THE XV FINNISH
MECHANICS DAYS

jamk

in association with
IFME 2024 Forum

OCT 2 - 4, 2024
Jyväskylä

Book of Abstracts
– XV Finnish Mechanics Days

Editors
Tero Tuovinen
Reijo Kouhia
Jarkko Niiranen

jamk | University of Applied Sciences

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The Finnish National Committee on Theoretical and Applied Mechanics

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Editors:

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Programme **The XV Finnish Mechanics Days in association with IFME 2024 Forum**

October 2 - 4, 2024, Jyväskylä (Rajakatu 35, 40200 Jyväskylä, Finland)

Time	Place	Wednesday 2.10.			
9:00	**F1/FP05**	**Registration & Coffee**			
9:30	**FP05**	**Opening words**			
10:00	**FP05**	**Plenary 1: Rolf Stenberg**			
	Title	Finite elements for elastic contact – Penalty and Nitsche			
	Chair	Tero Tuovinen			
10:45	**FP05**	**Plenary 2: Fredrik Larsson**			
	Title	On finite element procedures for efficient multiscale modeling in solid mechanic			
	Chair	Tero Tuovinen			
11:30	**Rajakatu**	**Lunch**	**Ravintola Twist**	**Café Curve**	
12:30		**Parallel sessions**			
	Place	D148	D149	F304	F305
	Chair(s)	Anneli Kakko and Silvia Satorres	Peter Råback	Tero Tuovinen	Timo Saksala / Matti Kurki
	Session	**IFME 1: Industry, innovation and infrastructure**	**1: Finite element analysis 1**	**2: Digital twins and artificial intelligence**	**3: Computational fluid dynamics / 4: Thin structures**
12:30		**Anneli Kakko**: International Forum of Mechanical and Mechatronic Engineering (IFMME) and its network	**Kilwa Ärölä**: A simulation workflow to evaluate the wearing comfort of in-ear headphones	**Paula Tapaninaho**: Solution of Boundary Value Problems using Machine Learning	**Ashish Pawar**: Analysis of flow behavior of bioinks outside the 3D-Printing Nozzles
12:50		**Arturo López Riquelme**: Specular Zero: Towards a sustainable production in plastic injection industry	**Humberto Almeida Jr**: Multiscale modelling of high- performance thermoplastic composites in transverse tension and bending using the FE2 method	**Atte Koskinen**: Enhancing digital twin development: The role of large language models in advancing maturity levels	**Mohamed A. Sayed**: Optimizing 2D Stormwater filter design through parametric analysis of grain characteristics
13:10		**Gia-Khanh Pham**: Indentation Hardness of 3D-Printed Metals	**Ole Kranzosch**: Effects of gradient elasticity in coupled Cahn-Hilliard type of diffusion	**Oleg Rogov**: Modern Approaches to Autonomous Excavation: A Literature Survey	**Jukka-Pekka Keskinen**: Large Eddy Simulation of the Flow Over Turku with an Application to an Operational Air Quality System
13:30		**Francisca Guerrero-Villar**: 3D printing technique by stereolithography applied to make an injection mold with photopolymer resin	**Timo Manninen**: Computationally efficient finite element model for continuous annealing of stainless-steel strips	**Mihiran Galagedarage Don**: An Improved Lumped Segment Numerical Model for S.A. Agulhas II Propulsion Shaft Line Digital Twin	**Esa Alakoski**: Flexible thin film thermoelectric devices for use as an energy source for autonomous sensors
13:50		**Javier Aceituno**: Efficient Modeling of the effects of discrete supports in railway track dynamics	**Alexander Nemov**: Numerical simulation of the human Achilles tendon: challenges and solutions		**Federica Mancini**: Geometry characterisation and structural stress analysis of welding-induced distortions in large thin-walled structures
14:10		**Silvia Satorres Martinez**: Discussion about the future cooperation - word is free	**Timo Saksala**: Phase field method for brittle fracture implemented with polygonal finite elements		**Mika Malinen**: On the derivation of constant-coefficient partial differential equations for elastic shells
14:30	**FP05**	**Coffee**			
15:00	**FP05**	**Round Table 1: Tutkimusyhteistyö – yliopistojen, tutkimuslaitosten ja yritysten roolit**			
	Chair	Jarkko Niiranen			
16:00		END			
16:10		Bus to Ylistö	Rajakatu 35, D1 (main door)		
16:30	Ylistö	Optional: Tour to JYU laboratory	Survontie 9 D	The parking lot at the lower yard of the Department of Physics	
17:30		End of tour	Walk to Aalto2	Alvar Aallon katu 7	
17:30		Bus to Aalto2	Rajakatu 35, D1 (main door) / Hannikaisenkatu 35 (in front of the Original Sokos Hotel Alexandra)		
18:00	**Aalto2**	**Welcome Cocktail and Tour at Aalto2**	**Aalto2 museum center**	**Alvar Aallon katu 7**	
19:30		End	Bus to city centre/Rajakatu		
20:00		End	Bus to city centre/Rajakatu		

Time	Place	Thursday 3.10.			
10:00	**F1/FP05**	**Registration & Coffee**			
10:30	**FP05**	**Plenary 3: Marcelo Dias**			
	Title	Is Fracture Failure or Function? The Two Sides of Meta-materials			
	Chair	Jarkko Niiranen			
11:30	**Rajakatu**	**Lunch**	**Ravintola Twist**	**Café Curve**	
12:30		**Parallel sessions**			
	Place	D148	D149	F304	F305
	Chair(s)	Anneli Kakko and Ciprian Lapusan	Antti Niemi	Sven Bossuyt and Mikko Hokka	Tero Frondelius
	Session	**IFME 2: Education in the digital age and applied research**	**5: Fracture, damage and wear**	**MS1: Imaging and image-based methods in experimental mechanics**	**MS2: Industry cases**
12:30		**Ciprian Lapusan**: Promoting Engineering Education Excellence - the NextGEng Project	**Akseli Leraillez**: Fracture toughness of hierarchical lattices	**Sven Bossuyt**: Optimizing patterns for DIC	**Sami Kreivi**: Transient thermal stress FE-analysis method development
12:50		**Petri Luosma and Tarja Moilanen**: Experiences of international co-teaching in a European higher education context	**Ville Vanhala**: Fretting Safety Factor	**Guilherme Corrêa Soares**: Micromechanical testing inside the scanning electron microscope: leveraging image-based methods to enhance materials research	**Ville Tuura**: Experimental study to determine static coefficient of friction
13:10		**Silvia Satorres Martinez and Anneli Kakko**: Cases of Experiential Learning projects: A successful model for HEI student-company cooperation	**Sulata Dhakal**: A continuum material model for concrete	**Ville Björklund**: High throughput tensile testing for characterization of static strain aging	**R. Arturo Rubio Ruiz**: Numerical analysis of mechanical integrity of marine engine components operating with zero- carbon fuels
13:30		**Steffen Greuling**: Experimental and numerical strength assessment of a plate with a notch subjected to uniaxial loading – A lab based approach in undergraduate mechanical engineering education	**Maliheh Jahanbakhsh**: Computer vision framework for crack detection and prediction of air leakage through concrete cracks in buildings	**Mikko Hokka**: X-Ray phase contrast imaging of dynamic compressive fracture of fiber reinforced polymer composite and granitic rocks	**Antti-Jussi Vuotikka**: Impact-induced leaking of fuel line
13:50		**Ciprian Rad**: Forward kinematics and assembly modes analysis of 3-RPS parallel manipulators by using Sylvester's dialytic elimination method	**Guijia Li**: Application of a linear-transformation-based anisotropic fracture model in quenching and partitioning steels	**Hossein Moghanni**: Simultaneous X-Ray diffraction, infrared and DIC measurements during tension tests of metastable austenite containing steels	**Eero Ikäheimo**: Reaaliaikainen termisten ja sähkömekaanisten systeemien dynaaminen monikappale rinnakkais-simulaatio pyöräkuormaajamallissa
14:10		**Ciprian Lapusan**: Discussion about the future cooperation – word is free		**Mikko Hokka**: Virtual mechanics laboratory based on DIC	**Eetu Autio**: AI-Empowered MODSIM for Design Exploration
14:30	**FP05**	**Coffee**			
15:00	**FP05**	**Round Table 2: Advancing researcher training in advanced manufacturing: innovative educational and collaborative models in Finland**			
	Chair	Heidi Piili			
16:00		End			
16:30	Rajakatu	Optional: Tour to Jamk laboratory			
17:30		end of tour			
19:00	**Vesilinna**	**Dinner**	**Café & Restaurant Vesilinna**	**Ihantolantie 5**	
22:30		End			

Time	Place	Friday 4.10.		
9:30	**F1/FP05**	**Registration & Coffee**		
10:00		**Parallel sessions**		
	Place	D148	D149	F304
	Chair	Anneli Kakko and Gia-Khanh Pham	Tero Frondelius and Reijo Kouhia	Pekka Neittaanmäki
	Session	**IFME 3: Industry, innovation and infrastructure**	**MS3: Fatigue-analysis, experiments and design**	**6: Vibration and stability**
10:00		**Kati Valpe-Ojala**: gH2ADDVA – Adding Value by Clean Hydrogen production	**Reijo Kouhia**: Some new developments in the continuum-based fatigue modelling approach	**Jussi Jalkanen**: Wind-induced vibration control in high-rise buildings
10:20		**Stefan Lampenscherf**: Simulation of Hydrogen Induced Failure in High-Strength Steel	**Joona Vaara**: On crack initiation and non-propagation	**Zeinab Soleimani Javid**: Numerical analysis of in-Plane static and dynamic behavior of triangular lattices in a curved beam structure
10:40		**Francisco Moral-Pulido**: Oscillating viscous flow around a circular cylindrical post confined between two parallel plates	**Kimmo Kärkkäinen**: The effect of over- and underloads on fatigue life	**Samuli Rytömaa**: Design of a non-linear wire-rope tuned mass damper; linearized model based approach
11:00		**Anneli Kakko**: Announcement IFM2E 2025 & Closing IFM2E 2024	**Saana Bergman**: Bayesian approach to uncertainty quantification in ultrasonic non-destructive testing	
11:30	**Rajakatu**	**Lunch**	**Ravintola Twist**	**Café Curve**
12:30		**Parallel sessions**		
	Place	D148	D149	F304
	Chair	Tero Tuovinen	Heidi Piili	Reijo Kouhia
	Session	**7: Finite element analysis 2**	**8: Additive manufacturing**	**9: Analysis**
12:30		**Tomi Kankkunen**: Design space exploration of manufacturability and mechanical performance of foldable Miura-ori origami structures	**Juha Jeronen**: Fundamental Thermoelastic Behavior Modeling for L-PBF Additive Manufacturing	**Qiang Cheng**: Natural Flame Spectral Analysis and Chemi-luminescence Imaging of Diesel Spray Combustion
12:50		**Youqi Zhang**: Damage Updating in Finite Element Models by Using Computer Vision and Phase Field Method	**Mohammaderfan Khodabakhshi**: 3D chiral metamaterial unit cell capable of two deformation mechanisms under compression	**Jarkko Niiranen:** Buckling and post-buckling of twisted strips
13:10		**Milad Omidi**: Engineering the micro-architecture of triangular lattice improving the resistance against crack propagation	**Matti Kurki**: LPBF Additive Manufacturing; Modeling and Material Test Results	**Pekka Neittaanmäki**: Kokemuksiani tutkijakoulutuksesta
13:30	**FP05**	**Coffee**		
14:00	**FP05**	**Plenary 4: Giovanni Meneghetti**		
	Title	The Peak Stress Method for the automated FEA-assisted design of welded structures subjected to constant and variable amplitude multiaxial fatigue loads		
	Chair	Reijo Kouhia		
14:45	**FP05**	**Closing words**		
15:00		End		

Welcome to the XV Finnish Mechanics Days!

You are warmly welcome to the XV Finnish Mechanics Days, a triennial forum for academic and industrial research in theoretical, computational and experimental mechanics. The conference is held at Jamk University of Applied Sciences in Jyväskylä, Finland, on October 2–4, 2024. The event of year 2024 is organized by Jamk University of Applied Sciences, together with the Finnish National Committee of Theoretical and Applied Mechanics and in association with International Forum of Mechanical and Mechatronics Engineering (IFME) providing the Special Technology Sessions of the program. This book of abstract starts with a few words about the objectives and history of the Finnish Mechanics Days, followed by some basic information about IFME and the city of Jyväskylä. More information about the conference can be found in the web pages of the event:

https://www.jamk.fi/en/project/welcome-to-the-xv-finnish-mechanics-days

Foreword

Collaboration across diverse fields – including civil engineering, mechanical engineering and fluid dynamics – as well as fostering partnerships between industry and academia are the key elements of the ethos of the Finnish Mechanics Days. The primary objective of the conference is to stimulate academic research and its alignment with industrial development in the variety of mechanics disciplines, from solid and soil mechanics to fluid dynamics. The conference offers a gathering point for researchers, educators, engineers and other professionals to come together for connecting, engaging in discussions and exchanging knowledge.

Throughout its history, the Finnish Mechanics Days has consistently fulfilled its mission of bringing together individuals involved in mechanics, from different perspectives: theoretical, computational and experimental; academic and industrial; from atomistic scales to the macro-scale. This enduring tradition continues to provide a vital forum for advancing the field of mechanics in Finland, Europe and beyond. This time, a special emphasis in the discussions is put on considering the possible advancements of artificial intelligence and the related technologies within the field of mechanics.

The Finnish Mechanics Days conference had its inaugural edition in Oulu in 1982 and has continued as a triennial event since then, except for the postponement caused by the global pandemic in 2021. After the first conference, the sequence of locations, i.e., university cities, have been Tampere (1985), Espoo (1988), Lappeenranta (1991), Jyväskylä (1994), Oulu (1997), Tampere (2000), Espoo (2003), Lappeenranta (2006), Jyväskylä (2009), Oulu (2012), Tampere (2015), Helsinki (2018) and once again Lappeenranta (2022).

The Finnish National Committee of Theoretical and Applied Mechanics, established in 1952 and representing Finland in the International Union of Theoretical and Applied Mechanics (IUTAM), is responsible for the continuation of the conference series by supporting the local organizing unit, a Finnish university or research institute.

From the beginning, this conference series has served as a vital platform for exploring mechanics, covering solids, soils, rocks and fluids. The conference topics have covered a wide range of sub-fields of science and engineering involving mechanics, encompassing structural analysis, mechanics of materials, fracture mechanics, fatigue, thermomechanics, micromechanics, contact mechanics, multibody dynamics, mechatronics, fluid dynamics, fluid-structure interaction, numerical methods and the design of structures and machines, as well as the related industrial and medical applications.

Once again, the conference program and the book of abstract confirm the topical diversity and invite us to learn, discover and enjoy – we wish you welcome to the conference!

Conference chairmen

Tero Tuovinen,
Jamk University of Applied Sciences
Reijo Kouhia,
Tampere University, Chair of Finnish National Committee of Theoretical and Applied Mechanics
Jarkko Niiranen,
Aalto University, Secretary of Finnish National Committee of Theoretical and Applied Mechanics

IFME Forum

IFM2E is an annual seminar taking place in different European countries. The IFM2E is organized by the local universities in different countries, and on 2024 the seminar will be held together with the XV Finnish Mechanics Days.

IFME network is a cooperation between companies and universities in the field of mechanical and mechatronic engineering. Strong dialogue between industry and universities is to support public sector decision making, and also get new insights for cooperation possibilities.

IFME chairmen

Anneli Kakko, Jamk University of Applied Sciences
Ciprian Lapusan, Technical University of Cluj-Napoca, Romania
Silvia Satorres, University of Jaen, Spain

Conference Committee

Tero Frondelius, Wärtsilä
Rami Korhonen, University of Eastern Finland
Reijo Kouhia, Tampere University
Marko Matikainen, Lappeenranta University of Technology
Antti Niemi, University of Oulu
Jarkko Niiranen, Aalto University
Heidi Niskanen, Patria
Heidi Piili, University of Turku
Peter Råback, CSC - IT Center for Science
Tero Tuovinen, Jamk University of Applied Sciences
Kati Valpe-Ojala, Jamk University of Applied Sciences

Jyväskylä

Jyväskylä, situated in the heart of Finland, is a remarkable conference destination known for its unique blend of natural beauty, modern facilities, academic excellence, and cultural richness.

One of the most striking aspects of Jyväskylä is its scenic setting. The city is surrounded by breathtaking natural landscapes, with Lake Päijänne. This stunning backdrop provides a picturesque and serene environment for conferences, offering attendees a tranquil escape from urban life.

Modern conference facilities in Jyväskylä are equipped with state-of-the-art technology, making them versatile and suitable for a wide range of events, from small meetings to large international conferences. These facilities ensure that attendees have access to the resources they need for a successful and productive conference experience.

Jyväskylä's academic influence is another noteworthy feature. It is home to the prestigious University of Jyväskylä, which is known for its research excellence. This academic prominence attracts conferences from various fields of study, fostering knowledge exchange and scholarly discourse.

The city places a strong emphasis on sustainability and eco-friendliness, which is reflected in many of its conference venues and accommodations. This commitment to environmental responsibility appeals to event organizers and attendees who prioritize sustainability.

Culturally, Jyväskylä offers a rich and diverse experience. The city boasts theaters, museums, galleries, and music festivals, providing ample opportunities for conference participants to explore Finnish culture and heritage during their stay. These cultural attractions add depth and enrichment to the conference experience.

Lastly, Finnish hospitality is renowned for its warmth and welcoming nature. Visitors to Jyväskylä can expect friendly service and assistance from the local community, ensuring that they feel not only well-accommodated but also genuinely welcomed. Attendees can feel secure and comfortable throughout their stay, contributing to a stress-free conference experience.

In summary, Jyväskylä, as a conference venue, offers a harmonious blend of modernity, natural beauty, academic excellence, cultural enrichment, and sustainability. Its unique combination of features makes it an appealing and memorable destination for a wide range of conferences and events, promising enriching experiences for all attendees.

Contents

Plenary lecturer – Rolf Stenberg

Aalto University

Prof. Stenberg obtained his Master of Science in 1980, Licentiate of Technology 1981 and Doctor of Technology 1984. He came the Professor of Mathematics in the Tampere University of Technology in 1999 and the Professor of Applied Mathematics in TKK–Aalto in 2001–2021. He has supervised 11 Ph.D. and 5 Licentiate theses. In his early career, Rolf Stenberg has visited for example, as a Research engineer, Philips Research and Development Laboratories, Eindhoven, The Netherlands between 1978–1979. He has given 51 invited talks at international conferences and 48 talks at foreign universities. He has also awarded The Lorenz Lindelöf Price in Mathematics by the Finnish Society of Sciences and Letters 2019. Now he has Emeritus contract at the Department of Mathematics and Systems Analysis in Aalto University.

