell-fatigue specimens occurred at a high-cumulated plastic strain and after a significantly lower number of cycles than at fatigue tests, indicating a substantial dwell-life debit of the Ti-6Al-4V alloy. The damage mechanism responsible for reducing the fatigue life when the dwell time was introduced was the plastic deformation accumulation observed in dwell-fatigue tests, possibly as a result of the stress redistribution mechanism in the α phase grains that leads to slip of dislocations and, consequently, early plastic deformation processes that instigate crack nucleation.

Acknowledgements
This work was supported by Sao Paulo Research Foundation, FAPESP (Grant Number 2019/02125-1).

Phenomenological modeling of thermomechanical coupling effects of highly alloyed TRIP-steels at different stress states

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Due to metastability, austenitic stainless steels can exhibit a phase transition from austenite to martensite during large deformation. The phase transition is accompanied by additional inelastic strains (TRansformation Induced Plasticity–TRIP) and leads to a remarkable strain hardening behavior, e.g., yield curves of sigmoidal shape. The martensite evolution highly depends on temperature and stress state. Therefore, self heating due to dissipation during intensive straining at elevated strain rates has a great influence on the behavior of the material. A typical phenomenon is the reduced hardening capability due to suppressed martensite formation which is linked to the temperature increase (curve-crossing-effect). In the present paper, a thermomechanically coupled viscoplasticity model at finite deformations is proposed accounting for strain-induced martensite evolution. The volume fraction of martensite is utilized as internal variable to extend the viscoplasticity model, especially the formulation of isotropic hardening. The evolution of martensite volume fraction is modeled by the established approach of Olson and Cohen, which is modified by a temperature and stress state dependence. Additionally, a Lode-angle dependent evolution of the hardening variable is proposed in order to capture the tension-compression asymmetry of hardening which is observed if martensitic phase transition or mechanical twinning (TWIP-effect) occur during deformation. The thermomechanically coupled model was successfully calibrated on data of a stainless CrMnNi cast steel using stress-strain curves as well as martensite evolution results from quasi-static tension and compression tests at various environmental temperatures. Subsequently, the calibrated model was applied in transient, fully thermomechanically coupled simulations of these tests at higher strain rates. The model was able to predict the experimentally observed behavior in terms of the crossing effect of yield curves and decreased martensite formation in both loading cases. Additionally, the recorded temperature histories at local measurement points during the tests were reproduced by the simulations.

Acknowledgements
The work has been financed by the the German Research Foundation (DFG), Project 54473466, CRC 799: TRIP-Matrix-Composite (SP C5).

Efficient monolithic FE²-simulation of the creep and ductile deformation behavior of cellular materials

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The most materials used in engineering have a characteristic inhomogeneity at some length scale, e.g. cellular materials like foam structures. Under certain loading conditions, these materials show a nonlinear, complex and irreversible behavior.Aiming to describe these effects, different modeling strategies can be deployed. Homogenized material laws are often favorable, since they are computationally efficient, still they can only reflect the material response in a smeared way. If the accuracy of the homogenized model is not adequate for a given problem, the field of micro mechanics offers the possibility to evaluate the actual deformation and failure processes at the micro scale. However, these models can become unfavorably large.Making use of the assumption of scale separation, multi scale modeling constitutes an elegant way of model size reduction, while keeping the accuracy gained by examining the actual processes at the microscopic scale. The usage of the finite element method as solution method on both scales is referred to as FE² method.Simulating the macro and all micro FE problems concurrently, as required in nonlinear and irreversible computations, yields a generally very high computational effort. To lower the computing time, a highly efficient monolithic solution strategy is presented in this contribution.To show the capabilities of the FE² method, we demonstrate that a complex material behavior can be described through a geometrical description of micro structures together with simple constitutive laws at the homogeneous phases of the micro scale. More specifically also effects like damage and ductile failure can be described, when the present effect results from a loss of load bearing cross section at the micro structure at large deformations.

Pneumatic fracture computations with peridynamics

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In this study, we investigate a peridynamic approach to pneumatic fracture. The examined peridynamic model relies on the classical state-based formulation, where a critical bond-strain damage is assumed for a linear solid material. We show that the bias of the domain's spatial discretization is uncritical as long as the attributed material point volume is uniformly distributed. A penny-shaped initial crack is subjected to internal pressure and it is found that that the crack tip opening displacement agrees well with the analytical solution. Therefore, the peridynamic model to pneumatic fracture captures the crack evolution quantitatively correctly. With the results at hand, we simulate the pneumatic cracking inside a concrete cylinder and show that the shape of the cracks and fragments is in good qualitative agreement with the results of our supporting experiments.

Investigation of the constraint effects on the ductile fracture resistance using a non-local GTN-model

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Ductile materials operating in the upper-shelf regime are used nowadays in many trending applications such as renewable energy plants, hydrogen transport and additively manufactured components. High safety standards are vital for such applications, which require a reliable fracture mechanical assessment. However, an overestimation of the defect's criticality using conservative fracture mechanical assessment approaches leads to increasing material usages and costs. Usually, in the upper-shelf regime, fracture toughness K_{Jc} is determined from crack-growth resistance curves J-Δa on specimens with high constraint, as e.g. Compact Tension C(T) or Bending SENB. For such specimens, a high state of stress triaxiality at the crack tip is observed, which leads to flat resistance curves and low tearing modulus. On the contrary, cracks in most structural components or in tensile specimens M(T) show a much lower constraint, which results in steeper resistance curves. Thus a component specific fracture toughness could improve the lifetime prediction accuracy and increase the cost-effectiveness of the design without endangering the level of safety.In this work, a specific non-local version of the Gurson-Tvergaard-Needleman (GTN) ductile damage model, which has been developed by Seupel et al. [1], is used to investigate the unlike fracture mechanical behavior for different specimens geometries. This model avoids pathological mesh dependency during simulation. A set of successfully calibrated parameters of the damage model for the reactor pressure vessel steel (18Ch2MFA) is employed here to numerically simulate the crack growth and crack resistance J-Δa-curves for different specimen geometries with high and low constraints. Additionally, the different parameters to describe the constraint, e.g. T-stress, Q-parameter and stress triaxiality (σ_m/σ_{eq}) are evaluated for the different specimens.

References

[1] Seupel, A., Hütter, G., Kuna, M. (2020). On the identification and uniqueness of constitutive parameters for a non-local GTN-model. Engineering Fracture Mechanics, 229, 106817.

Impact loading of interface cracks: effects of cracks' closure and friction

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The fracture mechanics problems of dynamic loading of cracked engineering materials are traditionally of interest in academia and industry, as cracks could be the main reason of structures' collapse. Solving any crack problems, the possible contact of the crack faces must be taken into account, as it changes the distribution of the stresses and the displacements in the vicinity of the crack not only quantitatively but also qualitatively. The linear crack between two dissimilar elastic isotropic half-spaces under impact loading is considered. The system of boundary integral equations for displacements and tractions at the interface is derived from the dynamic Somigliana identity in the frequency domain, and the loading is presented by the exponential Fourier series. To take the crack faces' contact interaction into account we assume that the contact satisfies the Signorini constraints and the Coulomb friction law.The problem is solved numerically using the iterative process – the solution changes until the distribution of physical values satisfying the contact constraints is found. The numerical convergence of the method with respect to the number of the Fourier coefficients and mesh size is analysed. The effects of material properties and values of the friction coefficient on the distribution of stress intensity factors (opening and shear modes) are presented and analysed. Special attention is paid to the size of the contact zone and the results are compared with the classical model solutions obtained for the static problems with friction. In the future the approach can be extended to three-dimensional fracture mechanics problems for layered cracked materials under dynamic loading.

Simulation of elastoplastic response using Prandtl operator approach in a finite element analysis

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Structural components are subjected to variable thermomechanical loads during use. These loads can lead to fatigue failure therefore it is important to detect potential weak points in the structure already during early stages of the R&D process. Reliable results of the stress-strain response are of crucial importance during the structural analyses. In this paper, a metallic structural member is subjected to a variable thermomechanical load and its structural response is investigated. The loads reach beyond the yield stress of the material, therefore an elastoplastic stress-strain response is observed. Prandtl operator approach implemented into the finite element analysis is used to simulate the response of the structural member. It enables fast and accurate structural simulations using the material parameters gained from uniaxial low-cycle fatigue testing at few test temperatures. The approach considers a cyclic elastoplastic material behaviour with multilinear kinematic hardening at variable temperatures. The results of the simulation provide an insight into behaviour of the structural member under thermomechanical loading and highlight potential redesign options if the design criteria have not been met.

Acknowledgements

The authors acknowledge financial support from the Slovenian Research Agency (research core funding No. P2-0182 entitled Development evaluation).

Localizing implicit gradient damage based treatment of softening in elasto-plasticity

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As opposed to brittle fracture, the failure of ductile materials is preceded by severe plastic deformations. Microscopic mechanisms i.e., void growth and coalescence result in macroscopic property degradation causing softening, localization, and finally macroscopic crack. This contribution focuses on softening in elasto-plasticity and its mesh-objective description using an implicit gradient type of non-local damage mechanics framework. As reported in several studies, artificial widening of localization zone is observed when conventional implicit gradient type regularization is used. To circumvent this non-physical artefact, localizing implicit gradient damage (LIGD) formulation that is motivated by higher order continuum arguments, is adopted. As opposed to previous remedies to artificial widening of the localization zone, LIGD proposes an internal length scale that decreases with deformation. A three-field (displacement-pressure-non-local equivalent plastic strain) tetrahedra element is formulated and implemented in commercial finite element software Abaqus through user element (UEL) subroutine. The effectiveness of the approach is demonstrated by solving several benchmark problems.

Crystal plasticity based modelling of shear response of carbon fibre reinforced composites

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Keywords: carbon fibre reinforced composites (CFRP), crystal plasticity, hardening.