He delivers the Plenary Lecture 1 on Wednesday at 10:00 - 10:45 in FP05 (Chair: Tero Tuovinen):

Finite elements for elastic contact – Penalty and Nitsche

Finnish Mechanics Days 2024

Finite elements for elastic contact – Penalty and Nitsche

Rolf Stenberg[1], Tom Gustafsson[2], and Juha Videman[3]

Abstract

The penalty method is widely used method in contact mechanics [3]. (As an example, we mention the program package ABAQUS.) This despite the shortcomings of the method, which are evident from a mathematical analysis. First, it is non-conforming which has the consequence that the penalty parameter has to be chosen big, in order that the convergence rate is optimal. A high penalisation, however, leads to a ill conditioned discrete linear system. Furthermore, a high penalisation leads to an overrefinement along the boundary when adaptive schemes are used, cf. [2]. However, in the engineering literature the question of how to choose the penalty parameter is not adequately addressed [1]. In our work we investigate these questions.

We perform both an priori and a posteriori error analysis, and thorough numerical tests, which show that the conflicting requirements for the penalty parameter have the consequence that an optimally convergent method cannot be obtained. As a reference we use the Nitsche method [1], which can be seen as a consistent variation of the penalty method.

References

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[3] Peter Wriggers. *Computational Contact Mechanics*. Springer, 2 edition, 2006.

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[2]Department of Mechanical Engineering, Aalto University
[3]CAMGSD/Departamento de Matemática, Instituto Superior Técnico, Universidade de Lisboa, Portugal

Plenary lecturer – Fredrik Larsson

Chalmers University of Technology, Sweden

Fredrik Larsson is Professor in Structural Mechanics at the Department of Industrial and Material Science, Chalmers University of Technology, Sweden. He received his doctorate in Solid Mechanics at Chalmers University of Technology in 2003. His research interests concern numerical efficiency for finite element simulations, in particular for multiscale problems in solid mechanics. In 2021 and 2023 he has co-chaired the ECCOMAS Thematic conference on Adaptive Modeling and Simulation (ADMOS).

He delivers the Plenary Lecture 2 on Wednesday at 10:45 - 11:30 in FP05 (Chair: Tero Tuovinen):

On finite element procedures for efficient multiscale modeling in solid mechanics.

Finnish Mechanics Days 2024

On finite element procedures for efficient multiscale modeling in solid mechanics.

Fredrik Larsson[1], Kenneth Runesson and Ralf Jänicke

Abstract This contribution concerns finite element procedures for micro-heterogeneous solids. Multiscale formulations using computational homogenization, reduced order modeling for simulations and the pertinent error control are discussed.

Key words: Computational Homogenization, Reduced Order Modeling, error control

Introduction

A vast amount of problems in engineering and science involve partial differential equations that need to be resolved on vastly separated length and time scales. Rather than resolving all scales in a single simulation, it is often sufficient to include the effects of the micro-scale features in terms of the macro-scale response. This can be obtained using computational homogenization. For solid mechanics applications exhibiting two distinct length scales, this means solving the structural problem of engineering interest, while accounting for the material micro-structure explicitly through micro-scale problems that replace conventional (empiric) constitutive model for the effective material.

For linear stationary problems, computational homogenization can be conducted in an "off-line" phase, where by the effective coefficients for the macroscale problem can be pre-computed. However, for the case of a non-linear and/or transient problem, the macroscale and microscale problems have to be solved for concurrently. Although significantly more efficient than resolving the original problem on the finest length-scale, this results in extremely demanding computations.

This contribution targets the formulation of and efficient numerical solution techniques for problems with with two distinct spatial length scales.

Methodology

We adopt the technique of Variationally Consistent Homogenization (VCH), cf. Larsson et al. [1], as one means of constructing schemes for computational homogenization. By introducing the kinematics of chosen homogenized fields on the macro-scale, the effective macro- and microscale problems can be derived from the weak form of the original problem. Furthermore, if the the original problem is derived from a potential, VCH allows for

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the identification of a generalized macro-homogeneity condition, whereby the variational structure of the problem can be retained in the two-scale formulation.

In order to further decrease the computational cost of the problem, we introduce Numerical Model Reduction (NMR) on the (discrete) micro-scale problems by adopting a reduced basis approximation. In order to assess the introduced approximation, goal-oriented error estimators are implemented for the problem. For the special case of linear transient problems, guaranteed bounds for the error due to the NMR approximation has been developed, cf. Ekre et ak. [2].

Considered applications

We consider a number of relevant applications. As a first example, transient heat flow in microheterogeneous solids is considered, see [2]. The VCH-procedure is used to derive macro- and micro-scale problem formulations. From linearity, NMR based on spectral decomposition is combined with guaranteed error control. Further examples (linear and nonlinear) consolidation (cf. [3, 4]), electro-chemical transport (cf. [5], and modeling deformation in poly crystals.

References

[1] F. Larsson, K. Runesson and F. Su. Variationally consistent computational homogenization of transient heat flow. *Int. J. Num. Meth. Engng.*, 81:1659–1686, 2010. doi:10.1002/nme.2747

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Plenary lecturer – Marcelo Dias

The University of Edinbourgh

Dr Dias obtained his bachelor's in physics at the State University of Sao Paulo, Brazil. Four years later, he commenced a MSc in theoretical physics from his alma mater. In 2012, he obtained his PhD degree from the University of Massachusetts, USA, where he researched on the mechanics of origami structures and growth mechanisms. Dr Dias has worked as a researcher on a broad range of topics in structural engineering and applied mathematics at Brown University School of Engineering (USA), Aalto University (Finland), and the Nordic Institute for Theoretical Physics at KTH (Sweden). Before joining the University of Edinburgh, Dr Dias was an Associate Professor of mechanical engineering at Aarhus University in Denmark, where he lead his research group 'Mechanical Metamaterials and Soft Matter'.

He delivers the Plenary Lecture 3 on Thursday at 10:30 - 11:15 in FP05 (Chair: Jarkko Niiranen):

Is fracture failure or function? The two sides of meta-materials

Finnish Mechanics Days 2024

Is Fracture Failure or Function? The Two Sides of Metamaterials

Marcelo A. Dias[1], Leo de Waal, and Matthaios Chouzouris

Abstract The subject of mechanical metamaterials has garnered significant attention due to their unique properties, yet their practical applications remain limited. Traditionally viewed as stand-alone structures, metamaterials are characterized by their geometry at all length scales. This work proposes a novel application of mechanical metamaterials as interface regions joining two materials, offering a potential replacement for bulk adhesives. This paradigm shift has implications for both metamaterials and adhesive joints, necessitating a new methodology for testing and evaluating confined lattice materials within a fracture mechanics framework. Theoretical and numerical approaches reveal critical design parameters, exploring lattices dominated by stretching and bending, and proposing failure maps based on confinement levels and unit cell dimensions [1].

We investigate the fracture toughness of architected interfaces, focusing on their ability to maintain structural integrity and ensure stable damage propagation beyond the failure load. Our theoretical and numerical frameworks assess the fracture properties of these interfaces, designed with 2D and 3D microscopic geometries. Our models predict compliance before failure and failure loads, with novel insights into damage propagation indicating the effectiveness of a fail-safe design. Certain cell geometries unfold during fracture, increasing the failure load and ensuring controlled damage propagation [2].

Modeling these media with complex architecture is challenging. Thus, this task requires advanced homogenization techniques, which can be achieved by applying micropolar elasticity. We enhance the elastic foundation theory, widely used in fracture mechanics and composite material delamination analysis, to incorporate micropolar behavior. Our theory uses stress potentials and a unique normalization approach to derive closed-form solutions for stress and couple stress reactions, as well as the associated restoring stiffness. Validation through double cantilever beam configuration confirms the theory's validity. We quantify parameters for micropolar materials, highlighting the benefits and limitations of this integrated framework, which enhances material response understanding and offers versatile analysis for heterogeneous materials in engineering applications [3].

We further delve into the mechanics of damage within Maxwell lattices, which are nearly mechanically stable and possess robust topological properties conducive to regulating damage processes. We present principles enabling fracture control in kagome lattices and employ these principles to study fracture patterns. Representing these lattices as networks of interconnected harmonic springs, we analyze their susceptibility to stretching and bending failures. Our findings demonstrate that topological principles can effectively govern crack propagation, providing new insights into damage mechanics in architected materials.

With this integrated approach to mechanical metamaterials, architected interfaces, micropolar elasticity, and topological fracture, we hope to offer a comprehensive framework for advancing materials' design and application in various engineering fields.

Key words: Mechanical metamaterials; Bonding; Adhesive; Homogenization; Fracture; Maxwell lattices

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Plenary lecturer – Giovanni Meneghetti

University of Padova, Italy

Giovanni Meneghetti received his PhD in 1998 at the University of Padova with a final dissertation entitled Fatigue design of welded structures by means of local approaches. Giovanni is Professor of Machine Design at the Department of Industrial Engineering of the University of Padova since October 2017 and Expert Member of Commission XIII (Fatigue Behaviour of Welded Components and Structures of the International Institute of Welding (IIW) since 2008. In 2003 he received an award from the Editorial Board of the Journal Fatigue & Fracture of Engineering Materials & Structures for the best published paper entitled 'Fracture Mechanics and Notch Sensitivity' and in 2024 from the European Structural Integrity Society (ESIS) for his strong contribution to the fatigue design of welded structures. Giovanni's research fields deal with the development of local approaches for structural durability analysis of welded components and structures, fatigue design of structures in metallic materials, experimental analysis of strains, in-field load data acquisition, development of design methodologies for structural integrity of conventional and additive manufacturing processes.

He delivers the Plenary Lecture 4 on Friday at 14:00 - 14:45 in FP05 (Chair: Reijo Kouhia):
The Peak Stress Method for the automated FEA-assisted design of welded structures subjected to constant and variable amplitude multiaxial fatigue loads

Finnish Mechanics Days 2024

The Peak Stress Method for the automated FEA-assisted design of welded structures subjected to constant and variable amplitude multiaxial fatigue loads

Giovanni Meneghetti[1], Alberto Campagnolo, and Alberto Visentin

Abstract. In modern engineering, the fatigue design of large-scale welded structures involves complex geometries and real-life time-variant multiaxial loadings. Design methods currently available do not always guarantee accurate fatigue strength estimations, particularly when non-classified welded geometries are considered [1-3]. The Peak Stress Method (PSM) is a FE-oriented local approach to estimate the fatigue lifetime of welded structures under Constant Amplitude (CA) and Variable Amplitude (VA) uniaxial and multiaxial loadings, starting from the local geometry of the welds.

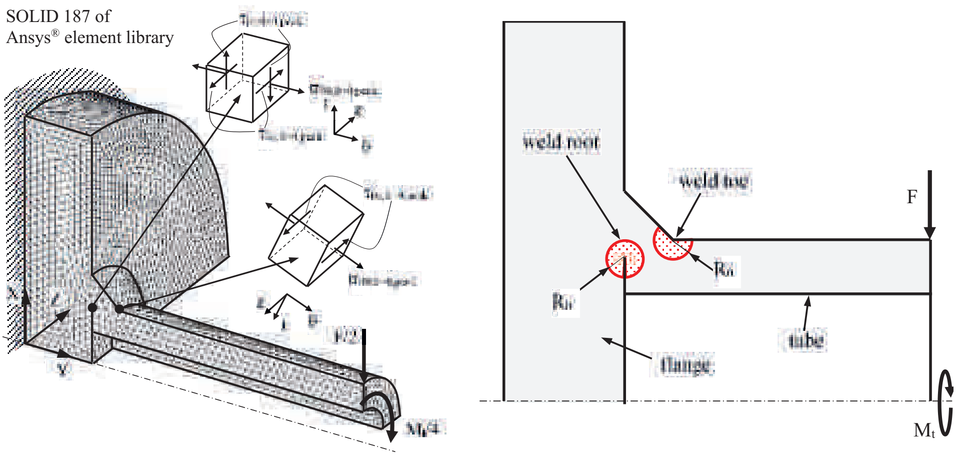

Figure 1. FE models to apply the PSM according for a partial-penetration tube-to-flange welded joint under combined bending and torsion loading using 3D 10-node tetra elements.

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Despite considering local stress at the fatigue critical locations (weld toes and weld roots), the PSM adopts relatively coarse FE mesh patterns, which proved useful to estimate the notch-stress intensity factors at the fatigue critical locations. Figure 1 shows a typical 3D 10-node tetra element mesh to use in the PSM, where the weld root and weld toe are modelled as sharp V-notches [4]. A dedicated software - the PSM App - has been created and integrated directly with native Ansys® Mechanical UI as a custom analysis toolbox. In particular, a dedicated PSM App toolbar is available in Ansys® Mechanical for results visualization and post-processing analyses, as depicted in Figure 2 [5].

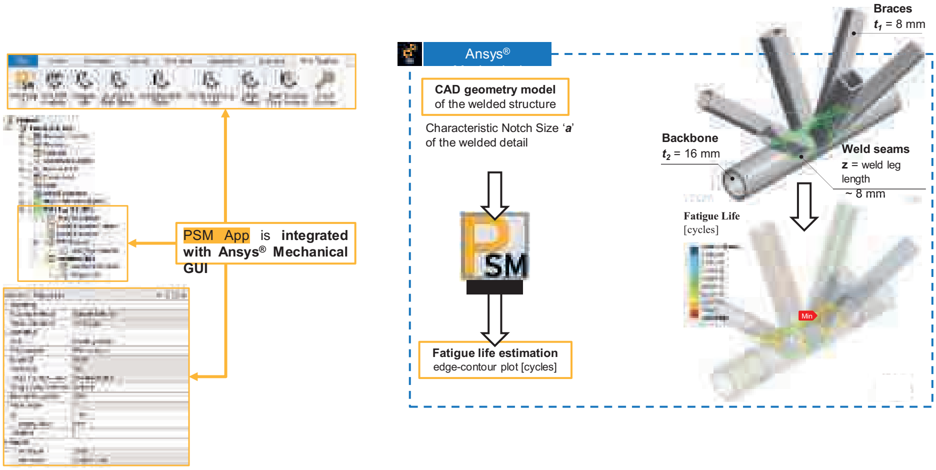

Figure 2: Automated application of the PSM using the tool developed in Ansys® Mechanical.

Keywords: welded joints, local approaches, notch-stress intensity factors, coarse mesh

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Chapter 2

Contributed papers 1: Finite element analysis 1

October 2, Wednesday at 12:30 - 14:30. Room: D149 Chair: Peter Råback

Finnish Mechanics Days 2024

A simulation workflow to evaluate the wearing comfort of in-ear headphones

Kilwa Ärölä[1], Markus Vaalgamaa, and Laura Laaksonen

Abstract. In-ear headphones or earbuds have become very popular, and we see people with wireless headphones everywhere. The requirements for an ergonomic earbud design are a comfortable and secure fit, and visual appeal. Regardless of all innovations, it's very difficult to find one design that fits every individual ear. Companies that develop and manufacture earbuds struggle with this issue.

Traditionally, the design of earbuds has relied on iterations through trial and error. Prototypes of the earbud design have been made, and their ergonomics have been evaluated with smaller or larger scale human ergonomics tests. In the ergonomics test, selected test subjects try out the design in their ears and rate the designs for fit, comfort, and other variables. Based on the outcome, the best design candidates are selected for further development. This design process however has shortcomings: (i) Creating physical prototypes is time-consuming, (ii), an adequate number of test subjects must be recruited for the ergonomics tests, (iii) the results of the subjective tests cannot directly indicate what should be improved in the current design, and (iv) Results may be biased due to possible problems in the test design.

The proposed simulation workflow consists of two parts. The first part is a structural mechanics simulation of the contact between the earbud and the ear based on explicit dynamic structural analysis using the Finite Element Method (FEM). The ear is modelled using a hyperelastic material model, with material properties calibrated based on tests of actual human ears. The second part, the comfort model, converts the simulation results into the comfort and ergonomics perceived by people when wearing the earbuds.

In this presentation the simulation workflow and the material calibration procedure are presented. The earbud comfort simulation results are compared to those of a human ergonomics test.

The demonstrated workflow allows the design team to test and optimize earbud ergonomics without using physical prototypes, and about 10 times faster and more precisely than the old approach relying on human ergonomic tests. The proposed simulation workflow has been proven very effective with several earbud projects.

Keywords: earbuds, comfort, structural FEM,

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Multiscale modelling of high-performance thermoplastic composites in transverse tension and bending using the FE^2 method

Humberto Almeida Jr [1], Bruno G. Christoff, Federica Mancini and Volnei Tita

Abstract A sophisticated multiscale approach, known as the direct FE^2 method, has been devised to analyse the mechanical behaviour of fibre-reinforced composites with varying void fractions. This method operates concurrently at two nested scales: the macro and the micro-scale. At the macro scale, the method employs a finite element (FE) mesh, with each Gauss point encompassing a representative volume element (RVE) where stress and strain evaluations occur. The RVEs, positioned within the macroscopic FE mesh, are subjected to linear boundary conditions at their boundary nodes and are connected to the macro-scale nodes through Multi-Point Constraints (MPCs). This integration facilitates the resolution of a unified equilibrium problem, imposing boundary conditions and loadings at the macro scale while supplying data for all defined RVEs. The methodology is exemplified through its application to a composite laminate under transverse tension and transverse bending. The computational predictions are validated against experimental tests assisted by digital image correlation (DIC).

Key words: Multiscale modelling, Concurrent approach, FE^2 method, Composites with voids

Description

Multiscale methods for modelling fibre-reinforced composites can be categorised into two types: sequential (hierarchical) and concurrent methods. Sequential approaches lose information about the interaction between phases (e.g., fibre and matrix) when transitioning from the constituent (micro) to the homogenised (macro) level. This loss becomes problematic when phase interactions critically influence the composite's damage processes, particularly during strain localisation.

In contrast, concurrent methods maintain continuous information exchange between the micro and macro levels within a unified global model. This dynamic interaction ensures that each analysis step incorporates current data from both scales, preserving the live interaction between different phases of the material.

A notable concurrent multiscale method for simulating the mechanical behaviour of fibre-reinforced composites is the FE^2 approach. This method employs two nested continuum models, necessitating constitutive assumptions solely at the local level (Representative Volume Element, RVE). The FE^2 method requires simultaneous computation of the mechanical responses at both scales: the macroscale homogenised structure receives information from the underlying microscale heterogeneous system through an RVE, where strains and stresses are calculated at each Gauss point.

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This work aims to implement, for the first time, the Direct FE^2 method in 3D for laminated composites by extending the Direct FE^2 in 2D recently proposed by Christoff et al. [1]. The main purpose is to bridge the macro and micro scales in fibre-reinforced composites using the Direct FE^2 method, offering an alternative to both mono-scale and sequential multiscale models. The void content is assessed at the micro level through Representative Volume Elements (RVEs). Within these RVEs, kinematics (stresses and strains) are locally evaluated at every Gauss point (GP) of the macro FE mesh and concurrently exchanged with the homogenised model at the macro scale, where loads and boundary conditions (BCs) are applied. The RVEs are positioned at each Gauss point of the macro FE mesh, thus characterising the FE^2 global model.