Due to their superior strength-to-weight performance, there is an increasing tendency to use carbon fibre reinforced composites (CFRP) in different engineering applications. Under transverse loading, the resulting stress-strain curve has a non-linear character with significant hardening. As far as modelling of CFRP is concerned, the hardening behaviour is typically described by fitting curves to experimental data. Obviously, this route does not take deformation mechanisms at constituent level e.g. fibre rotation and matrix yielding, into account and leads to descriptive models rather than predictive ones. Such models yield poor predictions particularly for CFRP's with 3D microstructural architectures, which have achieved much higher ductility level and texture evolution as compared to conventional 2D architectures. In recent studies [1, 2], motivated by the similarity between the shearing along slip planes and the plastic deformation of a tow, crystal plasticity is exploited to capture the evolution of the composite microstructure. This contribution focuses on the crystal plasticity inspired model of CFRP and its implementation within the commercial finite element software Abaqus through UMAT subroutine. The predictions of the model and experimental results are compared, and a parametric study is conducted to investigate the influence of different model parameters.

References

[1] L.R. Meza, J.M.J. Schormans, J.J.C. Remmers, V.S. Deshpande, 'Shear response of 3D non-woven carbon fibre reinforced composites', Journal of the Mechanics and Physics of Solids, 125 (2019), 276-297.

[2] W. Tan, B.G. Falzon, 'A crystal plasticity phenomenological model to capture the non-linear shear response of carbon fibre reinforced composites', International Journal of Lightweight Materials and Manufacture, 4 (2021), 99-109.

Investigation of failure initiation in syntactic foam core L-shaped sandwich structures

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In this study, a syntactic foam core was introduced to L-shaped laminates to create sandwich structures which have sharp corners. The syntactic foam core was a combination of epoxy and glass microballons (hollow particles). Honeycomb structures and PVC foams are not suitable for sandwich structures that have sharp corners because they do not take the form of corners due to the cell crushing and tearing. L-shaped sandwich structures were manufactured in two steps: manufacturing of L-shaped CFRP face sheets with different thicknesses, and stacking sequences and the pouring of syntactic foam between two face sheets using a mold. The bending characteristics and initial failure modes of the sandwich structure were analyzed by four-point-bending tests and finite element method (FEM). Cohesive Zone Model and Hashin's failure criteria were used for interlaminar and intralaminar failure, respectively, in the facesheets and brittle cracking failure model was used in the core material.

Simulation of residual thermal stress in a layered ceramic composite and estimation of its possible cracking

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The analysis of internal thermal stress is very important both in the process of producing composites and in the process of their operation when the temperature changes. In recent years, ultra-high-temperature ceramic materials designed for thermal protection of various products have attracted considerable interest. Such ceramics can act as components in layered composites or functionally graded materials. The presence of several layers in such materials with different values of thermal conductivity coefficients makes it possible to effectively solve not only the problem of thermal protection but also other problems, such as increased mechanical strength or chemical resistance. But the differences in the coefficients of thermal expansion that exist in this case can cause sufficiently large tensile internal stresses. According to the available estimates, the alternation of layers in layered composites leads to the appearance of compressive and tensile stresses on different sides of the interface. Compressive stresses perform a positive function, restraining the growth of the cracks, but negative stresses are dangerous for provoking the formation of new and the growth of existing cracks.The choice of the composite constituents and the shape of the products can significantly affect the quantitative values of the resulting internal stresses. So, in addition to qualitative results on the level and signs of temperature stresses, the quantitative assessment of internal temperature stresses in products made of composites of a particular composition is of great interest in engineering practice.The aim of this work is to analyze the internal stresses in an infinite plate and a disk-shaped sample of a five-layered ceramic composite consisting of layers of ZrB2-20% SiC with various additives of ZrO2 when it cools down from the sintering temperature to room temperature. The problem is solved numerically by the finite element method. The two versions of the simulation were performed. In the first version, it was supposed that all the properties of the constituent are temperature independent. In the second version, we take into account the dependence of the physical and mechanical characteristics of the composite components on the temperature. Comparing the results reveals the great influence of the property temperature dependence. The results for an infinite plate do not correspond to the results for the disk-shaped sample in all its sections. The internal residual thermal stresses determined on different interfaces of the layers vary in hundreds of MPa. It is shown that tensile stresses are more pronounced in the interfaces of inner layers and they are found to be dangerous for cracking.

Acknowledgements
The work was performed according to the Government research assignment for ISPMS SB RAS, project FWRW-2021-0009.

The modeling of the fracture of three-phase ceramic composite

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Currently, Al2O3-ZrB2(SiC) ceramic composite materials are widely used in various industries. Due to the addition of high melting and high-modulus compounds such as ZrB2 and SiC, ceramic composites have unique physical and mechanical properties, such as high melting point, high thermal conductivity, high hardness, chemical inertness, high electrical conductivity and thermal conductivity.To obtain products from these composite materials, it is necessary to know their strength properties and fracture characteristics. For this purpose, experimental and numerical methods are widely used.In this paper, a numerical simulation of the deformation and fracture of the three-phase composite based on aluminum oxide with additives of zirconium diboride and silicon carbide under uniaxial loading is performed. The content of ZrB2 and SiC inclusions was varied in the calculations in order to evaluate the strength characteristics of the composite.The study was performed on the basis of digitized photos of cross-sections of the real structure of the composite obtained using an electron microscope. The model structures were subjected to uniaxial tension and compression. The modeling was fulfilled in a two-dimensional statement under plane-strain conditions. The system of equations of solid mechanics was solved using the finite-difference method for the numerical study of deformation and fracture processes in the investigated composite. A mechanical response of ceramic composite materials is described by Drucker-Prager model with non-associated plastic flow rule. Fracture is described in terms of two criteria based the limit values of the accumulated inelastic strain and tensile pressure.As a result of the simulation, the fracture patterns in the ceramic composite with different contents of ZrB2 and SiC inclusions under compression and tension loadings at different stages of deformation and macroscopic stress-strain curves were analyzed. The effect of the ratio of ZrB2 and SiC inclusions in the composite structure on the fracture and strength properties was established.

Acknowledgements
The work was performed according to the Government research assignment for ISPMS SB RAS, project FWRW-2019-0035.

Epoxy fracture behavior in the metalized CFRP by cold spray

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Carbon fiber reinforced plastics (CFRPs) have been universally applied in the field of aerospace and automobile due to their high strength and lightweight characters. However, they are often vulnerable to thermal effects in harsh working conditions [1,2]. Therefore, the metallization of CFRPs by cold spray technology is one promising strategy to enhance its thermal conductivity, and improve the thermal resistance without severe superficial erosion due to the negligible thermal effects of cold spray. In this study, we conducted a numerical analysis to explore the fracture behavior of epoxy during cold spray. Here, we stimulated the fracture situations at various gas temperature conditions (473 - 623 K) of the cold spray process on the CFRP substrate. The shear damage distributions and their evolution over time were numerically analyzed on Abaqus 6.14. We used a 2D numerical model composed of ten laminates stacking in sequence with 245 carbon fibers (CFs) in the transverse laminates and evenly distributed four CFs in the longitudinal laminates in a dimension of 0.5 × 0.05 mm3. CFs and single-particle are modeled in diameter of 8 μm and 25 μm, respectively. During the spraying, the uppermost laminate was subjected to compression failure. Complete damage meets the criterion when its value reaches 1.0 [3]. In Fig. 3, when the gas temperature increasing from 473 K to 623 K, damaged areas in red color gradually expand from the central part beneath the particle to a larger area. As referring to previous researchers, the CF/epoxy interface triggers failure initiation [4]. Thus, these interfaces in our case were verified to act as distortion onset, damage propagates from these interfaces at 573, and 623 K. Bulk epoxy at 573, and 623 K were separated apart, which coincides with the morphology observation in the as-sprayed specimens. In this study, the epoxy fracture during cold spray was examined by numerical analyses. With the gas temperature increasing, epoxy was gradually distorted by shear damage. The distortion usually initiates from the epoxy/CF interfaces then propagates to other areas.

Acknowledgements

The authors thank Hajime Yoshinaga and Tsuyoshi Oguri, JAMCO Corporation, for providing CFRP specimens. This research was supported by the NEDO Feasibility Study Program "Multi-material 3D joining and optimum molding technology for higher reliability than the current joining in the aviation field".

Application of a robust, rate-independent crystal plasticity formulation to oligo-crystalline TRIP-/TWIP-steel modeling

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Crystal plasticity models allow for an accurate description of various inelastic processes at the scale of individual grains.Furthermore, they provide insight into the interaction of the inelastic deformation among neighboring grains, e.g. in oligo-crystalline simulations and can be employed to assess the impact of modeling assumptions at the grain scale onto the polycrystalline behavior by means of scale-bridging techniques, e.g. quantifying the influence of non-Schmid effects onto the macroscopic yield and flow behavior.At the same time, robust formulations and stable numerical algorithms are required to determine the set of active slip systems and the corresponding slip rates due to presence of the Taylor ambiguity problem, especially if the constitutive description in the rate-independent limit is sought.In the current contribution, a crystal plasticity model based on an augmented-Lagrangian formulation is adopted from the literature and its robustness is demonstrated for different hardening laws of varying complexity, accounting for self- and latent hardening effects.The model is employed in the modeling of oligo-crystalline miniaturized tensile specimens, in which the grain morphology of a TRIP-/TWIP-steel is reconstructed from EBSD measurements.Simulation results are compared in detail to available experimental data, like deformation fields obtained by DIC and the reorientation of the crystals, extracted from EBSD measurements.Additionally, the impact of the stiffness of the test setup and friction between specimen and loading device is investigated.

Acknowledgements
The authors gratefully acknowledge the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) for funding the research in the framework of the Collaborative Research Center “TRIP-Matrix-Composite”, (project number 54473466 – SFB 799, subproject C10)

A novel ordinary state based peridynamic truss element with uniform/nonuniform discretization

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Finite element method (FEM) has been the tool of choice for stress analysis which is still widely practiced. FEM is computationally robust and very effective for modeling structures with complex geometries and different materials under general loading conditions. Its computational model requires explicit representation of cracks for the prediction of crack initiation and growth. The governing equations of motion include spatial derivatives of the displacement components which are not valid in the presence of displacement discontinuities such as cracks. Peridynamic (PD) is a non-local reformulation of the classical conservation equations of continuum mechanics. The PD equation of motion is a nonlinear integro-differential equation in time and space. It does not contain any spatial derivatives of displacements. Thus, the PD equation of motion is valid everywhere whether or not displacement discontinuities exist in the material. This feature allows crack initiation and propagation at multiple sites, with arbitrary paths inside the material, without resorting to external crack growth criteriaThe basic PD equations are entirely consistent with the fundamentals of FEM and that coupling of peridynamics to conventional FEM models. This study presents a novel ordinary state-based PD element to perform peridynamic analysis. The PD material parameters are determined based on the discretized computational model; therefore, the correction procedure is not required and the interaction domain can have irregular shapes. The size and shape of the interaction domain dictates the element connectivity. Such connectivity results in a sparsely populated global system stiffness matrix. The solution of resulting system of equations is achieved through implicit solvers until damage initiation, and it continues with explicit time integration during damage progression. The PD element predictions based on structured and unstructured discretization schemes are compared with those of FEM by considering a plate with and without a pre-existing crack under tension.

Acknowledgements
This work has been supported by Erciyes University Scientific Research Projects Coordination Unit under grant number 11070

Modeling of reinforced concrete panels under blast loading

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Investigating reinforced concrete (RC) member behavior under high-strain loading has become popular in recent years due to the increasing demand for the design of such structures against terrorist attacks, explosions, and crash incidences. Finite element modeling is a preferred method for the analysis and design of RC structures for such high-strain rate loading conditions. On the other hand, experimental testing is also required to verify numerical methods for the use of extensive structural and loading conditions. The study presented here employed an explicit finite element method to investigate the behavior of RC panels under blast loading. For the verification of the method employed, shock tube tests conducted on RC panels at the İzmir Institute of Technology were used. The panel tested by Alkabbani (2021) was 1900x1900x50 mm in dimensions and had 5 mm diameter welded wire reinforcing bars with 150 mm spacing in both orthogonal directions. The panel was subjected to a measured peak reflected pressure of 44 kPa, which drops to zero in 42 ms. Displacements, support reactions, and accelerations on the specimen were measured during testing. This panel was modeled using finite element software LS-DYNA with material models MAT_72R3 for concrete and MAT_Plastic_Kinematic for steel bars. Obtained results were compared with the experimental data regarding maximum midpoint displacement, acceleration, and damage condition. Effects of some material model parameters on the performance of the numerical model were also investigated. A good correlation was obtained between the experimental data and numerical results. For the further investigation of the RC panel behavior under blast loading, a parametric study was also conducted using the model parameters verified with the experimental study. Effects of compressive strength of concrete, tensile reinforcement ratio, and panel thickness on the behavior of RC panels under blast loading conditions were investigated.

Acknowledgements
The authors gratefully acknowledge the financial support by TÜBİTAK (Project No: 217M442).

The effect of texture on the plasticity of Mg-6Sn-1Zn sheets processed by differential speed rolling

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The main reason of the limited usage of wrought Mg alloys in structural applications is their low ductility and poor formability that result from the unsatisfactory number of independent slip systems in Mg at room temperature. One of the approaches to increase formability of Mg is the use of alloying additions which decrease its stacking fault energy (SFE). Theoretical calculations showed that Sn strongly reduces the SFE of Mg and may facilitate dislocation slip in the basal and non-basal slip systems. Thus, the Mg-Sn-based alloy has been investigated in the present study. Since the formability of Mg is strongly affected by the basal texture, it can be improved by reduction of texture intensity by introducing intense shear deformation. Differential speed rolling (DSR) method allows to introduce such shear deformation by controlled differentiation of rotation speeds for upper and lower rolls. It has been shown for AZ31 Mg alloy that it is very effective in enhancing Mg ductility due to microstructural and textural modification.In the present work, the Mg-6Sn-1Zn (%wt.) sheets were obtained in the rolling process with a speed ratio between the upper and lower rolls varying from 1 (conventional rolling) to 1.25, 2 and 3. The billets were rolled in 4 passes with a thickness reduction per pass of 15%. Prior to each pass the sheets were annealed at 400^{o}C for 10 minutes. The mechanical properties and plastic anisotropy (expressed by Lankford parameters) of the DSR-processed sheets were evaluated based on the uniaxial tensile tests of miniaturized specimens with a gauge length of 10 mm and a cross section of 1.2 x 1.6 mm cut at angles of 0^o (RD), 45^o and 90^o (TD) to the rolling direction. The metallographic observations and X-ray diffraction (XRD) analysis were performed for microstructural and textural characterization. The essence of the present study is an analysis of the effect of applied speed ratio on the texture intensity of Mg-6Sn-1Zn sheets which, in turn, strongly affects their strength and plastic anisotropy assessed in the uniaxial tensile tests.

Acknowledgements
This research was financially supported by the National Science Centre, Poland, through the research grant no. 2018/29/N/ST8/01925.

Experimentally and simulations of predefined strengthening and damaged parameters of DP600 and DP800 steels

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Nowadays, the development of the automotive industry is continuously looking for new materials that are easy to process, safer and lighter, thus providing a positive impact in terms of ecology, environmental protection as well as low fuel consumption. One of the materials, that fulfil these criteria are DP600 and DP800 (dual-phase steel), which consist mainly of two phases: ferrite and martensite, and it is used largely in the automotive industry due to its mechanical properties such as strength and ductility. All investigation is done both experimentally and numerically. To determine the triaxiality damages of mechanical properties of DP600 and DP800 steels, the experimental tensile tests were performed in three different velocities (0.0083 s-1, 0.042 s-1, and 0.16 s-1). While the special characteristics of specimens (ASTEM E8) should be noted, because they were obtained from three different degrees of rolling production (0^o, 45^o, and 90^o), and they had four different geometric shapes.In this study, the modeling is done in relation to predefining strengthening and damage parameters of DP600 and DP800 ductile steels. And for both investigations the mechanical characteristics of the taken samples were similar. Therefore, to determine the undamaged (strengthening) parameters of ductile materials, the model MAT_98_SIMPLIFIED_JOHNSON_COOK is used. On the other hand, the following models MAT_120_GURSON, MAT_15_JOHNSON_COOK and MAT_120_GURSON_JC are used to determine the damage parameters of the same materials. Based on the virtuality models nature, for all investigated samples the appropriate parameters were calibrated by defining them through optimization, by using LS-OPT. The determination of modeling specimens imported in k-file, differs from shell to solid bodies based on the models used. And after calibrating and fitting the parameters, the comparisons were made between the experimental results and obtained optimization results, in terms of all key points of the ductile stress-strain diagram, including the differences between fracture points.

Acknowledgements
We are grateful to Res. Ass. Habip Gökay KORKMAZ for his contribution in terms of supporting us in the creation of modeling files. This research was carried out as a result of the work and preparation of the doctoral thesis, which will be defended in the Mechanical Engineering, Niğde Ömer Halisdemir University, Republic of Turkey.

A two-level homogenization method accounting for particle debonding for polymer nanocomposites with coated inclusions

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Polymer nanocomposites are materials that have polymer matrices and nanoscale reinforcement elements. It is well accepted that due to the higher surface area of inclusions, nano-inclusions make significant improvements to overall mechanical properties such as elastic modulus, yield strength, toughness as well as electrical and optical properties. Other than the matrix and the reinforcement element, another phase that occurs between the matrix and the inclusion, interphase, has been observed in nanocomposite systems. Some of the property enhancement or deficiency has been attributed to this phase. The interface and interphase regions between the matrix and the inclusion also play a significant role on the macroscopic behavior of composites [3]. Furthermore, debonding of the inclusion is an important phenomenon that should be taken into account to evaluate the mechanical performance of nanocomposites. The aim of this study is to propose a new two-level homogenization approach that accounts for debonding to model the polymer nanocomposites with coated inclusions. To this end, an extension of an already developed framework for elastic and viscoelastic homogenization of polymer nanocomposites without debonding is presented [1]. In order to simulate debonding at the interface, a bilinear traction-separation law is employed. The proposed approach is based on a replacement of the coated inclusion (inclusion+interphase) with an effective inclusion using finite element based computational homogenization at the first level. Then, the micromechanics-based Mori-Tanaka (M-T) method is employed at the second level to obtain the macroscopic response. This proposed method aims to model load transfer between the matrix and the reinforcement element through the interphase in a correct way. Two-level homogenization results are compared with micromechanics-based M-T results and reference three-phase finite element studies. The micromechanics model assumes linear kinematics and isotopic elastic behavior. Furthermore to obtain uniform stress fields equibiaxial loading condition is assumed as formulated in [2]. The effects of interphase stiffness and different interface parameters have been studied, and improvements for predictions in effective stress-strain curves have been achieved in comparison to micromechanics-based M-T method.

Acknowledgements
The authors gratefully acknowledge the financial support by TÜBİTAK (Project No: 218M274).

References

[1] D. Güzel. A two-level homogenization method for polymer nanocomposites with

coated inclusions. Master's thesis, Middle East Technical University, 2021.
[2] H. Inglis, P. Geubelle, K. Matouˇs, H. Tan, and Y. Huang. Cohesive modeling of dewetting in particulate composites: micromechanics vs. multiscale finite element analysis. Mechanics of Materials, 39(6):580–595, 2007.
[3] Y. Li, Y. Huang, T. Krentz, B. Natarajan, T. Neely, and L. S. Schadler. Polymer Nanocomposite Interfaces: The Hidden Lever for Optimizing Performance in Spherical Nanofilled Polymers, chapter 1, pages 1–69. John Wiley & Sons, Ltd, 2016.

Dynamic analysis of aluminum containing nano-scale helium bubbles based on molecular dynamics simulations

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It is well known that there are a large number of nano-scale helium bubbles in irradiated damaged metals. However, the influence mechanism of the helium bubbles on the dynamic properties of metals is still lack of physical knowledge. This report mainly introduces our recent researches on the microscopic modeling and simulation on aluminum containing helium bubbles. The stability and pressure of helium bubbles, the deformation process under dynamic compression and tension, and the response of internal and near surface helium bubbles under shock loading are simulated. Based on these simulation studies, some physical laws are revealed, such as the relationship between the pressure, size and temperature of helium bubble, the formation of tetrahedral or octahedral structures, the deformation and expansion mechanism of helium bubbles.