The equilibrium is assessed by balancing the external virtual work (macro level) and the internal virtual work (micro level) [1], resulting in

$$\tilde{K}_{ij}\tilde{d}_j\delta\tilde{d}_i = f_k\delta d_k, \tag{1}$$

where $\tilde{\boldsymbol{d}}$ represents the nodal displacement field within the RVEs, and $\delta\tilde{\boldsymbol{d}}$ and $\delta\boldsymbol{d}$ are the virtual displacement fields at the microscopic and macroscopic scales, respectively. The stiffness matrix $\tilde{\boldsymbol{K}}$ is constructed by assembling the contributions from all the RVEs within the FE^2 model, and $\boldsymbol{f}$ is the nodal forces at the macro level. The displacement fields of the macroscale and the microscale are related through the application of linear boundary conditions.

Mechanical tests assisted by digital image correlation (DIC) are carried out to validate the computational predictions. Two loading cases are considered: transverse tension through short-beam shear tests and transverse 3-point bending.

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Finnish Mechanics Days 2024

Effects of gradient elasticity in coupled Cahn-Hilliard type of diffusion

Ole Kranzosch[1], Sergei Khakalo and Aleksandr Morozov

Abstract Coupled diffusion with classical elasticity models are utilized in various applications, e.g., the phase decomposition and coarsening of solder alloys [1] or microphase separation in hydrogels [2]. In the present contribution, we consider a coupled mechano-diffusion problem in the framework of Mindlin's strain gradient elasticity and Cahn-Hilliard diffusion models [6]. This augments the modeling capabilities by incorporating elasticity-related length scales reflecting microstructural effects at the continuum level.

The higher-order boundary value problem of the coupled gradient elastic-diffusion model is formulated in a variational form within a proper Sobolev space setting. Conforming Galerkin 2D discretizations for numerical results are obtained via an isogeometric approach and implemented as user subroutines in commercial FE software Abaqus [5] as well as in Matlab. The latter implementation is especially beneficial due to its flexibility in the utilized methods such as the time integration scheme. It allows us to implement the so-called *generalized-α* method [4] together with an adaptive time step size [3] to achieve a very efficient time stepping procedure even for large times. We first consider a 1D problem and verify the implementation by comparing the results obtained to a finite-difference method. After that, a qualitative analysis of the different energy levels and their evolution during the separation process is carried out in order to estimate the influence of the coupling. Finally, we study an example of diffusional coarsening in solders and analyze the size effects in phase separation problems by extending the model in [1] towards the strain gradient elasticity framework.

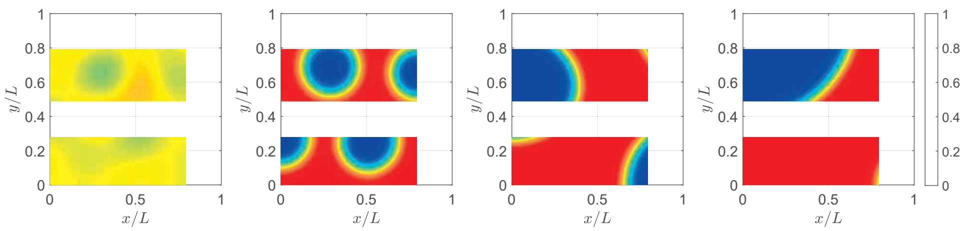

Figure 1. Phase separation process in a binary solder. Numerical results obtained via isogeometric analysis implemented in Matlab. Time increases from left to right. Color levels depict the mass concentration of one of the alloy components.

Key words: Phase separation, Strain gradient elasticity, Isogeometric analysis, Phase field modeling, Generalized-α method

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Finnish Mechanics Days 2024

Computationally efficient finite element model for continuous annealing of stainless steel strips

Timo Manninen[1], Peter Råback, and Juha Ruokolainen

Abstract. Continuous annealing is an essential process step in the production of cold-rolled stainless steel strips. Cold rolling is performed to reduce the thickness of the material. However, during cold rolling, the material work hardens significantly, making it unsuitable for producing goods. Therefore, the strip is heat treated in a continuous annealing and pickling line after cold rolling to recrystallize the deformed microstructure and restore the material properties. In this step, strips welded together are continuously passed through several horizontal annealing furnaces, then cooled and passed through several electrolytic and mixed acid pickling baths. The furnace is heated by direct-fired heaters positioned on the vertical walls. The power of burners in each furnace zone is controlled using a temperature sensor placed inside the furnace to maintain the specified atmosphere temperature.

A controlled heat cycle is needed to produce the desired microstructure and properties. Since different line speeds and furnace temperature profiles can produce the same microstructure, optimizing the process parameters can save energy and CO_2 emissions. Continuous annealing lines generally process many steel grades in various dimensions. Optimizing the process conditions for all strip dimensions and all steel grades by process trials is impossible as this would disturb production and increase the amount of scrap produced. The optimization can thereby only be done using computational methods.

In the present work, an economical finite element model was developed for simulating continuous annealing of stainless steel using Elmer FEM software. The simulation model is a three-dimensional steady-state heat transfer model enhanced with several features addressing the special needs of the problem. The aim was to create a model that includes all essential design parameters while being economical enough to be computed on the workstation during the lunch break.

The dominant heat transfer mechanism in the furnace is radiation from the burners and furnace walls. The burners are modeled as pointwise heat radiators, and their power is controlled based on the temperature in the control point positioned in the furnace inner wall. The radiative heat transfer from the flames to the visible surfaces and between surfaces is modeled using the radiosity method [1]. This method considers the temperature dependency of the radiative properties of surfaces.

The scattering of heat by the triatomic molecules in the furnace atmosphere is modeled using the Rosseland diffusion approximation. The mean extinction coefficient is determined based on the chemical composition of the flue gas [2]. The discontinuous Galerkin method handles the

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boundary layer in the flue gas near the strip surfaces [3]. A fine mesh would otherwise be needed to model the boundary layer near the strip surfaces.

The convective heat transfer from the flue gas to the strip was assumed constant in each furnace zone. The average Reynolds and Prandtl numbers were calculated based on the temperature and estimated average flue gas velocity in each furnace zone. The convective heat transfer coefficient was then estimated based on the Nusselt number for turbulent flow over a flat plate [4].

Modeling the radiation introduces computationally expensive view-factor computation that scales poorly with problem size. Therefore, the computations are performed sequentially for one furnace at a time, starting from the cold end of the furnace section. This approach significantly decreases the required computing time and memory and helps resolve the bottleneck.

A unique integrator was developed to solve the evolution equation for grain growth in the axially moving strip. The integrator is coupled with a fully featured heat transfer. A key ingredient in the coupled solution is to compute the heat transfer in a stationary coordinate system and the grain size in a moving coordinate system. This coupled solution is computationally highly efficient.

The simulator was validated using process data measured in industrial production. The simulation model is parametrized and capable of modeling any annealing line of the same type, provided that the parameters describing the heat transfer and grain growth are known.

Keywords: Continuous annealing, stainless steel, Elmer, FEM,

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Finnish Mechanics Days 2024

Numerical simulation of the human Achilles tendon: challenges and solutions

Alexander Nemov[1], Leonid Obrezkov, Stephanie Cone, Ajay Harish, Taija Finni and Marko Matikainen

Abstract The strongest tendon in the human body, the Achilles tendon, is crucial for locomotion. It is therefore heavily loaded both in everyday life and in sport activities, and is consequently relatively often injured. That makes developing techniques for rehabilitation and for preventing injuries of the Achilles tendon a pressing issue.

It has been recently demonstrated in cadaver and animal studies that the Achilles tendon consists of three twisted subtendons, with their parameters varying significantly among individuals. These subtendons are individually connecting the medial and lateral heads of the gastrocnemius muscle and the soleus muscle to the calcaneus, but at the same time, they are in tight contact, twisted around each other. However, the details of the collaborative work of the subtendons during various leg movements, as well as the influence of the subtendon parameters on the tendon performance, remain unclear. That does not allow making reliable individual predictions about the influence of various exercises on the deformed state of injured tendons and hinders developing personalized rehabilitation strategies. Due to the strongly limited amount of data that can be obtain in in-vivo studies, simulations are currently the main tool for enhancing the understanding of the inner mechanics of the Achilles tendon during various leg movements.

This study discusses challenges associated with numerical simulations of the Achilles tendon: strongly nonlinear behaviour of the tendon tissue, complex contact interaction between twisted subtendons, independent activation of muscles connected to those subtendons. At the same time, in order to simulate leg movements accounting for the deformational processes taking place incide the subtendons, the model must be exceptionally efficient computationally. To address those challenges, we propose a computational approach based on the combination of a finite element model of the Achilles tendon and multi-body model of the leg. Moreover, we propose a finite element model for the Achilles tendon based on continuum-based beam elements using the absolute nodal coordinate formulation (ANCF) [1]. The model includes three twisted subtendons and accounts for their nonlinear elastic behaviour as well as the contact interaction between them. The model was compared against 3D finite element model based on solid elements and was found computationally effective and reasonable accurate. We further propose a modified Hill-type model for the muscle-tendon unit incorporating the nonlinear response of the developed finite element model of the Achilles tendond. Incorporation of this modified muscle-tendon unit model into multibody model of the lower human extremity allowed us to perform simulations of various leg movements accounting for the nonlinear response of a specific Achilles tendon.

Key words: Achilles tendon, subtendons, simulation, multibody, finite element

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Phase field method for brittle fracture implemented with polygonal finite elements

Timo Saksala[1], Mahmood Jabareen, and Reijo Kouhia

Abstract. Phase field method has been an extremely popular approach to model fracture in computational mechanics for couple of decades. Its attraction stems from the ability to simulate crack initiation, propagation, and branching without the need for ad-hoc criteria. Moreover, with this method, cracks are tracked automatically by the propagation of a smooth crack field on a fixed mesh. However, the major shortcoming is the computational labor due to dense meshes required to reach convergence. In addition, it is challenging to find a suitable crack, or phase field, driving force for compressive/shear fractures.

In this study, some preliminary results on an implementation of the phase field method with polygonal finite elements are presented. The aim is to model fracture propagation in brittle materials, such as rocks and concrete. For this reason, the so-called hybrid formulation of the phase field theory is adopted. It enables using an ad-hoc, or a problem specific, crack driving force, here of Mohr-Coulomb type, to correctly model brittle materials under compression/shear. Hybrid formulations are variationally inconsistent because the crack driving force is not the same as the one used in the underlying energy functional (from which the expression for stress is derived). They are, however, thermodynamically consistent, and computationally cheap since they allow to use a linear balance of momentum equation within the robust staggered scheme to solve the coupled system for the phase field and the displacement field.

The phase field method is implemented with 2D polygonal finite elements based on the Wachspress interpolation functions. As numerical examples, typical testcases of notched samples under mode I and II loadings are simulated. Finally, a slope stability problem is solved as an engineering application.

Keywords: Phase field method, Hybrid formulation, Polygonal finite elements, Brittle fracture

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Chapter 3

Contributed papers 2: Digital twins and artificial intelligence

October 2, Wednesday at 12.30 - 13.50. Room: F304 Chair: Tero Tuovinen

Finnish Mechanics Days 2024

Solution of Boundary Value Problems using Machine Learning

Paula Tapaninaho, Lauri Kettunen

Abstract

Background

The design and RDI of various technical devices (airplanes, ships, cars, etc.) is based on solving boundary value problems (BVP). BVP:s are used to solve problems for example in the fields of electromagnetics, fluid mechanics, quantum mechanics and elasticity [1]. BVP:s are computationally intensive to solve, and typically requires a trained person. In practice, however, for many pragmatic needs one does not need a precise solution but instead a good approximation or estimate would be sufficient. There has been a lot of research regarding this issue during the past few decades [2]. Figuring out an efficient and reasonably accurate technique to solve BVP:s is the basic idea of this research, and for this purpose we exploit machine learning (ML) methods.

A ML system to solve any problem requires training data. In solving BVP:s this includes both geometrical or spatial information and data of the medium (such as the fluid, Young's modulus, permeability and permittivity, etc.). The amount of data in a training data set that includes all this information would be enormous, that is, an uncountable set that cannot be sampled. As any training set has to be finite, a more efficient way to teach a ML system to solve BVPs is needed.

A possible way to circumvent the problem of the training data set size is to represent the BVP on manifolds and distinguish the structures of differentiability and metric. The keypoint is, the medium data depends on the chosen metric. In more concrete terms, a long object with sparse medium corresponds to a short object with dense medium. Consequently, one may form equivalence classes whose representatives are pairs of size and density [2][4]. And now, instead of employing the representatives, the training data set is established directly on the equivalence classes. This implies, the set to be trained consist of equivalence classes instead of their representatives.

Objectives and methods

The goal of this research is to find quick estimates or approximation of the solution of BVPs with ML techniques. The main research question concerns pratice: How the training set is reduced as small as possible. In more detail, the focus is on managing the dimension of the training data and on establishing the BVP, the pair of differential equations and the constitutive law, in as simple form as possible.

BVP:s have been solved successfully using neural networks [4], and neural networks are also the ML method used in this study. Especially, convolutional neural networks have potential in learning intricate details about training data, which is very beneficial in the case of solving BVP:s in electromagnetic systems.

Results

The result is a method that yields quickly reasonable estimates of the solutions of BVPs. The practical relevance is that this method reduces the amount of resources needed in engineering design, which results in cost efficiency. The final paper will explain the main strategy and demonstrate examples.

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Finnish Mechanics Days 2024

Enhancing digital twin development: The role of large language models in advancing maturity levels

Atte Koskinen[1], Qasim Khadim, Emil Kurvinen

Introduction

Implementing digital twin (DT) technologies requires a robust infrastructure, advanced computational resources, and seamless integration between physical and virtual spaces [3]. This process often requires highly skilled professionals with expertise in data science, software engineering, system architecture, and domain-specific knowledge to ensure the effectiveness of real-time digital twins.

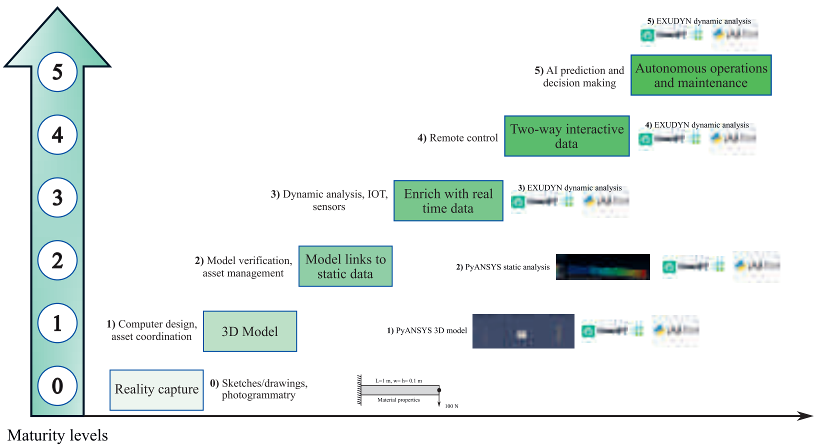

Figure 1. Advancement in the digital twin maturity levels [1], as demonstrated by the cantilever beam example, utilizes large language models (LLMs) like ChatGPT. The open source Python-environment software tools, PyANSYS and EXUDYN, have been used in developing the virtual space.

Recent advancements in large language models (LLMs), such as ChatGPT, BERT, and LaMDA, have significantly accelerated the development and enhancement of DT technologies [2]. LLMs can automate complex data analysis tasks, provide predictive insights, and enable more dynamic interactions between digital and physical entities. In Industry 5.0, which emphasizes human-machine collaboration, LLMs facilitate intuitive and interactive interfaces, significantly reducing the time and expertise required to deploy and maintain advanced levels of DTs. LLMs can create a holistic viewpoint of specific

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DT and evaluate its performance in different scenarios. The higher the maturity level of DT, the more trust and understanding it requires from the user. [4]

To demonstrate it, this study introduces the deployment of DT maturity levels, see Figure 1, using ChatGPT LLM. As an example, a cantilever beam has been investigated using Python open-source software EXUDYN and PyANSYS. This application demonstrates the effective role of LLMs in achieving DT maturity levels. It illustrates how these advanced AI tools can optimize the lifecycle management of DTs, enhance decision-making processes, and improve overall system resilience.

Methods

Figure 1 demonstrates the digital twin maturity levels [1], as demonstrated by the cantilever beam example, utilizes large language models (LLMs) like ChatGPT. At level **0**, the user initiates the process by sketching the cantilever beam and specifying the material properties. At level **1**, ChatGPT developed a 3D model of the cantilever beam within the open-source Python environment, PyANSYS. At level **2**, the analytical solutions for stresses and strains in the beam verified the Python script proposed by ChatGPT. At level **3**, EXUDYN created a real-time dynamic simulation model from the ChatGPT Python script. This model is further utilized at levels **4** and **5** for developing remote control, autonomous operation, and predictive maintenance capabilities. It is important to note that in this work, the physical space of DT is replaced by another simulation model.

Results and conclusion

This study proposes LLMs in advancing the DT maturity levels by using a cantilever beam example. The analytical stress and strain calculations show that LLM proposed model has less than 0.5 % and 10 % errors, respectively, during static analysis in PyANSYS. The LLM proposed dynamic model in EXUDYN demonstrates tasks according to user requests. These results should be demonstrated in greater details in another study. Further, a comparative study of different LLMs such as ChatGPT, BERT, and LaMDA etc. should be demonstrated in relation to the natural language models.

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Finnish Mechanics Days 2024

Modern Approaches to Autonomous Excavation: A Literature Survey

Oleg Rogov[1], Arto Liuha and Grzegorz Orzechowski

Abstract The integration of autonomous technologies in the construction and mining industries is revolutionizing excavation processes, traditionally dependent on human operators. Research shows that autonomous systems that utilize advanced robotics and control strategies are able to perform precise and consistent excavation tasks with minimal human intervention. A crucial aspect of these systems is bucket path planning, which determines the optimal trajectories for the excavator's bucket, ensuring efficient and safe digging operations [2, 3]. Recent advancements in this field include the application of optimization-based frameworks and deep learning algorithms that improve the adaptability and efficiency of these systems in various environments [4, 1]. Such technological innovations not only enhance productivity but also contribute to the safety and cost-effectiveness of operations. This review synthesizes the latest research in autonomous excavation and bucket path planning, providing insights into the challenges and future directions of this evolving field.

Key words: autonomous excavation, bucket path planning, machine learning, robotics, artificial intelligence, control

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Finnish Mechanics Days 2024

An Improved Lumped Segment Numerical Model for S.A. Agulhas II Propulsion Shaft Line Digital Twin

Mihiran Galagedarage Don[1], Sven Bossuyt

Abstract A numerical model that can simulate the complex dynamics of a shaft line is an essential component for a component-level digital twin. These digital twins can be employed in predictive maintenance and risk management [4, 2]. However, the available numerical models are limited to torsional loads and hence cannot accurately estimate the axial, shear, and bending loads. Therefore, the accurate estimation of moments on propellers and fatigue life prognosis of shaft lines has become a challenge [1, 3, 4, 5]. This study introduces a novel propulsion shaft numerical modelling approach along with improved flexibility to integrate other external effects such as fluid friction and inertial effects. The bond graph is a 3D lumped segment model developed using the Newton-Eular formulation and body fixed coordinates. The 20Sim™ bond graph simulation environment will be used to implement the model and further analysis. The successful implementation of the model will remove the barriers to S.A. Agulhas II propulsion shaft line digital twin research. Further, this will serve as a simulation infrastructure that facilitates future multidisciplinary research collaborations related to the S.A. Agulhas II and similar propulsion systems.