Exploring ballistic performance of alumina ceramic tiles with different surface profiles

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Designers in defense industry aim to increase the protectiveness of armors while decreasing their weight. On body armors, composites and ceramics are widely used due to their lightweight, high hardness, and less blunt trauma. Ceramic armor materials are usually used as the front face for their capability to erode or break up the projectile. There exist various parameters affecting the performance of ceramic armors, and one of these parameters is surface profile. It is a compelling parameter due to its ability to yaw the projectile, causing a reduction of projectile penetration capacity. This study aims to compare alumina ceramic tiles with different surface profiles by their backface signatures. In the NIJ standard for Ballistic Resistance of Body Armor, backface signature is a performance requirement. Although experimental results are necessary due to the acceptance of an armor system, numerical results will lead to a better understanding of surface profiling. In this study, LS-DYNA software is used for ballistic impact simulations to explore the effect of surface profiling. In the simulations, a steel projectile with varying velocities will penetrate a ceramic tile which is backed by Roma Plastilina No1 material. Johnson-Cook material model is used for sphere projectile, Johnson- Holmquist material model is used for ceramic tiles, and power law plasticity material model is used for backing material. For the modeling of ceramic tile smoothed particle hydrodynamics (SPH) and finite element (FE) methods are linked to capture fractures and debris while decreasing computational time and overcoming inconsistencies on boundary conditions. In this study, first the FE model that simulates a projectile impacting a ceramic tile will be generated and validated with the experimental and numerical results available in the literature. Then, the plastilina model will be validated by simulating a drop test (a steel ball impacting plastilina backing material). Finally, these two numerical models will be combined to simulate a projectile impacting a ceramic tile, which is backed by plastilina, and the backface signature in the plastilina will be predicted. This last FE model will be used to compare the ballistic performances of different surface profiles.

Prediction of local inhomogeneities in the TiN thin films deposited on the aluminum substrate based on the combination of nanoindentation and numerical modeling

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The work is focused on the determination of flow stress characteristics and fracture behaviors of TiN thin films based on a series of nanoindentation tests and full-field finite element calculations. TiN films obtained by the Pulsed Laser Deposition are selected as a case study for the investigation [1]. They were deposited on the aluminum substrate and investigated through the nanoindentation test and scanning electron microscopy. Additionally, to recalculate measured load-displacement values into the stress-strain curve and to determine fracture initialization and propagation factors, a finite element approach is used. Subsequent stages, including the deposition process of TiN thin film, room temperature nanoindentation tests, metallography, and development of a numerical model which takes into account the concept of the digital material representation (DMR) and cohesive zones type elements [2,3] are described in this work. Examples of obtained results presenting capabilities of the proposed approach in the prediction of local inhomogeneities influencing overall mechanical properties are also highlighted.

Acknowledgements
Numerical calculations have been performed with the use of the PLGrid Infrastructure. Funded by research subvention for maintenance of research potential no. 16.16.110.663/9.

References
[1] D. Craciun, N. Stefan, G. Socol, G. Dorcioman, E. McCumiskey, M. Hanna, C.R. Taylor, G. Bourne, E. Lambers, K. Siebein, V. Craciun, "Very hard TiN thin films grown by pulsed laser deposition", App. Surf. Scie., Vol. 260, pp. 2-6, (2012).
[2] K. Perzyński, D. Zych, M. Sitko, Ł. Madej, "Numerical investigation of the influence of pulsed laser deposited TiN thin film morphology on deformation inhomogeneities", Arch. of Metall. and Mat., Vol. 65(2), pp. 713-720, (2020).
[3] S. Rezaei, M. Arghavani, S. Wulfinghoff, N. C. Kruppe, T. Brögelmann, S. Reese, K. Bobzin, "A novel approach for the prediction of deformation and fracture in hard coatings: Comparison of numerical modeling and nanoindentation tests", Mech. of Mater., Vol. 117, pp. 192-201, (2018).

A phase-field fracture model for combined distortional and dilatational failure in rubber-like materials

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Rubbery polymers possess two main failure modes, namely the dilatational mode in terms of formation of cavities and the distortional failure governed by shear-type deformations. These modes correspond to deformations related to the volumetric and entropic elastic response under a general loading state, respectively. In this work, an energy-based approach for phase-field fracture as followed with a unique split of history field corresponding to the free-energy function terms of the compressible extended eight-chain model [2]. The resulting phase-field approach allows the definition of a failure criterion that can be shown as a failure surface in the principal stretch space. Moreover, unlike the classical phase field approach in the sense of Miehe et al. [1], we make use of distinct degradation functions for the dilatational and distortional parts, respectively. Herein, separate forms of a tunable Hermitian polynomial-based degradation function are applied to dilatational and distortional parts of the free energy function. The proposed degradation function recovers the quadratic, cubic, and quadric degradation functions from the literature as its special cases [3]. The parameter identification is carried out on the existing data from the literature. The resulting history field approach is finally compared to the existing principal stretch-based phenomenological failure criteria [4]. We demonstrate the qualitative results of the proposed model by means of representative boundary value problems.

References

[1] Christian Miehe, Martina Hofacker, Fabian Welschinger, A phase field model for rate-independent crack propagation: Robust algorithmic implementation based on operator splits,Computer Methods in Applied Mechanics and Engineering, Volume 199, Issues 45–48, Pages2765-2778,Computer Methods in Applied Mechanics and Engineering, 2010.

[2] H. Dal, O. Gültekin, K. Açıkgöz, An extended eight-chain model for hyperelastic and finiteviscoelastic response of rubberlike materials: Theory, experiments and numerical aspects,Journal of the Mechanics and Physics of Solids, Volume 145, 2020.

[3] C. Kuhn, A. Schlüter, R. Müller, On degradation functions in phase field fracture models,Computational Materials Science,Volume 108, Part B, Pages 374-384, 2015.

[4] P.L. Rosendahl, M. Drass, J. Felger, J. Schneider, W. Becker, Equivalent strain failurecriterion for multiaxially loaded incompressible hyperelastic elastomers, International Journal ofSolids and Structures, Volume 166, Pages 32-46, 2019.

In-SEM machining reveals plasticity effects at the cutting edge

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High-precision metal cutting is increasingly relevant in advanced applications. Such precision normally requires a cutting feed in the micron or even sub-micron dimension scale, which raises questions about applicability of concepts developed in industrial scale machining. To address this challenge, we have developed a device to perform linear cutting with force measurement in the vacuum chamber of an electron microscope, which has been utilised to study the cutting process down to 200 nm of the feed and the tool tip radius. The machining experiments carried out in-operando in SEM have shown that the main classical deformation zones of metal cutting: primary, secondary and tertiary shear zones - were preserved even at sub-micron feeds. Measurement of the cutting forces at deep submicron feeds and cutting tool apex radii has been exploited to discriminate different sources for the size effect on the cutting energy (dependence of the energy on the feed and tool radius). It was observed that typical industrial values of feed and tool radius imposes a size effect determined primarily by geometrical factors, while in a sub-micrometre feed range the contribution of the strain hardening in the primary share zone becomes relevant.

Acknowledgements
Basque governmentand from the Spanish Ministry of Science, Innovation and Universities for their funding to the research presented in this paper. The authors also wish to acknowledge Kleindiek Nanotechnik GmbH.

Yield criteria representable by elliptic curves and weierstrass form

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Elliptic curve terminology comes from their close association with elliptic functions, and not because of any physical resemblance to an ellipse. The curves investigated here represent various yield loci in the plane having cubic algebraic relationships between the second and third invariants of the deviatoric stress tensor. A well-known yield condition attributed to Drucker falls into this classification. In addition, the more commonly used Tresca yield condition represents a limiting case of elliptic curves. All yield criteria based on elliptic curves, including the Tresca, can be parameterized in terms of the Weierstrass elliptic -function. The properties of elliptic curves as they pertain to the formulation of various plastic yield criteria of materials are the topic of this investigation. Various perfectly plastic solutions of mode I crack problems are discussed.

Voided unit cell simulations with constant stress ratios

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Ductile fracture in metals and metal alloys occurs through nucleation, growth, and coalescence of micron-scale voids nucleated at second phase particles. A detailed experimental investigation of the stages of ductile fracture, especially that of void nucleation and coalescence, is rather challenging and requires guidance from numerical simulations. Since the seminal work of Needleman [1], finite element voided unit cell calculations performed on ideal materials containing periodically distributed voids became a convenient tool for numerical simulations of ductile fracture. In the last century, the effect of stress triaxiality on ductile fracture was well known, but shear loads were disregarded. Therefore, voided unit cell calculations were performed by prescribing only the ratios of normal stresses, i.e. $\rho_{11} = \sum_{11} / \sum_{22}$ and $\rho_{33} = \sum_{33} / \sum_{22}$. Experimental studies in the last decades (see. e.g. [2]), however, revealed a pronounced effect of shear loads on ductile fracture at low stress triaxiality, incorporated into ductile fracture simulations through the Lode parameter. In order to account for the effect of shear loads on void growth and coalescence, Tekoğlu (2014) [3] developed a finite element framework where the stress state on a cubic unit cell containing a spheroidal void at its center is represented by three non-dimensional stress ratios, i.e. $\rho_{11} = \sum_{11} / \sum_{22}, \rho_{33} = \sum_{33} / \sum_{22}, and \rho_{12} = \sum_{12} / \sum_{22}$. The present study attempts to extend the work of Tekoğlu (2014) [3] by allowing a complete definition of the stress state on a unit cell with five non-dimensional stress ratios, i.e. $\rho_{11} = \sum_{11} / \sum_{22}, \rho_{33} = \sum_{33} / \sum_{22}, \rho_{12} = \sum_{12} / \sum_{22}, \rho_{13} = \sum_{13} / \sum_{22}$, and $\rho_{23} = \sum_{23} / \sum_{22}$. Aside from being numerically efficient, the developed framework allows keeping the errors in the prescribed stress ratios below a few percent. The developed framework is generic and can be applied to any representative volume elements containing voids or particles.