Keywords: digital twins, bond graph, propulsion shaft line, predictive maintenance

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Chapter 4

Contributed papers 3: Computational fluid dynamics

October 2, Wednesday at 12.30 - 13.30. Room: F305 Chair: Timo Saksala

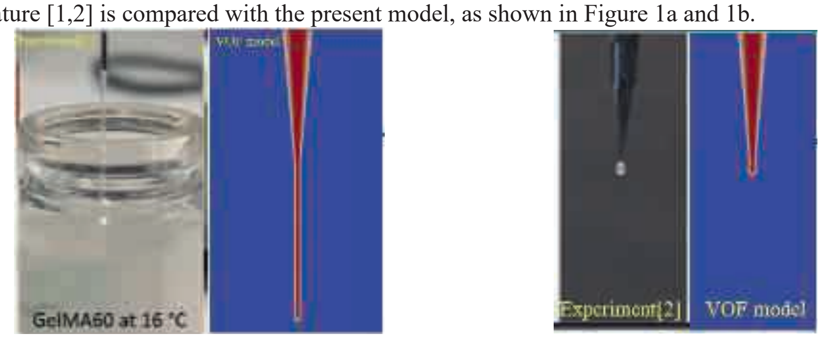
Finnish Mechanics Days 2024

Analysis of flow behavior of bioinks outside the 3D-Printing Nozzles

Ashish Pawar[1], Ashvin Chaudhari, and Eero Immonen

Abstract.

The major challenge in extrusion-based bioprinting for medical application is printability. Printability largely depends on the flow behavior of bioinks just outside the nozzle. This flow behavior is influenced by nozzle dimensions, bioink density, bioink viscosity, the surface tension between the bioink and air, and the desired printing speed. Predicting the flow behavior of bioink outside the nozzle beforehand can save the cost of experimental testing. In this work, Volume of Fluid (VOF) method is used to study the flow behavior outside a single nozzle. CFD simulations are conducted to analyze the behavior of bioinks outside the printing nozzles. Since water is the base of most bioinks, the influence of all process parameters on the flow outside the nozzle for water was studied. Using two non-dimensional numbers, Reynolds number and Weber number, flow demarcation regimes have been established for water. Furthermore, this study is extended to non-Newtonian materials. The flow behavior of bioinks reported in the literature [1,2] is compared with the present model, as shown in Figure 1a and 1b.



(a) (b)

Figure 1. Experimental and model comparison for (a)GelMA60 at 16ºC[1] (b) GelMA30 at RT[2].

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Keywords: Bioinks, 3D-Printing, CFD, Non-Newtonian

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Finnish Mechanics Days 2024

Optimizing 2d stormwater filter design through parametric analysis of grain characteristics

Mohamed A. Sayed[1], Ashvin Chaudhari, and Eero Immonen

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Abstract. Effective stormwater management is crucial for mitigating urban flooding and protecting water quality. Filtration systems are vital in removing pollutants and sediments from stormwater runoff. This study employs two-dimensional (2D) steady-state Computational Fluid Dynamic (CFD) models to optimize stormwater filter design through a parametric analysis of grain characteristics, such as grain size distribution, minimum spacing between the grains, and porosity of the filter, on stormwater filter performance. In the present work, more than 2000 filter models exhibited a porosity range of 0.55 to 0.65, circular grain diameters between 0.05 and 0.15 mm, monodisperse and polydisperse grain geometries, and minimum spacing between grains ranging from 0.02 to 0.04 mm. Figure 1 illustrates the filter geometry (5 mm × 5 mm), stormwater velocity and concentration for a model comprising 359 grains, with radii between 0.05 and 0.15 mm and a porosity of 0.60. Statistical analysis, including regression analysis and analysis of variance (ANOVA), is observed to reveal the parameters that significantly influence the pressure gradient and filtering or filtration rate. A multi-objective optimization approach is also employed to identify optimal parameter combinations that balance high filtering efficiency with low hydraulic resistance.

Keywords: Stormwater; filtration; CFD; grain size; porosity; optimization

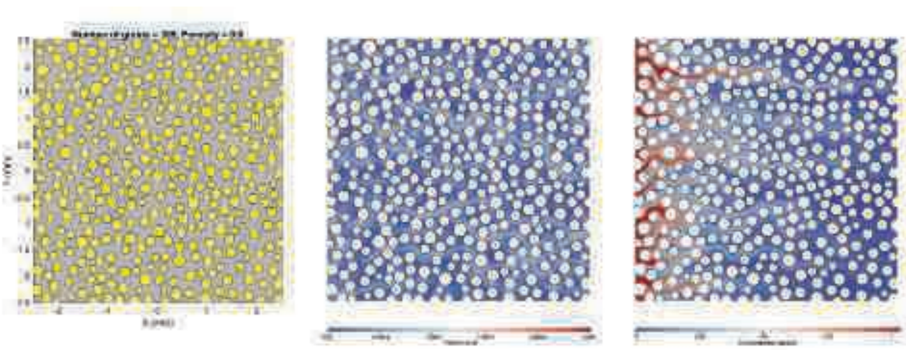

Figure 1. Model geometry and stormwater velocity and concentration for 359 grains and a porosity of 0.60

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Finnish Mechanics Days 2024

Large Eddy Simulation of the Flow Over Turku with an Application to an Operational Air Quality System

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Abstract Urban air quality significantly impacts the well-being of people in cities around the world. However, the production of detailed air quality information for the urban environment requires an access to the detailed wind fields, which are difficult to produce due to several aspects including the complex interaction between buildings and the flow. Using large eddy simulation (LES), it is possible to simulate accurately the wind within a city although the computational requirements are currently too large for it to be useful in direct operational usage. A compromise between highly accurate air quality simulation with LES and reasonable computational requirements can be achieved by utilising pre-computed LES fields in a lightweight air quality model.

We have performed a series of LESs for the flow over Turku using the PALM model [4]. PALM is a highly parallelisable code that is used widely in the simulation of various different atmospheric boundary layer flows. Our simulations considered an area that covers central Turku and spans approximately 25 km × 16 km × 670 m. The domain included two nested subdomains [1] with smaller extent and a resolution down to 4 metres. The largest domain considered the effects of the terrain only while the two smaller domains also included buildings and vegetation, obtained from existing LIDAR data. We conducted 12 simulations in total, with different mean wind direction at 30° intervals.

The resulting wind fields were highly complex, reflecting Turku's urban structure. Taller buildings and hills were seen as sources of turbulence and long wakes. High mean winds were observed in the open terrain. Depending on the wind direction, strong channeling effects were seen along the larger street canyons, the railway tracks, and the Aura river. Street canyon vortices were observed in the street canyons that had sufficient grid resolution. Overall, a the flow was strongly wind-direction dependent. This highlights the usefulness of the produced LES data set of 12 different wind direction: one can obtain a flawed view of the wind environment or the dispersion within the city if only one or two mean wind directions are considered.

The mean, variance, and the SGS dissipation of the wind field were then utilised in the ENFUSER model [2] to improve operational air quality forecasting for PM2.5. In the LES-enhanced ENFUSER [3], the normally used Gaussian puff approach was replaced by an approach based on Lagrangian particles with transport by fields computed with LES. The computational requirements of the new air quality system were low enough for it to run with resources comparable to a modern high-end PC system. The system was set up to run operationally for Turku: forecasts and hindcasts are produced hourly.

Acknowledgements This work was carried out as a part of the RESPONSE project and it has received funding from the EU's Horizon 2020 research and innovation programme under Grant Agreement no 957751. The authors wish to acknowledge CSC - IT Center for Science, Finland, for computational resources.

Key words: CFD, LES, urban flow, air quality, PALM, ENFUSER, dispersion modelling

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Chapter 5

Contributed papers 4: Thin structures

October 2, Wednesday at 13.30 - 14.30. Room: F305 Chair: Matti Kurki

Finnish Mechanics Days 2024

Flexible thin film thermoelectric devices for use as an energy source for autonomous sensors

E. Alakoski[0,1,4], A. J. Soininen[1,4], T. Laine[1,4], S. Kinnunen[2,4], J. Julin[2,4] G. Tewari[3], M. Karppinen[3]

Abstract. Atomic scale thickness control, superior conformality and the ability to accurately prepare multilayered superlattice structures make Atomic Layer Deposition a promising method for the preparation of thin film thermoelectric devices for energy recovery. The preparation of N -type semiconductor thermoelectric nanocomposite films utilizing ALD was demonstrated in joint research with Jamk University of Applied Sciences, University of Jyväskylä and Aalto University (Läsä -project 2020—2022, ERDF). Thermoelectric devices are composed of single thermoelectric components combining both N –and P -type semiconductors. Single components are connected thermally parallel and electrically in series. As a part of the actions of UKKO -project (2024-2027, ERDF) we aim to demonstrate the preparation of a thin film thermoelectric energy source for an autonomous sensor e.g. for surface temperature measurements of district heating pipes.
Keywords: ALD*, Thermoelectric generation, Finnish Mechanics Days*

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Finnish Mechanics Days 2024

Geometry characterisation and structural stress analysis of welding-induced distortions in large thin-walled structures

Federica Mancini[1], Matti Christmann, Jani Sandgren, Pauli Lehto, Jani Romanoff and Heikki Remes

Abstract The pursuit of enhanced ship performance has led to lightweight solutions for modern cruise ships. From economic and engineering perspectives, the simplest action towards structural weight reduction is using thin plates in stiffened panel units of ship superstructure decks [1]. Nevertheless, complex welding-induced irregular distortions in plates thinner than 5 mm cause non-negligible stress concentrations, which are detrimental to the fatigue performance of the structure. Extensive research has demonstrated the inaccuracy of engineering tools provided by ship design rules ([2]) for the structural stress assessment in the presence of irregular distortions [3, 4]. Therefore, costly Geometrically Non-linear Finite Element Analysis (GNL-FEA) based on an accurate geometry modelling from data-intensive full-field 3D scanning of welded plates is needed [5].

With the aim to simplify and streamline the structural stress assessment, this work presents computationally efficient methods for modelling distortions and predicting the structural stress concentration near the butt-weld location between thin plates in ship-deck panel units. The stress-rising effect of real distortions from shipyard production is studied under tension, simulating the effect of hull girder bending on the superstructure decks. An experimentally validated 3D finite shell-element model of panel units is considered as a reference model in gradually reducing the modelling scale from 3D to 1D; see Fig.1. The scale reduction leads to the development of a second-order beam analytical model of the butt-welded area by assuming ideal weld rigidity, a simple half-sine curvature, and moderate rotations, computed based on the von Kaŕmań strain definition. A beam-panel adaptation study is presented, along with the experimental validation of the analytical formulation on small-scale thin and slender butt-welded specimens. The validation is presented in terms of stress magnification factor, k_m, defined as the ratio between the hot-spot (or peak) structural stress and the nominal stress, and a comparison to the current k_m formulations provided by the International Institute of Welding (IIW, [6]) is given.

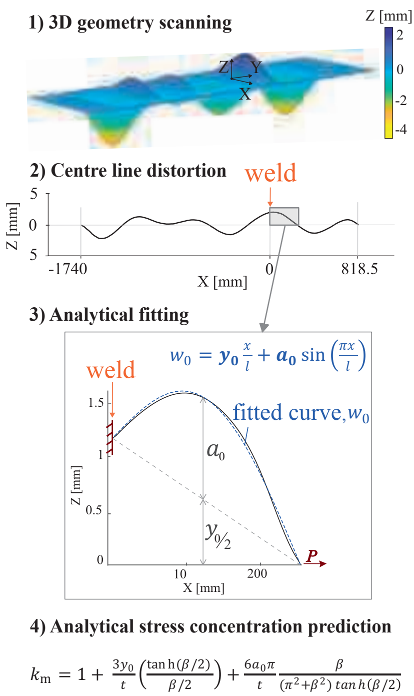

Figure 1. Modelling scale reduction for a Simplified, time-efficient structural stress analysis of distorted ship-deck panels.

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Based on this work, a 1D GNL-FEA can simulate the stress concentration on a distorted longitudinal profile within 60% of the plate width. Moreover, modelling the distortion up to its first half-wave from the weld location in the longitudinal direction guarantees a reliable prediction of the stresses near the weld and indicates the feasibility of the analytical solution. The analytical prediction based on a curved beam is validated under uni-axial tension with an average accuracy within 10% against the full-scale centre line distortions of the panel units, as well as against small-scale butt-welded thin and slender specimens.

Key words: thin plates, welding distortions, geometry scanning, structural stress, second-order beam, tensile test, stress concentration

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Finnish Mechanics Days 2024

On the derivation of constant-coefficient partial differential equations for elastic shells

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Abstract The paper of Pitkäranta, Matache and Schwab [2] presents a detailed treatment of boundary layer effects related to the modelling of thin elastic shells. Although the primary aim of their work is not related to the formulation of shell models, their paper describes an interesting derivation of simplified models suitable for analyzing shallow shells. This derivation is motivated by the desire to obtain a constant-coefficient system of partial differential equations over a two-dimensional domain, so that the geometric parameters need not be considered to depend on place. This simplifies the mathematical analysis given in [2]. We note that such simplicity could also be useful in practical computation.

In the study [2] the derivation of simplified shell models begins with the assumption that a global parametrization of the shell mid-surface by lines of curvature coordinates is available. Approximations are then introduced so that the shell equations may be expressed with constant coefficients by using a parametrization which gives only an approximation to lines of curvature coordinates. This process of approximation however appears to be proceeding in the reverse direction to what may occur in practical modelling of surfaces. We note that generating a parametrization by lines of curvature coordinates is not straightforward in general (moreover, attaining a global parametrization in this manner may even be impossible). Therefore, it is more common in practice that one usually has some initial parametrization of a surface and then one may proceed to seek for a more convenient reparametrization which gives an approximation to lines of curvature coordinates. Such a procedure has been considered in our previous work [1].

Here our aim is to discuss the application of the differential geometric results obtained in [1] by considering the derivation of simplified shell models. To pursue the simplifications sought in [2], we consider the approximations which are seen to be necessary so as to obtain a constant-coefficient shell model. We also discuss connections between our approach and that presented in [2].

Key words: shell, line of curvature, reparametrization, surface, orthogonal curvilinear coordinate

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Chapter 6

IFME Session 1st: Industry, innovation and infrastructure

October 2, Wednesday at 12:30 - 14:30. Room: D148 Chairs: Anneli Kakko and Silvia Satorres

Finnish Mechanics Days 2024

International Forum of Mechanical and Mechatronic Engineering (IFMME) and its network

Anneli Kakko[1]

Abstract. The first International Forum of Mechanical Engineering (IFME) was organized at JAMK University of Applied Sciences (JAMK) in Jyväskylä, Finland from the 30th of November to the 2nd of December 2006.

The main purposes of the Forum have been to review and find solutions for
- the goals and needs of European mechanical and mechatronic engineering industry
- the state of European mechanical and mechatronic engineering industry education
- the weak points in the circle of information between industry and education.

After the successful start, JAMK and its partner universities around Europe have organized this annual forum. In 2015 the name of the forum was changed to the International Forum of Mechanical and Mechatronic Engineering (IFMME) so that it interested bigger group of our partner universities and companies. This year the 17th IFMME is implemented as a part of the 15th Finnish Mechanics Days at JAMK. So far there have been eight host universities from seven European countries: Esslingen and Nürtingen-Geislingen Universities of Applied Sciences from Germany, Vorarlberg University of Applied Sciences from Austria, ESIX Normandie from France, University of Miskolc from Hungary, Technical University of Cluj Napoca from Romania and University of Jaen from Spain. In the history of IFMME, there have been only two years when it has not at all organized, year 2014 and 2020.

Alongside the annual forum, active network cooperation has all the time been operated which has opened new cooperation possibilities from which good examples are international company-university projects in the field of mechanical and mechatronic engineering. Three examples of EU funded projects are Reshaped Partnerships for Competitiveness and Innovation Potentials in Mechanical Engineering [1], Smart HEI-Business collaboration for skills and competitiveness [2] and International Cooperation Framework for Next Generation Engineering Students [3].

There has been strong dialogue between industry and universities to support public sector decision making, also new insight to new cooperation possibilities. IFMME network has offered a lot of benefits for industry and university partners.

In my presentation I will shortly go through the purposes and the history of the Forum, explain about important milestones, network activities, some examples of great international projects and open its future goals.

Keywords: company-university cooperation, mechanical and mechatronic engineering, international cooperation, international projects

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Finnish Mechanics Days 2024

Specular Zero: Towards a sustainable production in plastic injection industry

Arturo López Riquelme[1], Silvia Satorres Martínez, Diego Manuel Martínez Gila and Sergio Illana Rico

Abstract

Specular Zero represents a pioneering approach in the optimization of production systems and it is beign developed by the ISR company [1]. It is based on Zero Defect Manufacturing (ZDM), a concept that is being integrated in industry replacing the traditional quality improvent methods [2], [3]. The main goal of ZDM is: "making it right the first time", rather than trying to mitigate a problem at a later stage [4]. To achieve that end it is needed real time information of the productive process and the manufactured products to stablish correlations that makes it possible to lower costs, lower energy consumption, lower level of wasted materials, faster production processes and improved level of output quality.

Thanks to the already available machine vision systems for the automated inspection of plastic parts [5] and leveraging advanced Artificial Intelligence (AI) and Big Data techniques, Specular Zero enhances both the digitization of quality control and the quality of data generated, facilitating real-time defect detection and correction. This integration enables a comprehensive comparison of production quality with key parameters of the production process, material, and environment. The model incorporates pre-trained AI software and cross-references quality data from Optical Inspection Technologies from the company ISR Specular Vision, with production data from Autonomous Production Units (UAP), encompassing injection molding, oven, and coating systems. The AI-driven system optimizes production parameters, aiming to reduce energy consumption, carbon footprint, and operational costs while improving product quality and sustainability.

Specular Zero concept integrates detailed material properties, machine parameters, environmental conditions, and economic factors. This model predicts defects based on production parameters (Fig.1), material variability, geometry complexity, and environmental influences, while optimizing energy efficiency and reducing waste. By incorporating additional data such as machine runtime, maintenance schedules, tooling wear, and market dynamics, the model provides a robust framework for achieving sustainable production and economic benefits.

Key words: Specular Zero, AI in Quality Control, Big Data in Manufacturing, Automotive Lighting Industry, Sustainable Manufacturing

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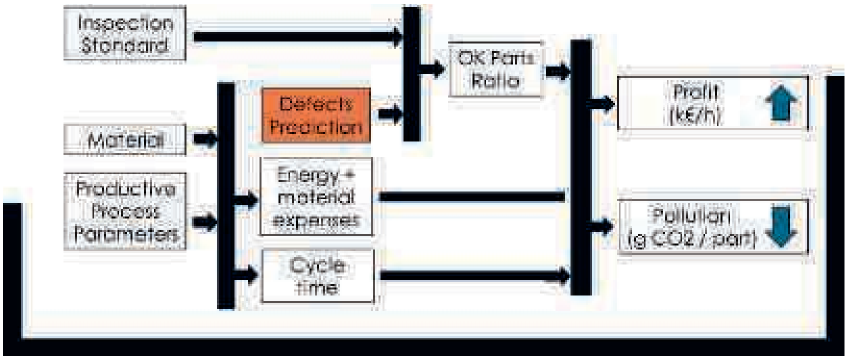

Fig. 1. Specular Zero model

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Finnish Mechanics Days 2024 / IFME2024

Indentation Hardness of 3D-Printed Metals

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Abstract.

Additive manufacturing of metals is widely used across various industries, enabling the rapid development of prototypes and the production of components with highly complex geometries [1]. The quality of 3D-printed metallic components depends on numerous influencing factors, including printing process parameters and material behavior [2]. To optimize the 3D printing process, understanding material behaviors and changes in material properties is crucial.

In this study, the hardness of 3D-printed AISI H13 hot work tool steel and AlMg1Si alloy AA-6061 was investigated using the micro-indentation test. It was demonstrated that this nearly non-destructive measurement method is highly suitable for analyzing small additively manufactured samples with relatively little effort while delivering high statistical reliability and providing meaningful insights into the mechanical properties of the materials, such as micro-hardness and indentation modulus. The statistical reliability of the measured properties can be captured very well with the Weibull distribution, correlating with the microstructural properties of the analyzed materials. Microstructural defects, such as pores and surface irregularities, lead to measurement errors, which were addressed in this work using a developed evaluation method.

The analyzed AISI H13 steel samples, produced with varying 3D printing parameters such as laser power and laser scanning speed, were measured in different orientations (build layer or X-Y printing direction, and build direction or Z printing direction). The micro-hardness measurements were conducted using the Picodentor HM500 from Helmut-Fischer GmbH (Sindelfingen, Germany) with a Berkovich indenter. The hardness

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of each sample was determined multiple times at different positions using array measurement mode to obtain good statistical results. As results the following parameters were determined: Martens or Universal hardness HM, Martens hardness HM_s from the slope of the rising force-penetration depth curve, Indentation hardness H_{IT}, Indentation modulus E_{IT}, Vickers hardness HV, projected contact area A_p of the indenter, distance h_c from the tip, and maximum penetration depth h_{max} with maximum test force [3, 4].

The results show that while all AISI H13 steel samples display similar mean values for hardness and indentation modulus, their standard deviations and Weibull moduli vary significantly depending on the 3D printing parameters. Samples produced with an optimized standard program exhibit the lowest standard deviation and the highest Weibull modulus. In contrast, standard deviations increase considerably with higher laser scanning speeds and lower laser power. Furthermore, samples measured in the X-Y printing direction show higher standard deviations and lower Weibull moduli compared to those in the Z printing direction, which is attributed to a greater number of small material defects and pores.

While no pile-up or sink-in effects were observed in the steel samples, the pile-up effect occurred during the hardness measurement of the AlMg1Si alloy. This effect increases the projected area A_p, resulting in a calculated lower hardness value. The pile-up effect and its correction were analyzed through indentations with varying measuring parameters and subsequent SEM imaging [5].

In future works, the micro- and nano-indentation tests will be optimized to investigate smaller microstructural features such as grain boundaries, precipitates, and different phases within the material. This will enable further optimization of the 3D printing process and its post-heat treatments.

Keywords: Indentation hardness, pile-up effect, LPBF 3D-printing technology, AISI H13 steel, Al-alloy AlMg1Si AA-6061

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Finnish Mechanics Days 2024

3D printing technique by stereolithography applied to make an injection mold with photopolymer resin

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Abstract. The use of additive manufacturing techniques in conjunction with injection molding is becoming increasingly popular, with financial and time benefits [1]. Rapid tooling evolved from rapid prototyping is a novel method for developing prototype tooling rapidly using various additive manufacturing techniques. Traditional injection molding is unsuitable for low-volume production because of the high initial cost [2]. This study is focused on a rapid tooling approach for producing an injection mold for low-volume production of propeller-shaped plastic components, developed using a photopolymeric resin by Formlabs named High Temp V2 [3], which has a heat deflection temperature (HDT) of 238 °C at 0.45 MPa, 2,8 GPa tensile modulus and 49 MPa ultimate tensile strength, alternative photocurable resins have been conducted for other authors to make such as tensile test specimens [4]. Stereolithography (SLA) technique has been used to make the mold, by means of a Form 3 station [5]. The mold geometry has been designed with Autodesk Meshmixer open software, the injection process of the part has been simulated with Autodesk Molflow Inshight-Synergy software (Figure 1); in this way potential defects in the final part can be identified, and how resin molds dissipate part heat, compared with metallic mold can be taken in account, due to the poor thermal properties of the die made with resin [6]. Finally, the mold was tested in a Thermoforming Centre 911, injecting polyethylene at 200 ºC inside the high-temperature resin mold, with a positive outcome; because the part could be demolded easily, the mold was not damaged and the part was well shaped (Figure 2), which is a very interesting result because of the high difficulty geometry of the part-propeller injected.

Keywords: rapid tooling, injection molding, *stereolithography*, high-temperature resin, polymeric mold.

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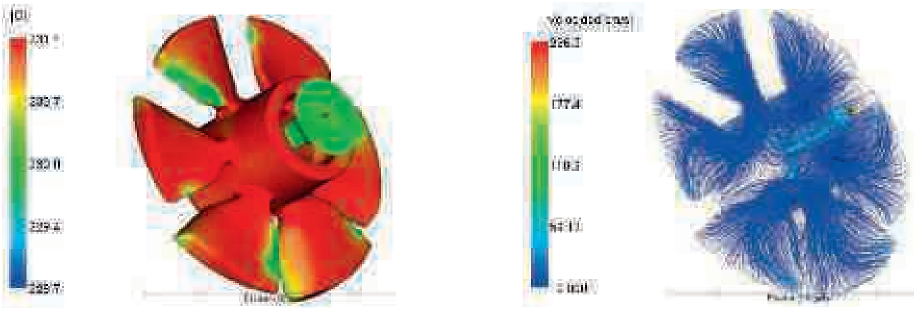

Figure 1. Left: Temperature at the flow front. Right: Trajectory lines.

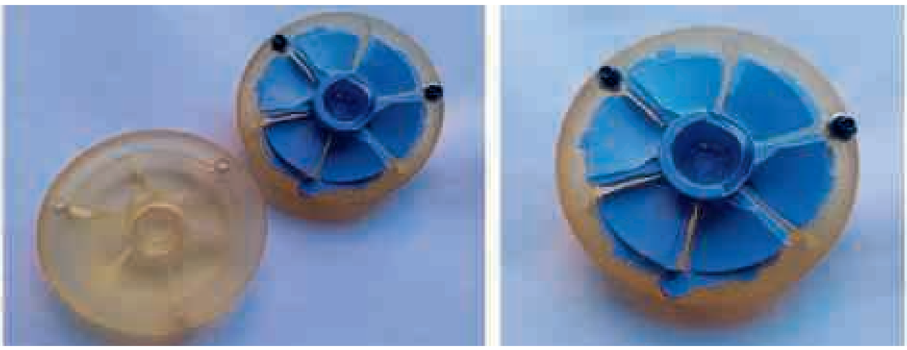

Figure 2. High temperature-resin mold after demolding polyethylene propeller.

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Finnish Mechanics Days 2024

Efficient Modeling of the effects of discrete supports in railway track dynamics

Álvaro Brazales[1], Javier F. Aceituno[1], Rosario Chamorro[2] and José L. Escalona[2]

Abstract. This study introduces a moving and periodically variable track model for use in railway vehicle simulation. The mechanical properties of the proposed flexible track model are determined from frequency response functions and periodic orbits obtained from a well-known finite-element track model. Given the challenges of modeling the discrete nature of railway tracks, the implementation of these computational models offers a highly computationally efficient alternative for numerically simulating the vehicle-flexible track interaction.

Keywords: railway track dynamics, discrete supports, moving track models.

Description

The inclusion of discrete supports in railway track models is crucial not only at high frequencies to describe rail response around the pinned-pinned mode but also at low frequencies for modeling the parametric excitation, responsible for the so-called sleeper-passing frequency [1]. Finite Element Method (FEM) has been successfully applied to railway track dynamics to this end, resulting in highly accurate computational models that capture the discrete nature of railroad tracks (see the left side of Fig. 1) [2]. Despite the accuracy of finite-element models, the influence of the boundary conditions imposes a limitation on the length of the simulated track, significantly reducing the computational efficiency of these flexible track models [3]. This limitation has motivated the researchers of Flexible Multibody Dynamics (FMD) to develop more computationally efficient techniques, such as the Moving Modes Method (MMM) [4].
In this context, a computationally efficient approach for modeling the flexibility of railway tracks with discrete supports involves attaching a set of concentrated masses or rigid body elements interconnected by sets of spring-dashpot elements to the moving wheelsets, loads or masses (see the right side of Fig. 1). Imposing a periodicity to the

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mechanical properties of these moving support models, with the spatial period matching the sleeper-spacing, the periodicity of railroad tracks can be modeled.

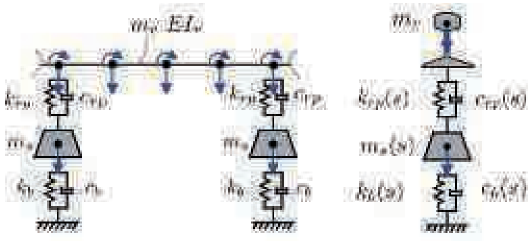

Figure 1. Left: Reference FEM model. Right: Moving and periodically variable track model.

Traditionally, models matching in railway track analysis has been done using frequency response functions (FRFs) (Fig. 2 left) [5]. This work extends the previously mentioned methodology by additionally using periodic orbits obtained from solving the moving load or moving mass problem in a finite-element railway track model (Fig. 2 right). Utilizing periodic orbits allows for the consideration of the dependence of railway track receptance on speed, which is not possible with only frequency response functions.

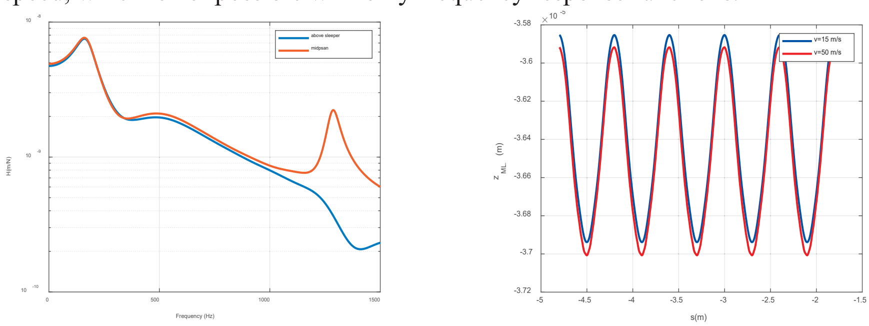

Figure 2. Left: Frequency response functions evaluated at different points in the finite-element track model [5]. Right: Vertical peridioc orbits derived from moving load simulations.

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Chapter 7

Round Table 1: Tutkimusyhteistyö – yliopistojen, tutkimuslaitosten ja yritysten roolit

October 2, Wednesday at 15:00 - 16:00. Room: FP05 Chair: Jarkko Niiranen

Finnish Mechanics Days 2024

ROUND TABLE:

Tutkimusyhteistyö -- yliopistojen, tutkimuslaitosten ja yritysten roolit

Jarkko Niiranen

Yliopistoilla on lain mukaan kolme tehtävää: "Yliopistojen tehtävänä on edistää vapaata tutkimusta sekä tieteellistä ja taiteellista sivistystä, antaa tutkimukseen perustuvaa ylintä opetusta sekä kasvattaa opiskelijoita palvelemaan isänmaata ja ihmiskuntaa". Näiden tehtävien lisäksi yliopistoille on annettu velvollisuus välittömämpään yhteiskunnalliseen vaikuttamiseen: "Tehtäviään hoitaessaan yliopistojen tulee tarjota mahdollisuuksia jatkuvaan oppimiseen, toimia vuorovaikutuksessa muun yhteiskunnan kanssa sekä edistää tutkimustulosten ja taiteellisen toiminnan yhteiskunnallista vaikuttavuutta." Yrityksillä on omat motivaationsa sekä tutkimukseen -- tosin yleensä vähemmän vapaaseen -- sekä tuotekehitykseen. Tämän pohjalta voidaan esittää useita oleellisia kysymyksiä teknillisten alojen tutkimukseen ja tuotekehitykseen liittyen, mutta yksi oleellinen kysymys on, miten nämä tehtävät, velvollisuudet ja motivaatiot voidaan yhdistää parhaalla mahdollisella tavalla, niin lyhyellä kuin pitkälläkin tähtäimellä. Voidaan myös kysyä, onko Suomessa toimittu toisin kuin muualla Euroopassa tai maailmassa, suunnilleen samojen vaatimusten ja olosuhteiden ollessa voimassa.

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Chapter 8

Mini-Symposium 1: Imaging and image-based methods in experimental mechanics

October 3, Thursday at 12:30 - 14:30. Room: F304 Chairs: Sven Bossuyt and Mikko Hokka

Finnish Mechanics Days 2024

Optimizing patterns for DIC

Sven Bossuyt[1]

Abstract. Generating synthetic patterns with features optimised for the intended measurements can significantly improve the accuracy, precision, and robustness of DIC measurements. We describe a method to first generate random patterns with specified frequency content, and subsequently ensure that the features satisfy other desired criteria.

Keywords: DIC, pattern, feature size, resolution, spatial frequency, autocorrelation

Methods

The Fast Fourier Transform (FFT) algorithm provides a convenient means of converting between the spatial representation of an image and its spatial frequency content. In particular, it allows to specify the frequency content of a pattern, and generate random patterns with that frequency content by randomising the phase of the frequency components [1]. However, analysis of the measurement uncertainty and noise-induced bias in DIC measurements indicates that these are reduced when the contrast of the pattern is increased [2]. Increasing the contrast with a limited intensity range ultimately results in clipping of the intensity range. This introduces higher spatial frequencies in the image, but it should be noted that the phase of these high-frequency components is determined by that of the band-limited components, and it may therefore in principle be possible to analyse such images in ways that avoid aliasing effects without discarding the information carried in the high-frequency components. Even when analysing high-contrast patterns as if they were band-limited, the increased contrast at least partly offsets the loss of displacement accuracy induced by interpolation error.

As a consequence of clipping the intensity range, some features may be much smaller than in the original band-limited pattern, or disappear entirely. In previous work, this was addressed with morphological operations to detect small features or large featureless areas [1]. An alternative method, less computationally expensive, consists of finding local minima and maxima in the greyscale pattern intensity that are on the wrong side of the threshold for clipping or close to it. This method can also easily detect saddle points in the greyscale pattern intensity that are close to the threshold for clipping, which result in “checkerboard” corners in the high-contrast pattern. Even if those are not necessarily

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problematic for the DIC algorithm, they may cause difficulties with some methods of applying the pattern and it may therefore be desirable to eliminate them from the pattern.

Results

Starting with a nearly "optimally sharp" pattern, and iteratively adjusting the level of any stationary points in the greyscale pattern away from the threshold used to convert it to a black and white pattern, results in a pattern with "worm-like" features with nearly uniform size and spacing. Whereas the pattern has a high density of high-contrast edges, the edges are smooth in the sense that the radius of curvature is everywhere as large as is compatible with the minimum size of the features.

Discussion and Conclusion

The worm-like features are in some locations close to a pattern of parallel lines, which causes relatively large uncertainty at those locations in the DIC results for the displacement component parallel to those lines. Whereas it is possible to identify and correct these manually, future work could detect and correct these automatically.

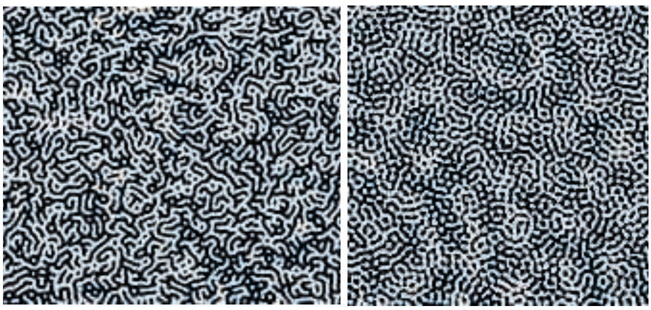

Figure 1. Comparison of the worm-like features (on the left) with the optimized patterns made earlier (on the right) [2].

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Finnish Mechanics Days 2024

Micromechanical testing inside the scanning electron microscope: leveraging image-based methods to enhance materials research

Guilherme Corrêa Soares[1], Matti Lindroos, and Supriya Nandy

Keywords: *micro digital image correlation, scanning electron microscopy, crystal plasticity modelling, quantitative microscopy, in-situ testing*

Material behaviour under mechanical loading is often more complex than what can be described using purely macroscopical measurements. To properly grasp what transpires within a material during deformation, it is essential to also understand the micron or nano scale phenomena leading to microstructural evolution. This work presents ongoing efforts at VTT Technical Research Centre of Finland in combining in-situ testing within the scanning electron microscope (SEM) with micro digital image correlation (μDIC). The procedures being developed allow for the quantitative measurement, correlation, and modelling of material response and evolution at a microstructural level. Different testing modules have been used to carry out in-situ tensile testing in the SEM utilizing monitoring from several detectors, providing data that describes different aspects of the microstructure. Although these results already provide microstructural insights, obtaining quantitative measurements of surface displacements and strains at grain level is important for direct comparison between the effect of different relevant environmental variables, as well as differences between distinct materials. Specific patterning solutions have been developed, which must be tailored for each material and pertinent scale. Several high-resolution SEM images of a region-of-interest (AOI) in specimens were taken at different deformation steps using an automated grid approach. The images were then merged into a single higher resolution image utilized for the μDIC analysis. Full-field displacements and strains obtained throughout the AOI were found to correlate well with grain boundary and kernel average misorientation data from electron backscatter diffraction (EBSD). This approach provided valuable data which have been successfully used to enhance and validate the development of crystal plasticity models of a reactor pressure vessel steel. Furthermore, the large datasets generated with this technique can be utilized for data-driven modelling and machine learning approaches, which can be implemented in the design of complex materials and components.

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Finnish Mechanics Days 2024

High throughput tensile testing for characterization of static strain aging

Ville Björklund[1], Sven Bossuyt

Abstract. A novel high throughput method for characterizing static strain aging (SSA) behavior in materials is presented. A tapered specimen with increasing cross-section is used for pre-straining to induce a pre-strain gradient along the gauge length. A second machining step with electric discharge machining (EDM) is used to remove the taper after pre-straining, making the specimen more typical "dog bone" shaped. An aging treatment is then applied to induce static strain aging in the specimen. Finally, an ordinary tensile test until rupture is conducted, using stereo digital image correlation (DIC) to obtain full-field strain measurements from the whole gauge section. The full-field strain data enables extraction of local stress-strain curves along the gauge length of the specimen, thus sampling material pre-strained to different levels in the original tapered specimen. However, the stress strain curves obtained from one continuous specimen with pre-strain gradient cannot accurately reproduce the yield point in detail as a drop in the engineering stress is not possible when multiple pre-strain levels are loaded in series. Therefore, the stress-strain data obtained needs a stress correction which is possible based on the local strain rate data obtainable from the DIC measurement. A variable smoothing process utilizing inverse approach is proposed for the noisy strain rate data to accurately estimate the strain rate peak and a strain rate-based stress correction is applied to obtain accurate local stress-strain data from the tapered specimen.