References

[1] Needleman, A., 1972. Void growth in an elastic-plastic medium. J. Appl. Mech. 39, 964–970.
[2] Bao, Y., Wierzbicki, T., 2004. On fracture locus in the equivalent strain and stress triaxiality space. Int. J. Mech. Sci. 46, 81–98.
[3] Tekoğlu, C., 2014. Representative volume element calculations under constant stress triaxiality, lode parameter, and shear ratio, Int. J. Solid Struct. 51, (25–26), 4544–4553.

Evaluating the effect of FRP composites on their fracture toughness

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The main aim of the research presented in the paper is verification of the applicability of selected ASTM/ISO standard procedures for delamination resistance assessment of finer plastic (FRP) laminates. The study allows for elastic coupling inducted by a special laminate sequences. One of the methods of clarifying the reason for differences in mode I and mode II delamination resistance is fractographic analysis. There were also made tensile bench test to identify the composite strength and fracture toughness in accordance with ASTM D3039. The experimental tests were carried out by fractographic analysis after using a Scanning Electron Microscope (SEM) which is characterized by imaging the real surface to inspect the delamination surface in the delamination plane. The results showed that there was much more energy consuming damage mechanisms in the ENF samples compared to the DCB ones in the interlayer inside the laminate and this could justify the result of GIIc coefficient being much higher compared to GIc.

Acknowledgements
This research was funded by the Ministerial Research Project No. DEC-2016/21/B/ST8/ 03160, financed by the Polish National Science Centre.

Ductile fracture of DX51D material sheet metal panel produced by hemming process

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In this study, the fracture problem occurring in the bending areas of the sheet metal panel produced by the hemming process was investigated by numerical method. The part is produced with cold-rolled continuous galvanized DX51D+Z grade material which is commonly used. As is known, there is no upper yield stress limit value for this material according to EN 10346:2015. In addition to this, for this steel grade when the yield and tensile stresses increase, ductility capability decreases significantly. Also, when the metal forming simulations are done with only uniaxial tensile test data of material, unexpected failures could arise for the hemming process. Therefore the type of stress that occurred on the material by the process applied in the production should be carefully examined and material data should be extracted for dominant stress types.The use of this material without limiting mechanical properites can cause unexpected cracks and tears, especially in processes with high plastic deformation such as hemming. In order to observe the damage occurrence, the stress triaxiality factor of the material was examined and the dominant stress triaxiality value with strain to fracture path in the hemming process was determined with finite element analysis. Due to their similar mechanical properties, being used as raw material for DX51D and having ductile fracture parameters available in the literature, hot-rolled S235JR and S275JR materials are choosen to observe fracture event in numerical analysis. Equivalent strain to fracture-stress triaxiality and lode angle curves were used with the Hosford-Coulomb ductile fracture model to examine the effects on the hemming process. All numerical calculations were performed in the commercial Altair RADIOSS software that can perform high nonlinearity calculations. Finally, a performance comparison was made between materials and experiment for the hemming process.

Acknowledgements
I would like to thank Borçelik Çelik Sanayii Ticaret A.Ş.

Highly sensitive methods for vibration diagnostics of fatigue damage in structural elements of gas turbine engines

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Vibration diagnostics of damage belongs to the class of non-destructive methods. The basis of such methods is the fact that while fatigue cracks or other types of damage occur in structural elements their rigidity decreases, which causes the change of certain vibration characteristics, such as natural frequencies and mode shapes. This change is used as an informative sign of damage. The main problem of such vibration diagnostics is relatively low sensitivity. Therefore, the main aim of the study is the development of methods for vibration diagnostics of fatigue damage as applied to structural elements of gas turbine engines, the sensitivity of which is one to two orders of magnitude higher than the sensitivity of vibration diagnostics based on the change of natural frequencies.The most common type of damage of structures and structural elements subjected to dynamic loading is a fatigue crack. In vibration problems, such crack is considered as a closing (or breathing) one. It is assumed that crack is completely open on one half-cycle of vibration and closed on the other half-cycle.A characteristic feature of vibrations of structural elements with closing crack, in addition to changes in natural frequencies, is the occurrence of the so-called nonlinear effects, that is the nonlinear resonances (sub- and superharomnic) and significant nonlinearity of vibrations at these resonances, as well as the considerable in certain cases increase of damping characteristics.Analytical and experimental studies of the indicated vibration characteristics and their effectiveness for the diagnostics of damage were carried out as applied to the blades of gas turbine engines. As a result of these studies, the intensity of changes in nonlinear resonances parameters and damping characteristics at different parameters of crack was determined. Besides, the experimental techniques for vibration testing of turbine blades were developed.Full-scale tests of turbine blades have revealed that even quite a small fatigue crack, which does not exceed 10% of the cross-section, causes the increase of nonlinear distortions of vibration at superharmonic resonance of order 2/1 up to five times, the increase of damping characteristic – up to two times. At the same time, the natural frequency of blades dropped by only 0.5%. Thus, the study demonstrates that nonlinear effects and change of damping can be used for the reliable vibration diagnostics of fatigue damage in certain type of structural elements. The sensitivity of considered methods of vibration diagnostics is several orders of magnitude higher than the sensitivity of conventional methods based on the change in natural frequencies and mode shapes.

The influence of bi-layer metal-matrix composite coating on the strength of the coated material

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Deformation and fracture in aluminum with bi-layer metal-matrix composite coating are studied. The coated specimens were manufactured by solid state sintering during hot pressing. The coating layers composed of an aluminum matrix reinforced by boron or titanium carbide particles were arranged in the following combinations: the substrate – Al- B4C layer– Al-TiC layer and the substrate – Al-TiC layer – Al- B4C layer. Microstructural analysis and compression tests for the manufactured specimens were performed. Deformation and fracture mechanisms of the gradient composite coatings were revealed.Thermomechanical behavior of the coated materials was carried out numerically during cooling followed by tension or compression. Two-dimensional dynamic boundary-value problems in the plane-stress formulation were solved numerically by the finite element method (FEM) using Explicit module of Abaqus software package. Microstructure of the bi-layer metal-matrix composite coatings takes into account the complex shape of particles explicitly. Isotropic elastoplastic and elastic-brittle models were used to simulate the mechanical response of the aluminum matrix and ceramic particles, respectively. To investigate the crack initiation and propagation in ceramic particles, a Huber type fracture criterion was chosen that takes into account the type of local stress state: bulk tension or compression. The influence of the coating layer arrangement and residual thermal stresses arising during cooling of the coated materials on the character of plastic strain localization in the aluminum matrix and fracture of ceramic particles and on the macroscopic strength of the coated materials is studied.

Acknowledgements
The work was supported by the Russian Science Foundation (Project No. 18-19-00273).

Microstructure and mechanical properties in AZ31 magnesium alloy processed by various plastic working

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Plastic working can control the microstructure of metals and alloys and improve their mechanical properties. This study investigated the effects of various plastic working on the microstructure and the mechanical properties of AZ31 magnesium alloys. We performed uniaxial compression, extrusion, rolling, equal-channel angular extrusion, and caliber rolling on the AZ31 alloy with equivalent plastic strain controlled to the same value. The stress-strain state induced by the plastic working was calculated using the finite element method (FEM). We discussed the microstructure and mechanical properties after various plastic working in the viewpoint of the stress-strain state obtained by FEM.

Computational modeling of strain-rate effects on the low-velocity impact response of sintered Al6061 plates

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This study investigates the effect of strain-rate dependency on the low-velocity impact response of sintered Al6061 plates by computational modeling. Two different computational models, rate-independent and rate-dependent, are developed using the explicit finite element code, LS-DYNA to present the effect of considering high strain-rate behavior of the plate. To consider the strain-rate effects, Al6061 cylindrical specimens are subjected to compression tests at three different strain-rates, a quasi-static strain-rate and two different high strain-rates up to the strain-rate of 2000 s-1. The high strain-rate compression tests are performed by a SHPB (split-Hopkinson pressure bar) setup while the quasi-static compression test is conducted using an electromechanical universal testing machine. To describe the material plasticity, an elastoplastic material model, MAT_PIECEWISE_LINEAR_PLASTICITY (MAT_024) is implemented to the computational model. In the rate-dependent model, the quasi-static compression behavior, and the high strain-rate compression behavior at two different strain-rates are described while only the quasi-static compression behavior is defined in the rate-independent model. The low-velocity impact analyses are performed for four different energy levels from 6 to 48 Joules to investigate the strain-rate effects depending on the impact velocity/energy, and the results are evaluated in terms of peak contact force, absorbed energy, and permanent central deflection parameters. Low-velocity impact experiments are also carried out to validate the computational models and to determine the effect of strain-rate dependency on the low-velocity impact response of the plate. Both computational models show good correlation with the experimental results, since the rate-dependent model does not have a significant difference compared to the rate-independent model in terms of all parameters for the considered impact energies. Thus, utilizing only the quasi-static compression behavior is sufficient for the low-velocity impact analysis of sintered Al6061 plates.

Analysis damage and failure mechanism under a lubricated slipper/swashplate interface in axial piston machines

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Nowadays, the phenomena of damage and fracture affect many machines and components in the good part of engineering. Hydraulic machines are also part of these components affected by these phenomena. Axial Piston Machine is undoubtedly one of the compact machines; however, it is also confronted with performance loss or even its destruction because of the complexity of the movements that perform its internal elements. A good part of the causes of loss of its performance and efficacies comes from the mechanism of rupture, fracture, and abnormal deformation that undergo its solid compounds. In this work, we implement an analysis of damage and fatigue exiting on the slipper/swashplate interface by predicting the solid deformation, strain, wear of the solid bodies (slipper and swashplate) for different materials. The loads are simulated, and hydrodynamic pressure deformation on that interface is predicted by solving Reynolds Equation for the different applied loads. Some suggestions are given to improve or avoid the damage and failure of the slipper and swashplate.

Acknowledgements
This work has been supported by the Key Research and Development Program of Zhejiang Province (Grant No. 2019C01134), the Key Research and Development Program of Zhejiang Province (Grant No. 2020C01153).

Texture control of high purity niobium tube by tube channel pressing

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In the present study, we applied Tube channel pressing (TCP) to high-pure niobium tube for up to three passes with subsequent annealing in order to modify texture and enhance the formability. We examined the effect of TCP on its texture of tubes using X-ray diffraction (XRD) and electron back-scattered diffraction (EBSD), and evaluated the formability of the tubes using tensile tests in three directions, e.i, axial, circumferential, 45 degrees directions. It was found that elongation to failures and Rankford value (r-values) in all three directions increased after TCP processing compared with as-received ones (conventional process). These high formability can be attributed to uniform equiaxial microstructures and textures, which was successfully modified by promoting recrystallization of deformation microstructure induced by TCP. r-value increased in comparison to the tube fabricated by conventional process and was highest after one pass, and decreased after the second, and third passes.

Characterizing and modeling the rate dependency of plastic deformation from single crystal to multiphase steels

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In the integrated computational materials engineering (ICME) roadmap, quantitative correlation of the material microstructure and its mechanical deformation properties by using a multiscale modelling approach is of high interest for material production and component forming industry. This study aims to demonstrate a systematic and multiscale approach to investigate the rate dependency and anisotropy of the plastic deformation from single crystals to polycrystalline dual-phase steel using both experimental and numerical methods. For single crystals, nanoindentation tests are performed in selective grain orientations with different deformation rates, while for the polycrystalline materials, typical tensile tests with different strain rates are used. An integrated multiscale modeling approach is developed to simulate the rate-dependent anisotropic behavior of these levels. It is demonstrated that the proposed integrated material modeling approach could be used to guide the parameter identification and material design at different scales.

Ductile failure criteria for predicting edge crack initiation of an aluminum sheet metal

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Edge crack initiation and growth in an aluminum sheet metal were investigated under overall uniaxial tension, plane strain tension and shearing loading conditions along its RD, DD and TD directions. Nonlinear finite element analysis was carried out to analyze the deformation of the test samples using anisotropic polynomial quartic yield function with the associate flow rule for the sheet metal plasticity modeling. Once the overall initial load-displacement responses of the test samples were successfully simulated in the finite element analysis, the local stress field in the samples due to the subsequent onset and growth of a diffuse neck prior to edge cracking were further analyzed in greater details using the experimentally measured local boundary conditions, A simple edge crack initiation criterion was derived from the integrated experimental and computational results. The calibrated anisotropic plasticity model and edge crack initiation criteria were applied to predict the locations of necking and potential crack initiation in a hole expansion test of the same aluminum sheet metal.

On the development of macroscopic quadratic plastic potentials for textured FCC crystals with cubic plastic anisotropy

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The overall anisotropic plasticity response of a textured polycrystalline sheet metal is often modeled by a yield stress function or a plastic strain-rate potential in macroscopic plasticity. Such dual plastic potentials may be derived from the micromechanical crystal plasticity analyses of the polycrystalline aggregate using two different approaches. One is the classical Taylor-Bishop-Hill (TBH) crystal plasticity method and another is the method using microscopic plastic potentials. The analytical macroscopic plastic potentials are obtained by the least-square fitting of the discrete plastic yield/flow surfaces using the TBH method. On the other hand, macroscopic plastic potentials are directly derived from the Taylor or Sachs average of microscopic plastic potentials. In this talk, we present some recent results of quadratic plastic potentials derived by these two methods for textured FCC crystals with various degrees of scatter. The similarities and differences between these plastic potentials are comparatively evaluated for the case of cubic plastic anisotropy. Possible applications of crystal plasticity derived macroscopic plastic potentials for modeling textured polycrystalline FCC sheet metals are discussed.

Peridynamic surface elasticity formulation based on modified core-shell model

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Continuum mechanics is widely used to analyse the response of materials and structures to external loading conditions. Without paying attention to atomistic details, continuum mechanics can provide us very accurate predictions as long as continuum approximation is valid. There are various continuum mechanics formulations available in the literature. The most common formulation was proposed by Cauchy two hundred years ago and the equation of a material point is described by using partial differential equations. Although these equations have been successfully utilised for the analysis of many different challenging problems of solid mechanics, they encounter difficulties dealing with problems including discontinuities such as cracks. In such cases, a new continuum mechanics formulation, peridynamics [1-6] can be more suitable since the equations of motion in peridynamics are in integro-differential equation form and do not contain any spatial derivatives. In nano-materials, material properties close to the surfaces can be different than bulk properties. This variation causes surface stresses. In this study, modified core-shell model is utilised to define the variation of material properties in the surface region and compared against peridynamic surface elasticity predictions.

Acknowledgements
This material is based upon work supported by the Air Force Office of Scientific Research under award number FA9550-18-1-7004.

References
[1] Silling, S.A., 2000. Reformulation of elasticity theory for discontinuities and long-range forces. Journal of the Mechanics and Physics of Solids, 48(1), pp.175-209.
[2] E. Madenci and E. Oterkus, Peridynamic theory and its applications, New York: Springer, 2014.
[3] Madenci, E., Barut, A. and Dorduncu, M., 2019. Peridynamic differential operator for numerical analysis. Springer International Publishing.
[4] Imachi, M., Tanaka, S., Bui, T.Q., Oterkus, S. and Oterkus, E., 2019. A computational approach based on ordinary state-based peridynamics with new transition bond for dynamic fracture analysis. Engineering Fracture Mechanics, 206, pp.359-374.
[5] Basoglu, M.F., Zerin, Z., Kefal, A. and Oterkus, E., 2019. A computational model of peridynamic theory for deflecting behavior of crack propagation with micro-cracks. Computational Materials Science, 162, pp.33-46.
[6] Zhu, N., De Meo, D. and Oterkus, E., 2016. Modelling of granular fracture in polycrystalline materials using ordinary state-based peridynamics. Materials, 9(12), p.977.

Deformation of AlSi10Mg parts manufactured by laser powder bed fusion: In-situ measurements incorporating X-ray micro computed tomography and a micro testing stage

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Over the last decade, many industrial sectors have been increasingly adopting Laser Powder Bed Fusion (LPBF) technology, also referred to as Selective Laser Melting, owing to its capability to produce near-net shape complex components from a CAD model and hence offering robust design flexibility without the constraints of conventional manufacturing methods that require a series of manufacturing processes, more material consumption, higher cost and energy.Despite offering numerous benefits, LPBF in a production environment could lead to sub-optimal parts (i.e., part densification is less than 98.5%) due to constraints like the machine capabilities, using recycled powder or time constraints. Even with the state-of-the-art advances in LPBF, parts with 99.9% densification still include defects that result in scattering in the mechanical performance of the parts. The driving force behind such inconsistency is due to randomly distributed defects including gas pores, voids or cracks which are formed during solidification. As each defect is different in size, shape and location, so is its contribution to damage progressions. In this study, LPBF was employed to produce miniature tensile testing specimens from recycled AlSi10Mg powder, leading to sub-optimal densification. To acquire 3D images of the defects and their evolution under different stages of increasing tensile loading, a combination of high-resolution X-ray micro-computed tomography (XμCT) and an in-situ micro-testing stage were utilised. The main drawback of such in-situ tests is that extension values can be measured based on the stage's cross head and hence involve the combined effect of actual deformation and compliance of the machine. While using such data gives an indication on the material behaviour, it doesn't allow for a detailed analysis of the effect of the pores on deformation. Therefore, the resulting 3D images were post-processed, using a combination of Python and MATLAB scripts, to analyse the strain evolution in the vicinity of defects. This approach could also be used to investigate the internal material state of near-net-shaped parts incorporating highly irregular defects during subsequent loading. Thus, helping to assess the reliability of custom build parts.

Acknowledgements
The authors gratefully acknowledge the financial support of the Engineering and Physical Sciences Research Council (EPSRC) under grant reference EP/R021694/1, "3D in-situ based methodology for optimizing the mechanical performance of selective laser melted aluminium alloys".

On the deformation behavior of lath martensite in advanced high strength steels

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Lath martensite is one of the main ingredients of advanced high strength steels. In contrast with what was previously thought as brittle, there is increasing experimental evidence of large strains incorporated with this phase. It is hypothesized that the high plastic deformation, which occurs more favorably parallel to the lath boundaries, can be governed by traces of thin austenite films trapped between series of the laths. In order to account for the key physical mechanisms underlying the apparent high ductility of lath martensite, a homogenized visco-plastic CP model is proposed. The two-scale model describes the aggregate of a locally infinite laminate of alternate BCC and FCC layers. It is shown that the model is capable to address the possible role of the interlath retained austenite films on the deformation and fracture of the martensite aggregate. Further, to reduce the computational cost of the model, a reduced framework is suggested to capture the anisotropic behavior of infinite periodic laminate of thick-thin layers of two phases.

A poro-fracture approach for numerical modelling of fluid-driven fracture in quasi-brittle materials

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Within the framework of nonlinear poromechanics; modeling of fluid driven fracture propagation for porous media has achieved increasing interest in recent years. Typical examples cover many industrial applications as the geologic sequestration of CO2, recovery of conventional and non-conventional oil and gas, radioactivity confinement for the nuclear industry...Investigating fluid-driven fractures is the key to understand and to assess the stability of structures under hydraulic fracturing. Analytical solutions have been proposed to solve the fluid driven fracture within the framework of linear and non-linear elastic fracture mechanics. However, most of these approaches are based on various simplifying assumptions (fracture shape . . .) and are limited to specific applications. On the other hand, several numerical investigations have been proposed to deal with HF in quasi brittle materials. The present contribution is an advancement of these numerical efforts aiming to propose a poromechanical- damage-based model to deal with hydraulic fracturing in concrete. The approach is developed within the framework of poromechanics (Biot's theory) using the FEM. The description of the concrete behavior (or cement-based material in general) and its coupling with other phenomena (Transport, ..) using Biot's theory is motivated by the fact that the value of the Biot coefficient reflecting the material porosity is still relatively high even at the mortar and concrete levels. Therefore, the behavior of concrete is affected by the solid phase (the matrix) and the fluid phase. In the present approach, a mechanical damage based model is used to describe the softening behavior of concrete. In order to describe the water-fracture interaction, crack openings are estimated using the practical method developed by Matallah et al. . This method implemented in the Finite Element code Cast3M (OUVFISS Procedure), is based on the fracture energy regularization. The description of the flow and the transport process in the un-cracked concrete is described by the well-known Darcy equation, which describes the volumetric flow through a saturated porous media under an imposed pressure gradient. When cracks occur, the physical-mathematical description of laminar flow through fractures is described by the cubic law . The physical-mathematical description of the formulation proposed is presented and a validation is performed on a wedge splitting test.