Keywords: High throughput, DIC, Static strain aging

Introduction and experimental

The development of full-field measurement techniques such as DIC has opened the possibility to gather experimental data more efficiently than previously. Typically, static strain aging is characterized on conventional tensile test specimens, pre-straining, doing an aging treatment, and then final tensile test. This type of testing is very laborious and requires a large set of specimens to gather data at different pre-strain levels and aging conditions. Utilizing a tapered specimen to create a specimen with a pre-strain gradient makes it possible to gather extensive data for combinations of pre-strain, aging temperature, and aging time. What would otherwise require tens or hundreds of

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conventional two step tensile tests, is possible to obtain from only a few of these experiments. Thus, the method presented makes it practical to do test campaigns that would otherwise require hundreds or thousands of tests and specimens. The use of tapered specimens in mechanical testing is not entirely new. However, the two-step process inducing pre-strain gradient for uniformly shaped tensile specimen to characterize SSA of material has not been done.

The strain rate-based stress correction brings unique challenges regarding the smoothing of the, usually rather noisy, local strain rate data as we are now interested in having as accurate a reading as possible regarding the maximum strain rate amplitude and moment of time it occurs. The smoothing is challenging as too conservative smoothing doesn't smooth the data enough and aggressive smoothing results in underestimating the strain rate peak. We propose a variable smoothing approach which aims to smooth the data heavily before and after the yield point and more conservatively at yield point to better estimate the true strain rate behavior. The smoothing is done according to equation (1), where ε_{DIC} is the strain measured with the DIC.

$$\dot{\varepsilon} = R\, e^{f(t)}, \quad f = \underset{f(\tau)}{\arg\min} \left\{ \sum_i \left\| \int_0^{t_i} R\, e^{f(\tau)} d\tau - \varepsilon_{DIC}(t_i) \right\|^2 + \alpha \int \| \dot{f}(\tau) \|^2 d\tau \right\} \tag{1}$$

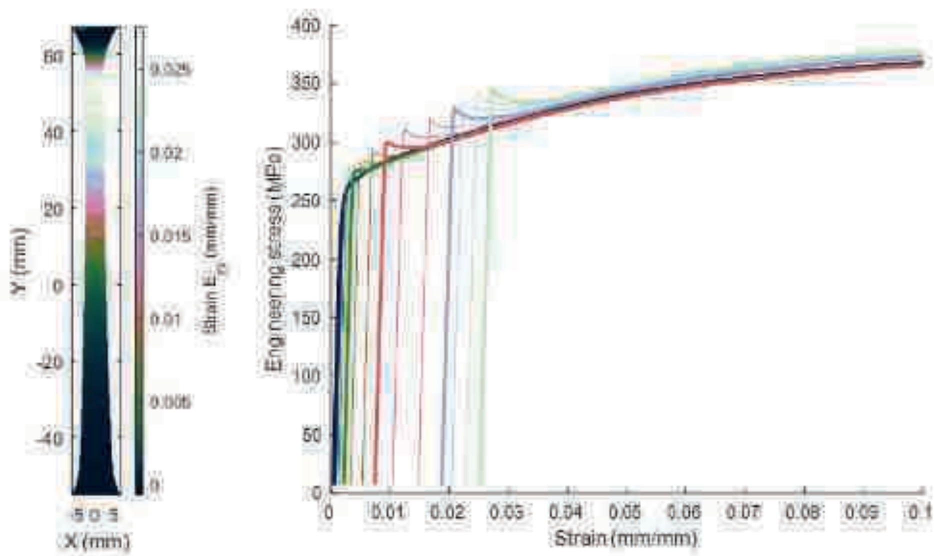

Figure 1. left) Tapered specimen with pre-strain gradient. right) Preliminary analysis of local stress-strain curves obtained with the specimen on the left after aging 1 day at 100 °C and removing the taper, including a stress correction to account for variations in the local strain rate.

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X-Ray phase contrast imaging of dynamic compressive fracture of fiber reinforced polymer composite and granitic rocks

Mikko Hokka[1], Arturo Rubio Ruiz, Nazanin Pournoori, Mikko Kanerva, Matti Isakov

Abstract. Understanding of fracture and fragmentation behavior of materials at high rates of loading is of great importance for developing new materials, components, and tools, where impact damage is either a risk or an opportunity. For example, development of rock drilling technologies requires good fundamental understanding of how the rock fracture depends on the structure of the rock and the loading conditions. Percussive rock drilling technologies are based on impacting the rock mass with a drill tool, which leads to complex stress states and transient high strain rate phenomena within both the rock mass and the drill tools. Rocks contain several different minerals, boundaries and interphases between the minerals, texture or fabric, microcracks, pores, absorbed liquids and gases etc. which lead to complex and unpredictable dynamic mechanical response, fracture, and fragmentation behavior. On the other hand, Carbon Fiber Reinforced Polymer (CFRP) composites are used extensively in lightweight applications across various industries including demanding impact-resistant structural designs. Here the impact damage is obviously not intentionally generated, but rather the materials are used to deflect and absorb the impact energy to protect other more critical components and structures. The inherent anisotropy of FRP composites, arises from the orientation of reinforcing fibres in a laminate, and it significantly affects the levels of strength, stiffness, and resistance to specific failure modes. Because of such complex multiscale structures, it is very difficult to predict how, where, and at which load CFRP laminates will fail. The X-ray phase contrast imaging (XPCI) enables the visualisation of damage initiation, propagation and fragmentation of complex materials under dynamic loading. This presentation describes successful examples of the application of ultrafast XPCI as a tool for characterising the failure and fragmentation processes of granite and CFRP. The experiments were carried out at ID-19 of the European Synchrotron Radiation Facility, where the sample was loaded mechanically using a Split Hopkinson Pressure bar device, while simultaneously imaging the specimen and its deformation during loading. This work complements the experiments carried out at Tampere University, where also high speed infrared imaging (IRT) and high speed imaging (DIC) were used to characterize the full thermomechanical phenomena related to the dynamic fracture. XPCI offers a helpful tool for observing the formation of internal damage in different materials under dynamic loading conditions. These observations serve as a qualitative reference for calibration and validation of numerical models to simulate damage evolution in granite and CFRP. Some examples of how the XPCI were used to validate finite element models used to simulate the fragmentation process of granite and CFRP are shown in this presentation.

Keywords: XPCI, Split Hopkinson Pressure Bar, polymer composites, granitic rocks, dynamic fracture

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Finnish Mechanics Days 2024

Simultaneous X-Ray diffraction, infrared and DIC measurements during tension tests of metastable austenite containing steels

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Abstract

This presentation describes recent developments in the experimental techniques at the DanMAX beamline of the MAX IV laboratory. This work has been carried out in collaboration between Tampere University and MAX IV with the aim of developing future high strength steel alloys, whose mechanical properties are enhanced by a phase transformation from face centered cubic austenite to (near) body centered cubic martensite taking place at an optimal rate when the material is externally loaded. The experimental campaign involved the development of novel experimental methodology for the *in-situ* characterization of mechanically induced solid-state phase transformations across a wide range of deformation rates. For this, a custom-built mechanical loading frame was incorporated into the DanMAX beamline so that high frequency (250 Hz) diffraction measurements could be carried out in transmission geometry on a bulk metallic specimen during loading. The test setup was supplemented by an optical camera which allowed contactless in-situ deformation measurement of the specimen. Finally, a high-speed infrared camera was added to the experiment to allow in-situ contactless temperature measurements of the specimen deforming at a high rate. With the developed test setup, material phase fractions can be measured with high temporal resolution during loading. For example, in a test lasting less than one second, over hundred diffraction frames were collected and precisely correlated with the external loading, amount of deformation, and temperature increase caused by the adiabatic heating. The simultaneous measurements of strain and temperature add further information on the thermomechanical state of the specimen, and altogether this measurement characterizes the overall thermomechanical behavior of the specimen at very high temporal resolution. This presentation describes the measurement and shows examples of our recent measurements at MAX IV laboratory.

Keywords: High energy X-Ray Diffraction, Infrared Imaging, DIC, in-situ measurements, tension tests, synchrotron light

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Finnish Mechanics Days 2024

Virtual mechanics laboratory based on DIC

Mikko Hokka[1]

Abstract. Engineering education, and especially the mechanics of materials, includes some difficult topics that would significantly benefit from hands on learning. A very simple example is to understand how the position and length of a strain gage or extensometer affect the stress-strain plot obtained from a tension experiment. Similarly a bit more complex example would be understanding of the micromechanical processes that govern plasticity, which can be rather difficult to understand if one cannot observe the phenomena in practice. For example the root causes discontinuous yielding or the sharp yield point and the formation of the Lüders band in a tension experiment of mild steels could be much easier to learn if one could 'see' how this actually happens. Observing the formation of the Lüders band and visually seeing its propagation would promote learning. Unfortunately, hands on experiments for large groups of students are very labor intensive and expensive. Similarly, most simulation software that could be used for education are too complicated for freshmen students, and therefore the teacher would first have to spend time on teaching the students how to use a software. In this abstract we describe a flexible and resource efficient digital learning environment based on Digital Image Correlation. This *Virtual Mechanics Laboratory* allows safe experimentation and visualization of material behavior in different conditions. When the virtual laboratory is coupled with the lectures and literature concerning the theories of materials the learning outcomes are greatly improved. We present some examples how this learning environment can be used as well as some statistics on the benefits of the learning outcomes from large number of students.

Keywords: Engineering education, digital image correlation,

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Chapter 9

Mini-Symposium 2: Industry cases

October 3, Thursday at 12.30 - 14.30. Room: F305 Chair: Tero Frondelius

Finnish Mechanics Days 2024

Transient thermal stress FE-analysis method development

Sami Kreivi[1], Janne Kemppainen, Teemu Kuivaniemi, Antti-Jussi Vuotikka and Tero Frondelius

Abstract This research paper investigates the recently discovered challenges associated with thermomechanically loaded components in four-stroke medium-speed engines, focusing particularly on exhaust pipe (Figure 1) failures. Wärtsilä has actively contributed to the energy transition towards 100% renewables [1] that has affected broadly engine operating conditions. As a result, this change has led to locating cracks in the exhaust components that have not had problems before, nor the simulations have pointed out. The dominant failure mode that has become more significant along this change in engine usage is low-cycle thermal fatigue (LCTF) [2] and the conventional workflow of using cyclic steady-state temperatures has proven to be insufficient. A more accurate transient method which vastly exploits measured temperatures during the engine's thermal cycle is developed and optimized due to transient heat transfer analyses' significantly longer calculation times. The revised simulation methods for daily engineering work fit well with the continuous development of simulation-enhanced research and product improvement that has been the nature of Wärtsilä's R&D for decades [3]. The improved agility of the workflow can be considered vital in the whole design process due to the numerous design iterations before the acceptable version.

The results from the newly developed transient workflow correspond to phenomena reported in the field, including high-stress concentrations in cracked locations. Along with better confidence in relying on the simulation results, the importance of geometric optimization becomes not only possible but also a valuable asset to obtain a longer lifetime for components. The optimization of structure design is one of the most effective approaches in LCTF problems [4, 5]. Thermal stress amplitudes are highly prone to develop in sharp shapes and areas that experience a wide range of temperatures and uneven changes in temperature distributions, for which some example solutions are explained. The results of this study provide a compromise between agile and accurate workflow for reaching trustworthy thermal stress results during a component's design process which can be further utilized in the component's lifetime estimation.

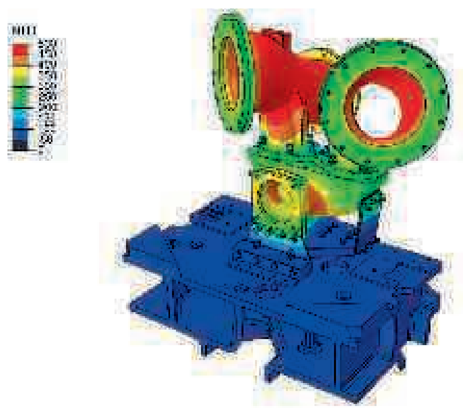

Figure 1. Temperatures [°C] in an exhaust pipe assembly 15 minutes after start.

Key words: Transient, Low-Cycle Thermal Fatigue, Medium Speed Four-Stroke Engine

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Suomen Mekaniikka Päivät 2024

Staattisen kitkakertoimen määrittäminen kokeellisesti

Ville Tuura[1], Teemu Kuivaniemi, Antti-Jussi Vuotikka ja Tero Frondelius

Tiivistelmä. Artikkelissa esitetään staattisen kitkakertoimen määrittämiseen suunniteltu laite, jolla voidaan tutkia kontaktipaineiden ja pinnankarheuksien vaikutusta staattisiin kitkavoimiin. Laitteella saatavia tuloksia voidaan hyödyntää simulaatiossa, joissa kontaktit vaativat todellisten kitkakertoimien käyttöä. Laite suunnitellaan ja validoidaan käyttäen hyväksi aiempia kokeellisia tutkimuksia [1,2,3,7,8,10] sekä standardeja [4,5]. Staattinen kitkakerroin määritetään tasopintojen normaali- ja tangenttivoiman suhteesta klassisen Amonton-Coulomb kitkalain mukaisesti, jonka mukaan todellinen kontaktipinta-ala kasvaa lineaarisesti normaalivoiman kasvaessa. Materiaaliparin kitkakerroin on tällöin riippumaton pintaan kohdistuvan normaalivoiman suuruudesta [6]. Adhesiivisen kitkateorian mukaan kitkavoimat syntyvät pinnan mikroskooppisten huippujen yhteenliittymisestä. Pintojen välinen liike mahdollistuu kun tangenttivoiman aiheuttama leikkausjännitys ylittää materiaalin leikkauslujuuden [9]. GBW:n (Global Boiler Works Oy) kitkamittauslaitteella voidaan tutkia kontaktipaineita 10 – 100 MPa välillä. Laitteen voimien tuotto hydraulisesti mahdollistaa suurten koekappaleiden ja eri materiaalien käyttämisen testeissä. Koekappaleiden suuret tasopinnat mahdollistavat erilaisten valmistusmenetelmien, pinnanlaatujen ja pinnoitteiden tutkimisen. Tasopintojen normaali- ja tangenttivoima todennetaan koko testin ajan voima-antureilla. Materiaaliparin staattinen kitkakerroin määritetään em. voimien suhteesta.

Avainsanat: Staattinen kitka, mittaus

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Finnish Mechanics Days 2024

Numerical analysis of mechanical integrity of marine engine components operating with zero-carbon fuels

R. Arturo Rubio Ruiz[1], Tero Frondelius, Jari Tuominen, Reijo Kouhia, Mikko Hokka

Abstract.

The shipping industry accounted for approximately 2% of the global energy-related CO_2 emissions in 2022. Thus, multiple initiatives have been directed to decarbonization of the shipping industry. One promising approach is the use of H_2 and NH_3 as marine engine fuels, either individually or in blends for flexible fuel operation. However, the differences of thermal input from zero-carbon fuels can result in unexpected oscillations of thermomechanical loads, leading to fatigue. Additionally, the presence of atomic H near the surface of metallic components can cause hydrogen embrittlement, reducing material fatigue resistance. Notice that engine parts operating with hydrocarbons like diesel experience the formation of wear-protective layers because of the accumulation of combustion products, also referred to as tribofilms [1, 2]. However, zero-carbon fuels do not present such protective layers and, as a result, the engine parts experiencing friction may exhibit increased wear rates. Besides, the presence of H_2 and NH_3 might accentuate the abrasive conditions during contact.

This study presents a numerical framework for evaluating wear and fatigue damage in engine components when using zero-carbon fuels. Note that such framework contributes to the advancement of engine simulations and modelling tools at Wärtsilä. For a comprehensive list of engine simulations developed at Wärtsilä, refer to the work of Frondelius et al [3]. The Ottosen time continuum fatigue model [4] is used to assess the damage evolution caused by realistic cyclic thermomechanical loads, which are computed using the Finite Element (FE) simulations. Furthermore, the wear rate of engine components is estimated by utilizing the contact history obtained from FE simulations of the operating part, in accordance with Archard's equation [5], defined as,

$$\dot{h} = kpv \tag{1}$$

where $\dot{h}$ is the rate of worn depth, p is the contact pressure, v is the contact slip rate and k is a constant. In this study, the Archard's equation is enhanced by incorporating a dependency of k on the concentration of agents like H_2. Thus, accounting for possible changes in tribological conditions caused by the presence of such agents. Additionally, material model calibration strategies are developed to integrate experimental data into the numerical models, enabling the

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accurate representation of the influence of each contributing phenomenon on both fatigue damage evolution and wear.

This study introduces a systematic methodology that combines realistic loading conditions and numerical models to effectively evaluate the fatigue and wear of engine components when operating with zero-carbon fuels. Besides, it emphasizes the importance of comprehensive experimental data in accurately predicting the influence of NH_3 and H_2 on the mechanical integrity of the involved materials.

Keywords: Decarbonization challenges, Wear, Fatigue damage, Finite element analysis.

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Finnish Mechanics Days 2024

Impact-induced leaking of fuel line

Antti-Jussi Vuotikka[1], Rami Kokko, Martin Rönnberg, Yao Xiao, Jonas Holm and Tero Frondelius

Abstract Impact loads are encountered in many different types of mechanical equipment. One notable application is the four-stroke medium-speed engine [1], which has a wide variety of motions and processes that can cause impact-like loads [2, 3].

Wärtsilä has recently invested a lot in the utilization of renewable fuels [4]. New fuels have unexpected physical properties compared to previously used liquid fuels, which can cause challenges in the design of fuel components.

The fuel components of a diesel engine typically include compression joints [5] that seal the bores where the fuel passes through the separate components. Fuel components and their joints may be subject to shock loading due to external or internal load sources leading to fatigue or leaking issues.

A flow fuse is used to cut off the fuel flow when the spring presses the piston against the sealing surface, figure 1. Fuel flow is possible in one direction when there is a favourable pressure difference during fuel injection. During the opposing pressure difference, the flow fuse closes the fuel line, preventing the flow of fuel in the opposite direction. Depending on the levelling speed of the pressure difference, the piston can cause an impact-like load on structures when it hits the sealing surface. An impact occurs in every injection cycle causing potentially unwanted loading in the structure. This presentation focuses on how the root causes of leaking and cracking of the components have been addressed through measurement, FE modelling and data processing.

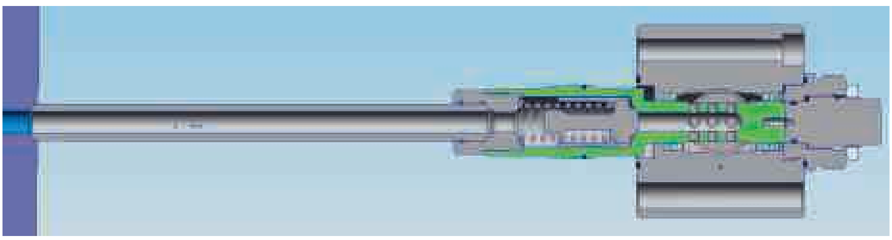

Figure 1. The flow fuse with the surrounding fuel line components is shown in the figure. Support parts such as the cylinder head have been omitted.

Key words: impact, piston, leaking, methanol, fuel line, data analysis, Explicit FEM, Wärtsilä

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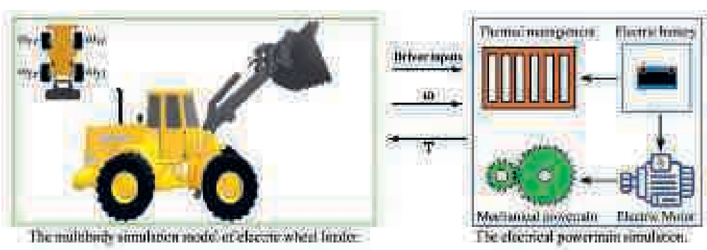
Finnish Mechanics Days 2024

Reaaliaikainen termisten ja sähkömekaanisten systeemien dynaaminen monikappale rinnakkaissimulaatio pyöräkuormaajamallissa

Eero Ikäheimo[1], Qasim Khadim, Tuhin Choudhury, Emil Kurvinen

Tiivistelmä Yhä monimutkaisemmiksi ja digitaalisemmiksi muuttuvat ajoneuvot, sekä työkoneet vaativat tehokkaampia suunnitteluratkaisuja, joilla voidaan välttää kalliita virheitä prototyyppejä rakennettaessa. Reaaliaikaiset simulaatiot voivat tuoda apua koneiden suunnittelussa, sekä analysoinnissa ja mahdollistavat laitteen käyttäjän osallistumisen suunnitteluvaiheeseen [1]. Ongelmallista reaaliaikaisen simulaation toteutuksessa ovat korkeat laskennalliset kustannukset, kun yritetään simuloida monia alajärjestelmiä, kuten hydrauliikkaa, voimansiirtoa, renkaita, kitkaa ja kontakteja [2]. Yhtenä ratkaisuna edellä esitettyyn ongelmaan tutkimuksemme esittelee reaaliaikasen rinnakkaissimulaation, jossa on käytetty monikappaledynamiikka, hydrauliikka ja sähkötermistä systeemimallia. Simulaatiomalleja tehdään ja lasketaan useimmiten monoliittisinä, eli yhdellä ohjelmistolla, mutta rinnakkaissimulaatiolla voidaan optimoida ohjelmistoja tutkittavan kohteen mukaisesti ja laskean laskennallista kuormaa käyttämällä useita tietokoneita ja paremmin laskettaviin haasteisiin sopivia ohjelmistoja [3]. Tutkittavaksi koneeksi valitsimme abstraktin pyöräkuormaajan, johon on tehty jälkiasennuksena sähköinen voimalinja.

Rinnakkaissimulaatiossa käytetään kahta tai useampaa ohjelmistoa laskemaan simulaatiota host-client-mallilla, jolloin voidaan hyödyntää käyttökohteen mukaan optimoituja ohjelmistoja keventämään laskennallista kuormitusta [4]. Tutkimuksessa monikappaledynamiikka ja hydrauliikkamalli lasketaan MEVEA-ohjelmistolla (host), kun taas voimansiirto, sekä akkumalli lasketaan simulink-ympäristössä (client). Ohjelmistojen välinen yhteydenpito on tehty TCP/IP-protokollaa käyttäen, joka mahdollistaa nopean tiedonsiirron ohjelmistojen välillä. Rinnakkaissimulaation toimintaa on havainnollistettu kuvassa 1.



Kuva 1. Rinnakkaissimulaatiota havainnollistava kuvaaja. Käyttäjä pyytää nopeutta, joka muuntautuu renkaiden kulmanopeudeksi $\boldsymbol{\omega}$. Voimalinja pyrkii vastaamaan pyyntöön välittämällä vääntöä $\mathbf{T}$, kunnes pyyntö ja vastaus ovat tasapainossa. Muita käyttäjän pyyntöjä ovat vaihde, suunanvalinta ja jarrutus.

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Systeemi mallinnettiin neljän vapausasteen pyöräkuormaajan malliin, jossa hyödynnettiin monikappaledynamiikkaa, yhdistettyjen nesteiden teoriaa, LuGre-rengasmallia, Thevenin akkumallia Li-ion akulle ja voimansiirtosysteemiä. Mallin dynaamista ja sähkötermistä suorituskykyä testattiin kolmessa eri lämpötilassa +0 C, +15 C ja +30 C. Rankemman kuormituksen lisäämiseksi käytimme pehmeän maan mallia lisäämään ajovastuksia ja tutkimaan mallin laskentatehokkuutta, sillä pehmeä maa lisää kuormittavuutta monin tavoin, jolloin alasysteemien laskennalle voi jäädä vähemmän kapasiteettia [5].

Tuloksista selvisi simulaatiomallin olevan suorituskykyinen ja toimivan asetetun aika-askeleen sisällä, vaikkakin samalla lasketaan monia alasysteemejä. Lisäksi akun lataustila ja akun osioiden lämpötiloja pystytään tarkkailemaan reaaliajassa ja analysoimaan tarkemmin simulaation päätyttyä [6]. Tutkimuksen tavoitteena oli tuoda uudenlaisia työkaluja suunnittelijoiden käyttöön ilman suuria kustannuksia tai laskennallista kapasiteettia. Reaaliaikainen rinnakkaissimulaatio voi edesauttaa energiatehokkaampien koneiden ja ajoneuvojen suunnittelussa, sekä digitaalisten kaksosten luomisessa.

Avainsanat: Monikappaledynamiikka, rinnakkaissimulaatio, lämmönhallinta, reaaliaikasimulaatio, systeemisuunnittelu

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Finnish Mechanics Days 2024

AI-Empowered MODSIM for Design Exploration

Autio Eetu[1] and Shakil Saani

Abstract. We will explore the benefits of AI-Empowered MODSIM technology to accelerate Physics-based Design Exploration. While MODSIM compresses development cycle times, for large complex products the execution of the used physics-based solvers can sometimes be a significant bottle neck. Machine Learning generated 3D surrogates can come to the rescue to significantly accelerate the process by eliminating the computational cost of physics computations once a model is trained. We'll illustrate several multiphysics examples including structural, fluids, electromagnetics applications from various industries. The examples include scenarios that train Machine Learning surrogates from either parametrized designs and excitations or from data that is not parametrized but may exist historically from previous years. With trained surrogates reducing execution times from hours to seconds, they may enable much more extensive optimization exercises when thousands of evaluations are no longer a prohibitive endeavor.

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Chapter 10

Contributed papers 5: Fracture, damage and wear

October 3, Thursday at 12.30 - 14.30. Room: D149 Chair: Antti Niemi

Finnish Mechanics Days 2024

Fracture toughness of hierarchical lattices

Akseli Leraillez[1], Luc St-Pierre

Abstract. Previous studies have consistently demonstrated that incorporating hierarchy into lattices can significantly enhance their mechanical properties. Many biological materials, known for their exceptional fracture toughness K_{IC} possess a hierarchical architecture. The objective of this study is to quantify the fracture toughness of three hierarchical topologies (hexagonal, Kagome, and triangular) through finite element (FE) simulations employing the boundary layer method. Additionally, analytical predictions are provided to explain the effect of hierarchy on fracture toughness. The findings indicate that hierarchy only enhances the fracture toughness of bending-dominated lattices. The hierarchical hexagonal lattice exhibits superior fracture toughness compared to the simple hexagonal lattice. Notably, the fracture toughness of the hierarchical hexagonal lattice scales linearly with the relative density $\bar{\rho}$, while the fracture toughness of the simple hexagonal lattice scales as $\bar{\rho}^2$. For hierarchical Kagome and hierarchical triangle introducing hierarchy did not enhance fracture toughness.

Keywords: lattice materials, fracture toughness, hierarchy, finite element

Introduction

Lattice materials are periodic cellular solids that are generated by tessellating a unit cell. Lattice materials allow for a wide range of mechanical properties and are often used in lightweight applications. Lattice materials are known to be light and stiff, but they also possess a high fracture toughness [1]. The strength and stiffness of lattice materials have been investigated extensively and are limited by theoretical upper bounds. The relative elastic modulus and the relative yield strength cannot exceed the relative density. In contrast, the fracture toughness of lattice materials is theoretically unbounded. Prior studies have shown that hierarchy can increase the elastic modulus and strength of lattices, but a detailed analysis of its impact on fracture toughness is missing [2].

This work aims to quantify the enhancement to fracture toughness that can be achieved by incorporating hierarchy. This is done by studying three topologies shown in Fig. 1a. The topologies are hexagonal, triangular and Kagome. This selection is made to cover a range of deformation behaviour and fracture toughness. Hexagonal is bending-

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dominated, triangular is stretching-dominated, and Kagome is also stretching-dominated but has an exceptional fracture toughness.

A new property, large scale lattice stockiness, is introduced to characterize the ratio of the two different length scales. The number of triangular elements in the longitudinal direction of the hierarchical strut is varied in this study resulting in change of stockiness for the hierarchical lattices. Large scale lattice stockiness is defined as c/L, where c is the thickness and L is the length of the hierarchical strut, see Fig. 1b, and three values of stockiness are illustrated in Fig. 1c for a hierarchical hexagonal unit cell.

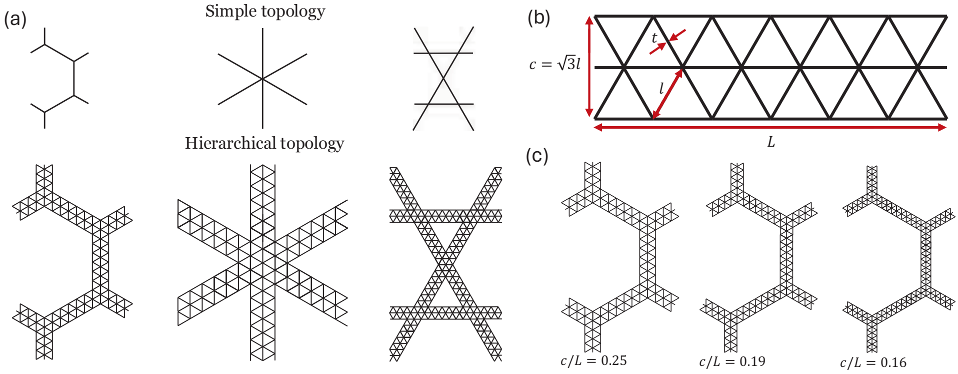

Figure 1. a) Unit cells of simple and hierarchical topologies. b) Hierarchical strut. c) Three hierarchical hexagonal designs

Results

The mechanical properties of three hierarchical topologies were investigated using FE simulations and analytical calculations. Our findings indicate that hierarchy provides significant benefits to the hexagonal lattice, which is bending-dominated. This is attributed to the increase in bending stiffness and bending failure moment. The analytical and computational results were in good agreement. The introduction of hierarchy results in a stretching-dominated response, and the fracture toughness scales linearly with $\bar{\rho}$.

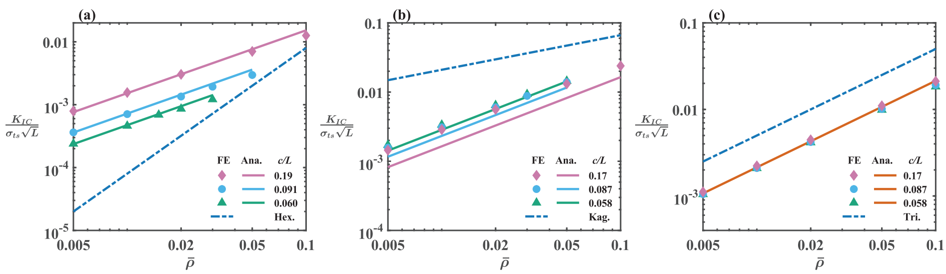

Figure 2. FE and analytical predictions of normalized fracture toughness as a function of relative density for hierarchical and simple (a) hexagonal, (b) Kagome, and (c) triangular lattices.

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Finnish Mechanics Days 2024

Fretting Safety Factor

Ville Vanhala[1], Antti Mäntylä, Jouko Hintikka, Teemu Kuivaniemi, Janne Juoksukangas, Reijo Kouhia and Tero Frondelius

Abstract. In modern machine component design, there is an increasing effort to predict the loads and durability of machine components using simulation models. Several problems that occur in machine components cannot even be easily tested physically, and therefore one method of modeling those problems is to utilize virtual analyses. One such problem is fretting fatigue, which poses a significant challenge in dynamically loaded machine component connections. As a result of fretting fatigue, the components experience accelerated fatigue crack growth, and their fatigue life is shortened. Consequently, cracks occur in the components and propagate faster than under plain fatigue conditions. Therefore, it is important to be able to model the fretting fatigue process and to design machine components that are more durable against it.

The goal of this thesis is to find a unified criterion that could be unambiguously used to detect the failure of a component subjected to fretting fatigue. To form such a criterion, crack growth in fretting fatigue was examined using the methods of linear elastic fracture mechanics.

The theoretical part of the study investigates the general principles of fretting fatigue and closely related fretting wear. In addition, the theory of crack initiation and crack growth is discussed. After that, in the research part of the thesis, a simulation model based on previous experimental studies is created and analyzed. Based on the information obtained from the model, crack growth and component failure are predicted. Several different equations were used in the evaluation of component failures, and it was discovered that some of these equations were able to predict the failures quite realistically.

Crack growth and potential component failure were predicted quite well in the study. In addition, results of most of the computational models corresponded well to the previous experimental studies. However, based on this research, no certain conclusions could be drawn about the predictability of crack propagation or the resulting component failure as there were several uncertainties in the results. Nevertheless, the study serves as a good basis for further research that could be conducted utilizing similar methods.

Keywords: *fretting fatigue, crack propagation, linear elastic fracture mechanics, LEFM*

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Finnish Mechanics Days 2024

A continuum material model for concrete

Sulata Dhakal[1], Juha Hartikainen[1], Reijo Kouhia[1], Timo Saksala[1], Jani Vilppo[1], Kim Calonius[2], Alexis Fedoroff[2], Kari Kolari[2]

Key words: constitutive model, continuum damage model, plasticiti, strain softening, regularization

Abstract A thermodynamically consistent constitutive model for concrete is presented. The model is based on proper expressions for the specific Gibbs free energy and the complementary form of the dissipation potential. Damaging of the material is described by a symmetric positive definite second order damage tensor. Invariant theory is used in construction of the potential functions which guarantees that the proper symmetry behaviour is satisfied and no artificial symmetrisation operations need not to be done. Especially, the failure surface is formulated in such a way that it will mimic the behaviour of the well known Ottosen′s four parameter failure surface. While testing the model against the experimental results found in literature, the results were in good agreement in uniaxial tensile and compressive loadings as well as in biaxial compression. Besides the correct failure stress states, the model predicts the correct failure modes of concrete: axial splitting along the direction of uniaxial compression and tensile damaging normal to the direction of tension, which is extremely important in analysing complex loading paths. The predictions of the proposed model are compared to the Concrete Damaged Plasticity (CDP) model available in the commercial finite element software Abaqus in uniaxial and equibiaxial cases.

Addition of the plasticity component is also discussed as well as issues related to the regularization of the model for reliable computation in the strain-softening range.

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Finnish Mechanics Days 2024

Computer vision framework for crack detection and prediction of air leakage through concrete cracks in buildings

Maliheh Jahanbakhsh[1], Andrea Ferrantelli

Abstract. Over time, buildings inevitably experience physical and functional deterioration. Regular, accurate inspections are essential to ensure safety and functionality, helping to avert hazardous and uncomfortable conditions. Cracks, a common indicator of structural distress, also facilitate air infiltration due to pressure differences between the interior and exterior. Therefore, the precise and efficient detection of cracks, along with the estimation of air infiltration through these cracks, is critical for civil engineering applications aimed at reducing energy consumption and enhancing indoor air quality. An image processing framework for the automatic detection of cracks in building envelopes, coupled with the measurement of indoor and outdoor air parameters could be used to assess crack size and predict air infiltration rates using theoretical heat transfer and fluid mechanics analyses. The methodology begins with developing a computer vision-based system for automatic crack detection, followed by geometric quantification of the cracks, and concluding with air leakage prediction through the cracks. The initial step involves crack detection that is conducted using YOLOv5, which has been previously evaluated for speed and accuracy in defect detection. The next step is crack segmentation, where the detected cracks are further refined using Mask R-CNN for more precise segmentation, allowing for the separation of fine cracks. Following segmentation, the geometric properties of the cracks, such as length and width, are quantified at the pixel level using methods like Hough line detection. The pixel measurements are then converted into actual geometric dimensions, facilitating a simplified assessment of crack severity. The quantification process includes extracting the crack skeleton, calculating the crack length and width, and detecting straight-line segments within the skeleton for more accurate measurement. Finally, the morphological characteristics of the cracks are used to predict airflow through them. Since fluid flow through concrete cracks depends heavily on crack morphology, this study employs fractal geometry to simulate crack tortuosity at the micro-level. This approach integrates fractal curves into a statistical model to better understand fluid dynamics through concrete cracks, allowing for a more generalized model applicable across various conditions.

Keywords: Crack detection*, Computer vision-based methods, Crack geometric, Airflow*

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Description

In this paper, crack detection is performed using YOLOv5 due to its superior speed and accuracy compared to other models. While Faster R-CNN combines region proposal and detection networks for fast and accurate object detection, and the Single Shot MultiBox Detector (SSD) uses anchor boxes to detect objects of varying sizes without the need for pixel or feature resampling, YOLOv5 outperforms both in terms of accuracy and detection speed. Building on the advancements of YOLOv3, YOLOv5 offers enhanced performance in detecting cracks and accurately extracting crack regions based on detected bounding boxes, making it the preferred choice for this study. [1, 2, 3, 4, 5, 6].

When calculating airflow through cracks, measuring crack length and width is of great importance. This paper employs high-precision object detection and fine-grained crack segmentation to post-process the cracks after segmentation, enabling automatic geometric quantization. The proposed pixel-level crack quantification method includes four parts: crack skeleton extraction, crack length calculation, straight-line segment detection, and crack width calculation. [7].