Numerical modeling of hydration-induced fracture propagation in concrete gravity dams

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The mechanical behavior and the durability of massive concrete structures are mostly affected by the hydration process of early age concrete. These reactions are thermo-activated. In a massive structure at early age, the thermal properties of the material, the boundary conditions of the structure and the geometry of the structures contribute to an increase in temperature at the heart of the concrete. This temperature increasing has mechanical consequences on the behavior of the structure. Hydration–induced fractures affect the structural stability.The concrete dams are typical examples of massive structure. They exhibit very complex behavior during the construction phases. Temperatures and autogenous stress evaluations should be assessed in order to improve safety.In the present paper, a numerical modeling strategy is developed to assess the behavior of a massive concrete structure at early ages. The temperature fields and the hydration induced stresses are evaluated at early age. A Chemo-Thermo-Mechanical Models is proposed. The early age behavior is driven by the degree of hydration. A mechanical damage based model is used to describe the softening behavior of concrete. Crack openings are estimated using the practical method developed by Matallah et al [1].Based on the experimental studies, the evolution of the mechanical properties that describe strength and stiffness of the concrete are related to the hydration degree. We propose to compute the initial state due to the hydration process in a concrete gravity dams. The influence of the initial state on the mechanical (under static and seismic loading) behavior is assessed.

References

[1] Matallah M, Borderie CL, Maurel O. A practical method to estimate crack openings in concrete structures. Int J Numer Anal Methods Geomech 2010;34:1615–33. https://doi.org/10.1002/nag.876.

Analysis of interfacial cracks reinforced by nonlinear springs

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The model of different materials joint with bridged interfacial crack is considered. It is assumed that the mechanical bonds or fibers constraining the crack opening exist between the crack faces. The size of the zone filled with bonds or fibers (the bridged zone) can be comparable to the whole crack length. Under the action of the uniform external load normal to the interface normal and shear bond tractions due to different properties of materials are occurred. The bond tractions depend on the crack opening at the bridged zone according to the prescribed nonlinear bond deformation law. The system of two non-linear singular integral-differential equations with Catchy-type kernel is derived for evaluation of bond tractions at the interfacial crack bridged zone. A phenomenological description of the non-linear laws of bonds deformation in the crack bridged zone, taking parts of hardening and softening into account is given. A procedure for the numerical solution of the system obtained is considered. Numerical experiments have been conducted to investigate the influence of the parameters of the non-linear part of the bond deformation curve, the size of the crack bridged zone and the magnitude of the external load on the convergence of the iteration process of the numerical solution of the system. The solution convergence regions for different values of curvature of the bond deformation law non-linear part were obtained. In particular, numerical analysis is revealed that for a given external load, a smaller number of iterations before the solution convergence correspond to a convex bond deformation curve. An increase in the degree of the polynomial for the convex curve leads to a reduction in the number of convergence iterations of the solution over the entire admissible range of external loads and bridged zones. The reverse dependence is observed for a concave bond deformation curve. The stress intensity factors at the crack tip are calculated taking into account both the external loads and the compensating bond tractions in the bridged zones. Analysis of stresses distribution over bridged zones of interfacial cracks was performed. Some steps of the problem solution also are presented in the papers [1-3]. The results obtained may be useful (in spite of the limited potential for transferring the solution of non-linear problems to other scales) in developing procedures for solving problems within the framework of the model of a crack with bonds by finite and boundary element methods.

Acknowledgements

This work is supported by the Russian Science Foundation under grant No. 19-19-00616.

References

[1] Goldstein R.V., Perelmuter M.N. Modeling of bonding at the interface crack, Int. J. of Fracture, 1999, vol.99, N 1-2, p.53-79.

[2] Perelmuter M. Boundary element analysis of structures with bridged interfacial cracks, Computational Mechanics, 2013, vol. 51, N 4, P. 523-534.

[3] Perelmuter M. Analysis of interaction of bridged cracks and weak interfaces, International Journal of Mechanical Sciences, 2018, V. 149, P. 349–360.

Kinetic regularities of the stages of yield plateau and linear strengthening during tension of steel samples. Numerical simulation

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A numerical analysis of the stages of plastic deformation is carried out: the yield plateau and the stage of linear strain hardening of low-carbon steel. During plastic flow, some of the maximums of plastic deformation disappear, while others become leading. The latter provide the basis for the formation of an early macroscopic fracture zone. On the basis of the obtained kinetic diagrams, the features of the localization of plastic deformation at the stage of linear hardening are revealed. Finite-difference analysis based on microstructure is applied. The step-by-step filling method was applied to obtain a representative volume of a polycrystalline sample.It is shown that the Luders bands propagate inhomogeneously, with an average ratio of the front velocity to the loading velocity equal to $\approx$35, which is in good agreement with the data obtained in experiments. It is also shown that the absolute position of the maxima of the distribution of plastic deformation changes with a rate equal to the loading rate. The latter indicates that the relative position of the maxima does not change in the course of plastic flow.

Acknowledgements
This work was supported by the Russian Foundation for Basic Research, Grant No. 20-31-90016.

Efficient and robust fully implicit return mapping algorithms for crystal and continuum plasticity

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Crystal and continuum plasticity theories describe plastic behavior in metals on two tightly linked material scales, i.e. the grain scale and the component scale. From the multi-scale material modelling perspective, the efficiency and robustness of the solvers involved in the modelling framework, are of vital importance for the overall performance. Stable, fully implicit return-mapping algorithms are developed for solving both crystal and continuum plasticity models. Their implementation into user-defined material subroutines (UMAT) in a finite-element (FE) software are made available as open-source. Numerical stability is gained by an improved initial guess for the stress solution and by applying a line search for each Newton iteration. FE simulations were run, demonstrating the performance of the new implementations. A simulation of the necking of an aluminium single crystal and of the deformation of a representative volume element of a polycrystalline aluminium were performed, demonstrating the stability and high efficiency of the new crystal plasticity approach. Similarly, continuum plasticity simulations revealed unconditional stability and very high efficiency of the new implementation of the advanced anisotropic Yld2004-18p yield function. It performs equally fast as the much simpler von Mises and Hill implementations available as standard models in the software. This enables full exploitation of advanced yield functions as the new standard in industrial FE applications.

Failure analysis of water wall furnace tube

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Water wall furnace tube in vertical boiler at power plant was failed after 15 years in-service. The failed tube made of low alloy steel type (DIN 17175, Grade 15Mo3) with outer diameter and wall thickness 57 mm and 5.6 mm, respectively. The failed tube was received for failure analysis. The tube was subjected to visual examination, non-destructive test, chemical analysis, microstructure observation, and hardness test. The results of chemical composition showed the conformity of tube material with the required specifications of (DIN 17175, Grade 15Mo3). Moreover, The deposited products collected from tubes inner surface at the fire side were analyzed using X-ray diffraction (XRD) technique. Microstructure of the bulging area exhibited complete decomposition of pearlite structure in addition to intersected voids at grain boundaries. The failure may be attributed mainly to localize overheating at this damaged area, where the metal temperatures exceed design limits. Generally, bulging occurs when fire side temperatures are not uniform, which develop hot spot regions. Moreover, the relatively heavy internal deposition of the oxide scales insulated the tube wall from cooling effects of the water, contributing to overheating. These overheating results in structure degradation (pearlite decompositions and voids formation) of the tube wall thickness causing decrease of material strength.

Microstructure and mechanical properties of AISI4130 steel processed by L-PBF

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In this study, we investigate the relationship between the mechanical properties and the microstructures of L-PBF processed low alloy AISI4130 steel in as-built and heat treatment condition processed by water and gas atomized. As a result of TEM observations, Precipitates of the type Si, Mn were observed on as-built and direct tempering samples respectively in the gas atomized. It has also confirmed that lath martensite occurs in the as-built sample. In the water atomized samples, TEM images reveal precipitates of rich Si. We also performed the Vickers hardness tests for As and direct tempered AISI4130 respectively. The hardness value decreases 20% in the gas atomized, whereas decreases only 10% in the water atomized by direct tempered heat treatment. This is because the inclusions and the carbide precipitates are located at the grain boundaries in the water atomized more than in the gas atomized which would cause a more refined grain structure than that in the gas atomized samples. These results showed that the water atomized variant of the steel powder could improve their performance comparable to the gas atomized alloy by heat treatment.

The effect of overload block size on fatigue crack growth life

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In this study, the effect of the block overload duration on fatigue crack propagation life was experimentally investigated. In the experiments, different sizes of overloads involving different number of cycles were applied on compact tension (CT) specimens machined from rolled Al-7075-T6 plates. The experiments showed that if the number of cycles in the repeated block overloads are extended, the crack growth accelerates, since the overload cycles dominate the overall crack growth. In the case of repeated block overloads with small number of cycles, because of the higher number of newly generated and repeated plasticity-induced crack closure effects at the crack tip, crack propagates slower than the case of single overload. After the tests, crack growth lives were also calculated using some models existing in the literature, and the results were compared with the experimental data. Close results to those of the experiments were obtained with Wheeler model and some modifications of it.

Acknowledgements
The financial support by The Scientific and Technological Research Council of Turkey (TUBITAK) under Project Number: 217M609 for this study is gratefully acknowledged.

Verification and validation of numerical models of materials of the lumbar spine

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Currently, one of the main causes of disability in the population are degenerative-dystrophic diseases of the spine. The intervertebral disc is exposed to the most degenerative changes, which needs to be replaced with an artificial element. The intervertebral disc has a complex structure, which ensures the redistribution of stresses in the vertebrae. The intervertebral disc consists of three major types of tissues: the nucleus, which is a gelatinous mass, and surrounding the dense fibrous anulus. Above and below the discs are covered with a thin layer of white fibrous cartilage. Intervertebral discs perform a shock-absorbing function in the spine [1-2]. Such damping properties of the intervertebral disc prevent premature wear of the vertebrae. To study the mechanical properties of the constituent discs of materials, in-vitro methods are mainly used: experiments on tension, compression, shear, and indentation. Computer modeling is used to assess the stress-strain state of the intervertebral disc under dynamic loads equivalent to physiological conditions. To create a numerical model of the intervertebral disc, it is necessary to develop models of its constituent materials. Tensile and compressive experiments are used to verify and validate material models. The aim of this work was to develop numerical models of intervertebral disc tissues and their verification. A poroelastic model was used to describe the mechanical behavior of materials, implemented in the method of movable cellular automata. The parameters of the poroelastic model for different types of components of the intervertebral disc were taken from the literature [3-4]. To verify the material models, numerical experiments were carried out on uniaxial tension for the material of the annulus fibrosus, uniaxial compression for the material of the nucleus pulposus and indentation for the cartilaginous plate. The loading curves and stress distribution in the model specimens were analyzed. The analysis showed that the developed models of materials describe rather accurately the mechanical behavior of the tissues making up the invertebrate disc under dynamic loading. The developed numerical models of materials are supposed to be used in the future to create a numerical model of the lumbar spine L4-L5 under dynamic loading equivalent to physiological loads.

Acknowledgements
The investigation has been carried out at financial support of the Russian Science Foundation (Project No. 21-79-00296).

References

[1] Ding F., Jia Z., Zhao Z., Xie L., Gao X., Ma D., Liu M. European Spine Journal. 2017. No 26 (3). pp. 806-815.
[2] Park W.M., Kim Y.J., Wang S.B., Kim Y.H., Li G.A. Mathematical Biosciences and Engineering. 2020. No 17 (4). pp. 2970-2983.
[3] Hansson T., Sandström J., Roos B. Spine. 1985 No 12. pp.158–160.
[4] Salzmann S.N., Plais N., Shue J., Girardi F.P. 2017. No 10 (2). pp 153-159.

Numerical analysis and extension of a porous plasticity model for ductile failure

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The nucleation, growth, and coalescence of micro voids are known to be the dominant micromechanical phenomenon that drives ductile failure. The porous microstructure of materials led to the development of many predictive computational models. In the current study, a rate-independent porous plasticity model is analyzed and extended through representative volume element (RVE) calculations. The model is based on the yield potential presented in Cocks (1989), which is implemented as a user material subroutine for finite element solver Abaqus. Preliminary results of the model are presented previously in Yalcinkaya et al. (2019). RVE simulations has been a widely used for the prediction of void evolution and the ductile damage of porous materials. In this work, RVE simulations are performed on cubic models with a spherical void in the center whose matrix material is represented by classical von Mises plasticity. A constant triaxial stress state is applied to the RVE model with a displacement-controlled method. Based on the results from the current model and the RVE analysis, a modification to the constitutive framework is proposed. Numerical results show a good fit between the modified porous plasticity model and the RVE calculations. In addition, ductile failure simulations are performed using smooth and notched tensile specimens using the current model, the GTN model and the uncoupled Johnson-Cook (JC) damage model. Calibration parameters of all three models are obtained from the RVE calculations. The extended framework provides a compact coupled damage model while having comparable predictions to the GTN and the JC models.

Acknowledgements
Tuncay Yalçinkaya gratefully acknowledges the support by the Scientific and Technological Research Council of Turkey (TÜBİTAK) under the 3501 Programme (Grant No. 117M106).

References
[1] A. C. F. Cocks, Inelastic deformation of porous materials, Journal of the Mechanics and Physics of Solids 37 (1989) 693-715.
[2] T. Yalçinkaya, C. Erdogan, I. T. Tandogan, A. Cocks, Formulation and implementation of a new porous plasticity model, Procedia Structural Integrity 21 (2019) 46-51.

Numerical analysis of anisotropic grain structure effect through crystal plasticity

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Different manufacturing processes such as flow forming, rolling, wire drawing and additive manufacturing induce anisotropic grain structure and texture evolution at the micro scale, which results in macroscopic anisotropic plastic behavior. Especially, the development of columnar grain structure is quite common in such processes. A systematic physical analysis is necessary to evaluate the influence of both grain morphology and texture on the mechanical response of the metallic alloys. In this context, the objective of the present study is to investigate the influence of the grain morphology and texture through crystal plasticity finite element (CPFEM) simulations (see e.g. [1,2]). Various types of representative volume elements (RVE) are generated through Voronoi tessellation and subjected to uniaxial tensile loading in different directions. A detailed analysis is conducted to evaluate the influence of grain structure and orientation alignment separately on the constitutive behavior of the material through homogenization for different microstructures. The initially employed local crystal plasticity model cannot predict the size effect, which should be considered for certain microstructures. Therefore, a strain gradient crystal plasticity framework (see e.g. [3]) is also applied for particular microstructures and preliminary results are discussed considering the effect of size, orientation and morphology.

References

[1] T. Yalcinkaya, W.A.M. Brekelmans, M.G.D. Geers, BCC single crystal plasticity modeling and its experimental identification, Modelling and Simulation in Materials Science and Engineering 16 (8) (2008) 085007.
[2] T. Yalcinkaya, S.O. Çakmak, C. Tekoğlu, A crystal plasticity based finite element framework for RVE calculations of two-phase materials: Void nucleation in dual-phase steels, Finite Elements in Analysis and Design 187 (2021) 103510.
[3] T. Yalçinkaya, İ. Özdemir, İ.T. Tandoğan, Misorientation and grain boundary orientation dependent grain boundary response in polycrystalline plasticity, Computational Mechanics 67 (2021) 937-954.

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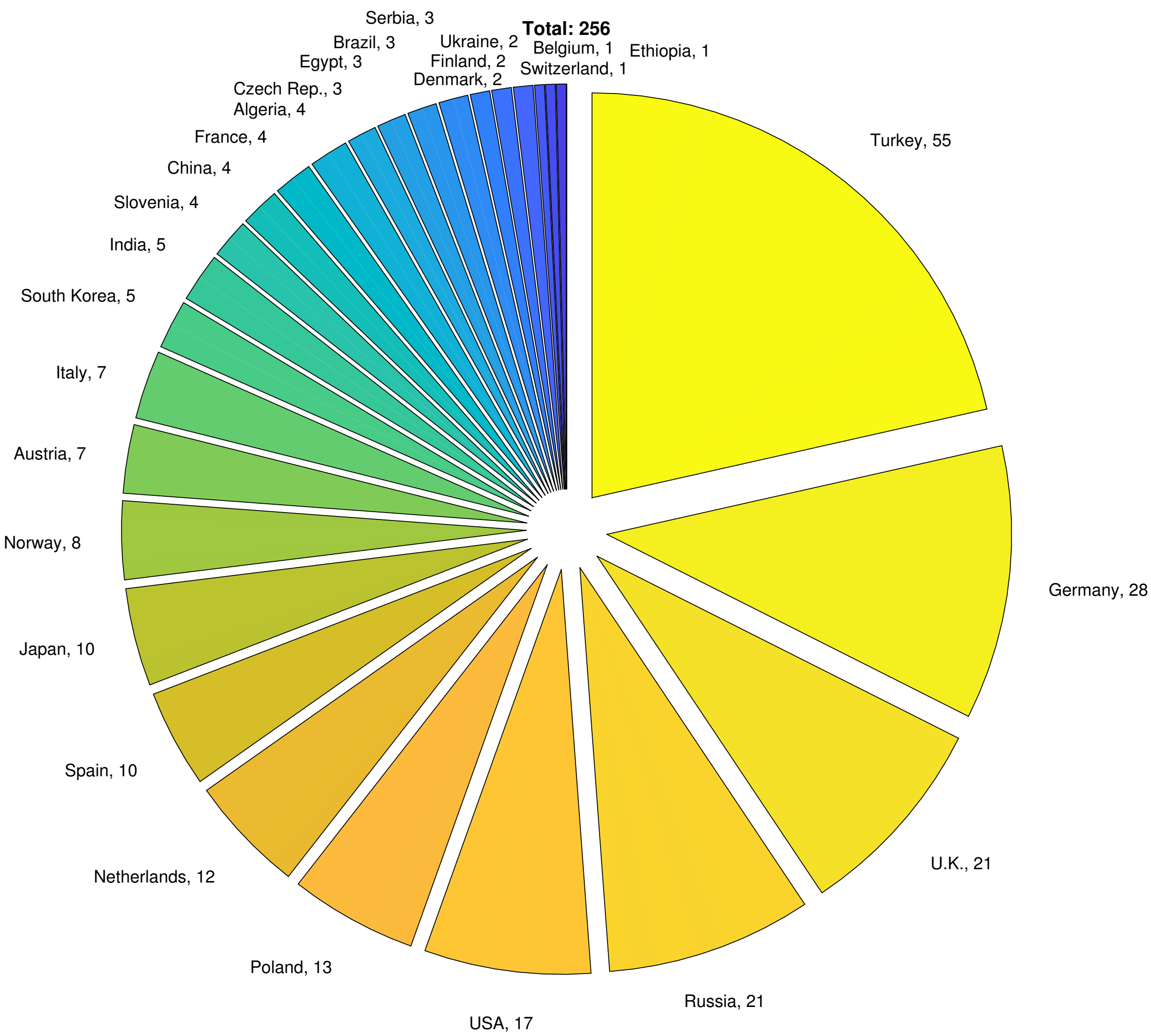

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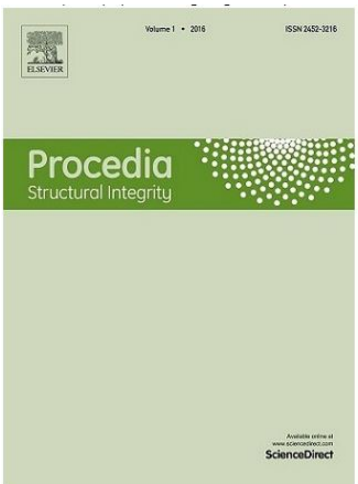

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