After calculating the length and width of the crack through image processing of the view side, a fractal geometry model is developed to simulate micro-level crack tortuosity, which is integrated into a statistical model of millimeter-scale crack segments. The crack propagation through concrete is modeled as a tortuous path through the porous cement paste, characterized by straight segments with lateral deviations determined by surface roughness parameters. Using a random midpoint displacement method, fractal curves are generated to represent the crack morphology, providing a more refined understanding of fluid flow through concrete cracks. [8,9,10]. Finally, using formula (1), the flow through crack will be described [11].

$$\Delta P = A.Q + B.Q^2 \tag{1}$$

In formula (1), Q is the is the volume flow rate and ΔP is drop pressure for a wide range of crack geometries. Since ΔP is a function of Tortuosity of the path (T_p), Length (L) and Width (w) of the concrete cracks according to the formula (2), after using fractal model we can have a range of ΔP to describe the air flow.

$$\Delta P = f(T_p, L, w) \tag{2}$$

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Finnish Mechanics Days 2024

Application of a linear-transformation-based anisotropic fracture model in quenching and partitioning steels

Guijia Li[1], Zinan Li, and Junhe Lian

Abstract. The application of advanced high-strength steels (AHSS) plays a crucial role in the automotive industry, particularly in enhancing energy efficiency and driver safety. Quenching and partitioning (QP) steels, as promising representatives of the third generation of AHSS, offer exceptional tensile strength and ductility. However, while the strength and ductility of QP steels have been well studied, their fracture properties, which are also critical performance metrics, remain underexplored. This study aims to systematically investigate the fracture behavior of QP steels under various stress states using both experimental and numerical approaches. In particular, we focus on the anisotropic behaivor of both plasticity and fracture, which are more obvious in these third generation AHSS. The anisotropic plasticity is characterized by tensile tests along seven directions with respect to the rolling direction and on the numerical side it is effectively described using the evolving non-associated Hill48 (enHill48) model. To enhance predictive accuracy, a new fracture model based on linear transformation is developed, incorporating additional parameters. The performance of two anisotropic fracture models with different parameters is compared, alongside the fracture behavior and tensile properties of QP steels. The findings reveal that the fracture resistance of QP steels is highly sensitive to loading directions. The linear-transformation-based anisotropic fracture model proves to be an efficient method for characterizing and predicting the anisotropic fracture behavior of sheet metal, with its accuracy further improved by incorporating additional linear transformation tensors.

Keywords: QP steel, Anisotropic fracture, Fracture model, Linear transformation.

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Chapter 11

IFME Session 2nd: Education in the digital age and applied research

October 3, Thursday at 12:30 - 14:30. Room: D148 Chairs: Anneli Kakko and Ciprian Lapusan

Finnish Mechanics Days 2024

Promoting Engineering Education Excellence - the NextGEng Project

Ciprian Lapusan[1], Ciprian Rad

Abstract. The NextGEng project aims to develop novel international and cooperative teaching models for engineering studies by fostering collaboration between EU universities and companies. This initiative aligns with the objectives of the European Education Area 2025 and addresses the labor market's need for engineers with interdisciplinary skills that are able to navigate complex global challenges. Funded by the Erasmus+ Cooperation Partnership program, NextGEng includes six partners from three European countries, establishing a robust international cooperation framework.
The project activities focused on three main directions:

- NextGEng Tailored Training Program:
  Two rounds of training sessions are organized for participating teachers, focusing on developing student-centered teaching methods that enhance international team-teaching capabilities. The program develops new skills and offers the opportunity to share good practices between participating teachers.
- Team-Teaching Pilot Program:
  This program aims to increase the quality and relevance of existing courses in partner higher education institutions (HEIs) through international and cooperative efforts. It introduces new content and teaching methods by involving lecturers and industry experts to help students apply theoretical knowledge to practical scenarios. The program features a flexible, modular course design, allowing students to tailor their learning based on their individual abilities and background. It includes real-world industry examples, eco-friendly elements to develop green competences, and emphasizes student-centered learning, experiential learning, and self- and peer-evaluation.
- Cases for Experiential Learning projects:
  These projects facilitate collaboration among students, HEI staff, and industry experts. Students from diverse study programs and nationalities are grouped in teams to solve an industry or research problem during one-semester activity. The project starts with an intensive week hosted by the organizing HEI, which includes dedicated extracurricular courses, company and laboratory visits, project work tasks and social events. After the intensive week, students continue collaborating remotely to solve their assigned topic. At the end of the semester, an online event is organized where all student teams present their project's results. During this event the supervisors give grades, and the company/research group representatives select the winning team.

This paper presents and analyzes the results from the first half of the project implementation. The analysis examines the impact of both curricular and extracurricular activities, focusing on internationalization, experiential learning, the quality of course and laboratory materials, the effectiveness of new teaching methods, and the acquisition of green skills. The obtained results

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highlight the transformative potential of the proposed methods in increasing the students' competences and improving educational practices in engineering programs.

Keywords: engineering education, international co-teaching

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Finnish Mechanics Days 2024

Experiences of international co-teaching in a European higher education context

Petri Luosma[1], and Tarja Moilanen

Abstract. International co-teaching has lot to offer to higher education. In addition to bringing enriching elements to the teacher's knowledge, co-teaching has the potential for wider pedagogical change. [1]. International co-teaching can be approached through a well-known six different strategies [2]. This paper describes the different ways of implement international co-teaching from the perspective of a mechanical engineering lecturer. Insights and conclusions are drawn from several years of Erasmus exchanges between different universities, supervision of joint projects, and a co-taught course of strengths of materials like the NextGEng project [3].

The Erasmus exchanges discussed here have focused on the courses of Static, Strength of Materials and Machine Elements, while the projects have been related to product development in companies. Key success factors for international co-teaching included joint commitment, mutual flexibility, and the adaptable use of multiple methodologies. From the learner's perspective, international co-teaching provided a richer learning experience and reinforces acquired knowledge. Additionally, learners could enhance their cultural awareness, language skills, and broaden their horizons.

Keywords: co-teaching, mechanical engineering, *Finnish Mechanics Days*

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Finnish Mechanics Days 2024

Cases of Experiential Learning projects: A successful model for HEI student-company cooperation

Silvia Satorres Martínez[1], Diego Manuel Martínez Gila, Rubén Dorado Vicente and Anneli Kakko

Abstract In recent years, there has been a significant rise in the quantity of research initiatives and policies focused on innovation in education [1], [5]. One fundamental area involves enhancing collaboration between Higher Education Institutions (HEIs) and companies. Evidence has shown that fostering stronger connections between HEIs and companies can be advantageous for all involved. Working closely together can create long-term partnerships and opportunities, driving innovation, sharing of knowledge and creativity.

There exists a whole range of models of cooperation in which companies offer HEIs students the opportunity to gain work experience in their field before completing their studies. These forms of cooperation are included in the generic concept of Work Integrated Learning (WIL) [6]. In the course of several European projects, a WIL model has been created, put into practice and improved, enabling students to develop their competences in multidisciplinary and multilingual environments.

The first implementation was known as multidisciplinary Real Life Problem Solving (RLPS) and was created in the RePCI project [3]. In this project, Mechanical Engineering students, from two different HEIs, formed mixed groups to solve a problem proposed by a company. Student groups found solutions and, in the end, the company selected a winning one. In another european project, the HEIBus [2], the model was taken into a new and multidisciplinary cooperation level by widening it from Mechanical Engineering to other study areas. In addition, the model included a virtual implementation for those students unable to travel. Now, in our last project, the NextGEng [4], the model has been upgraded by involving students not only in solving problems proposed by companies, but also problems proposed by research groups.

The NextGEng is an Erasmus+ Cooperation partnership in higher education project that involves a consortium of six partners from European universities and companies. It aims to develop an international cooperation framework that promotes international team-teaching aligned with the European Education Area 2025 and labour market needs, including actions to support collaborative international and experiential learning in engineering. To achieve that end, NextGEng is based on three lines of action: a tailored training process for teachers, an international team-teaching pilot program and cases for experiential learning.

This work presents the results obtained so far in the last line of action, the Cases for Experiential Learning, with the acronym of CEL projects (Fig. 1). One of the two rounds has been carried out with two CEL projects proposed by companies and one by a research group. Specifically, the Spanish company ISR has proposed a topic related with the agri-food sector: the design of a machine vision system for the inspection of fruits, to be installed at the reception yard in an oil mill. The Finish company, Valmet, proposed the topic: pressing manufacturing test object, with a variety of designed geometries, for new pulp based manufacturing technology. Finally, the research group of Applied Mechatronics Research Laboratory, from TUCN (Romania), proposed a project whose main objective was the design a 3-axes GANTRY ROBOT subjected to a predefined requirements. The feedback from companies, the research group, supervisors and students was quite positive in all the three CEL projects, fulfilling with the quantitative and qualitative indicators of the NextGEng project.

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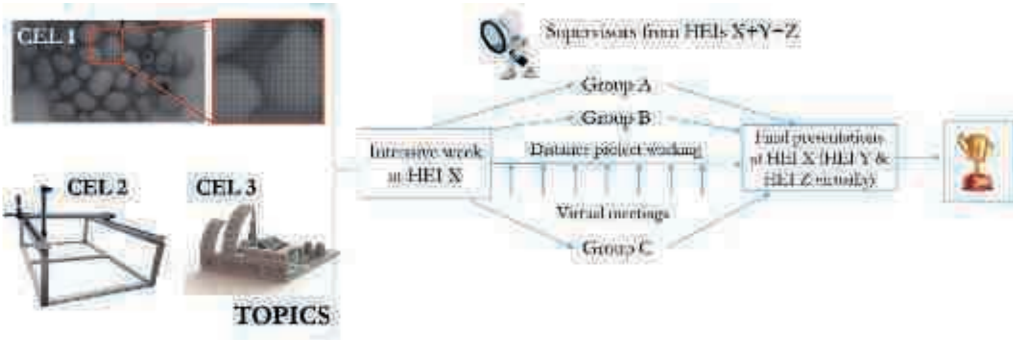

Figure 1. Cases of Experiential Learning"CEL" projects implemented during the first round

Key words: International collaborative learning, University-Business cooperation, innovation, multidisciplinary

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Finnish Mechanics Days 2024

Experimental and numerical strength assessment of a plate with a notch subjected to uniaxial loading – A lab based approach in undergraduate mechanical engineering education

Steffen Greuling[1] and Elmar Schuch

Abstract One of the key requirements in the development of machines and components is to ensure strength under static and repeated loads. In principle, experimental and numerical methods are available for this purpose, which experience has shown to be a major challenge for students at the beginning of their mechanical engineering studies.

In order to increase the understanding of issues relating to strength of materials and to make learning more fun, the laboratory sessions for the lecture Strength of Materials 2 have been revised as part of the bachelor's programme in Mechanical Engineering. These now consist of the following dates:

1. Local strain measurements with strain gauges
2. Strain field measurements with digital image correlation (DIC)
3. Fatigue testing
4. Finite element analysis (FEA)

The same geometry, a plate with a circular inner notch, is used for all laboratory exercises so that the results from one laboratory exercise can also be used in the subsequent sessions. Each laboratory session lasts three hours.

As students should also be prepared for dealing with large amounts of data, Python scripts are prepared for analysing the strain measurements using digital image correlation, which should introduce students to the field of data science.

In the third semester, students on the bachelor's programme in mechanical engineering have not yet had any lectures on the theory of elasticity, e.g. Airy's stress function, or the finite element method, so modelling and analysing a notched plate structure is far beyond their level of expertise. Nevertheless, we have decided to integrate finite element analysis into the laboratory exercises in order to demonstrate the practical implementation of strength assessment and to motivate participants to study in greater depth. The basics of the finite element method are demonstrated by analysing a cantilever. The associated differential equations of the elastic line for the Euler-Bernoulli beam are dealt with in the lecture Strength of Materials 2.

The first feedback from our students was positive. Especially the FEA part was mentioned to increase the motivation.

Key words: Strain measurement, strain gauges, digital image correlation (DIC), fatigue testing, finite element analysis (FEA)

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Finnish Mechanics Days 2024

Forward kinematics and assembly modes analysis of 3-RPS parallel manipulators by using Sylvester's dialytic elimination method

Ciprian Rad[1] and Ciprian Lapusan

Abstract. Forward kinematics problem (FKP) of parallel manipulators is an important step is the design, programming and control of parallel robots [1]. Parallel manipulators with many forward kinematics solutions have more than one *assembly modes* – an assembly mode is a solution to FKP [2]. This means that for a given geometry and a set of values for the input joints different configurations of manipulator exists.

In the case of 3-RPS parallel manipulators FKP involves the solving of three nonlinear polynomial equations in three unknowns [3,4]. The solutions of these equations can be determined in two ways: either numerically (by using Newton-Kantorovich iterative method for example) or analytically (by using elimination methods, continuation method, standard bases method, etc.).

Numerical methods have the disadvantage that provide only one good solution (one assembly mode of the manipulator) - the one closest to the *initial guess*. Therefore, the efficiency of the algorithm is influenced by the initial guess and once o solution is found it is not guaranteed that additional ones can be found [5]. Elimination methods are analytically techniques that overcome these problems and have the advantage that yields all the solutions from a set of nonlinear polynomial equations [6].

In this paper the FKP of 3-RPS parallel manipulators is investigated using Sylvester's dialytic elimination method. The geometry of the manipulator is presented first and then the three nonlinear governing equations are derived. The Dialytic elimination method is used to obtain all the possible solutions (assembly modes) for a given geometry and set of lengths of the input joints (prismatic joints).

Finally, the influence of the ratio between the radius of mobile platform to the dimension of the radius of fixed platform is investigated in term of assembly modes for three different designs. The obtained numerical results are analysed and designing guidelines/recommendations are presented.

Keywords: Sylvester's dialytic elimination method, forward kinematics, parallel robots

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Chapter 12

Round Table 2: Advancing researcher training in advanced manufacturing: Innovative educational and collaborative models in Finland

October 3, Thursday at 15:00 - 16:00. Room: FP05 Chair: Heidi Piili

Finnish Mechanics Days 2024

ROUND TABLE:

Advancing Researcher Training in Advanced Manufacturing: Innovative Educational and Collaborative Models in Finland

Heidi Piili

Abstract. In Finland, researcher training is undergoing significant changes, especially within the fast-evolving field of advanced manufacturing. This round table discussion will explore innovative educational and collaborative models that are transforming researcher training in advanced manufacturing. With the rapid advancement of advanced manufacturing technologies, there is an increasing need for highly skilled researchers capable of driving innovation and applying the latest techniques.

We will focus on progressive educational approaches, including hybrid learning environments that integrate traditional classroom instruction with practical, real-world advanced manufacturing experiences. The discussion will also examine the role of interdisciplinary collaborations, connecting academic institutions with industry leaders and research organizations. Such collaborations facilitate knowledge exchange, align training programs with technological advancements, and address industry needs.

A key emphasis will be placed on doctoral education, highlighting how advanced training and research opportunities at the doctoral level can better prepare researchers for the demands of advanced manufacturing. Additionally, we will address the value of informal networking opportunities, such as workshops, seminars, and peer mentoring, which complement formal training and foster a collaborative learning environment.

By evaluating existing models, experience of panelists and best practices from Finnish institutions and industry partners, the discussion aims to provide practical recommendations for enhancing researcher training in . E advanced manufacturing mphasizing adaptive training models that blend formal and informal methods, this approach is essential for ensuring Finland’s continued leadership in advanced manufacturing innovation.

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Chapter 13

Mini-Symposium 3: Fatigue-analysis, experiments and design

October 4, Friday at 10:00 - 11:30. Room: D149 Chairs: Tero Frondelius and Reijo Kouhia

Finnish Mechanics Days 2024

Some new developments in the continuum based fatigue modelling approach

Reijo Kouhia[1], Mohammad Jalaei[1], Juho Kuupakko[1], Heikki Orelma[2], Niels-Saabye Ottosen[3], Matti Ristinmaa[3] Arturo Rubio Ruiz[4], Joona Vaara[4], Tero Frondelius[4,5]

Key words: high-cycle fatigue, low-cycle fatigue, continuum based model, endurance function, fatigue damage evolution, anisotropy, plasticity, defect size

Abstract Ottosen, Stenström and Ristinmaa proposed in 2008 a continuum based high-cycle fatigue model which is inherently multiaxial and offers several advantages in comparison to classical multiaxial fatigue models. The key ingredients of such model are construction of a moving endurance function and the evolution equations describing the movement and damage evolution. This format is quite general, inherently multiaxial and is not based on heuristic cycle-counting approaches. It is easily extended to capture various fatigue phenomena; extensions to anisotropy and low-cycle fatigue will be considered. Different forms to construct the endurance function are given, e.g. how to better capture the mean stress behaviour (Haigh-diagram). Based on the famous Murakami equation, which describes how fatigue strength depends on defect size, this paper also discusses how the influence of defect size on the endurance function can be taken into account.

Acknowledgement: Funded by the European Union (Grant Agreement No. 101058179; ENGINE). Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or the European Health and Digital Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.

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Finnish Mechanics Days 2024

On crack initiation and non-propagation

Joona Vaara[1], Kimmo Kärkkäinen, Miikka Väntänen, Mari Åman and Tero Frondelius

Abstract Murakami-Endo found that crack non-propagation commonly defines the fatigue limit from defects [1]. After this finding, the study of crack initiation has been receiving less attention. However, experimental studies show that in certain cases, no non-propagating cracks are observed at the fatigue limit, i.e., the fatigue limit is defined by the mere crack initiation. In this study, we will discuss the recent findings relative to the role of crack initiation and non-propagation in defining the fatigue limit in different conditions. The most prominent application for this increased understanding is notch fatigue.

Acknowledgement: Funded by the European Union (Grant Agreement No. 101058179; ENGINE). Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or the European Health and Digital Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.

Key words: Crack initiation, Crack closure, Fracture mechanics, Fatigue strength

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Finnish Mechanics Days 2024

The effect of over- and underloads on fatigue life

Kimmo Kärkkäinen[1], Joona Vaara, Miikka Väntänen, Mari Åman and Tero Frondelius

Abstract Fatigue life is a crucial parameter in fatigue design. Estimating and predicting the fatigue life of a component allows for safe operation and timely maintenance. Tensile overloads and compressive underloads have been shown to have a distinct influence on fatigue crack propagation [1, 2, 3]. It is commonly reported that crack growth rate is reduced after overloads [1] and increased after underloads [2], making the former beneficial, and the latter harmful in terms of fatigue life. Both effects have been commonly attributed to transient crack closure behavior. According to the author's awareness, a straight-forward method for estimating the effect of over- and underloads on fatigue life is lacking in current literature. In the present study, the transient crack closure behavior following over- and underloads is modeled using a finite-element crack propagation model. The result is used to quantitatively estimate the over- and underload response in terms of crack growth rate and fatigue life through a simple analytical approach. This method was briefly demonstrated for the case of underloads in [4].

To estimate the effect of over- and underloads on fatigue life, it is first necessary to estimate their effect to crack growth rate, $\mathrm{d}a/\mathrm{d}N$. A rough estimate can be easily given by the Elber–Paris equation, Eq. 1. The transient behavior of plasticity-induced closure is taken into account by the effective stress intensity factor range, ΔK_{eff}.

$$\mathrm{d}a/\mathrm{d}N = C\left(\Delta K_{\mathrm{eff}}\right)^m \tag{1}$$

The relative change of crack growth rate is expressed as acceleration factor, δ. Acceleration is predicted if $\delta > 1$, and deceleration if $\delta < 1$. Fig. 1(a) schematically illustrates the effect of over- and underloads on crack growth rate. This result can be processed further to assess the effect of over- and underloads on fatigue life by integrating the inverse of function of δ over a given crack propagation interval. To account for numerous over- and underloads, the following assumptions can be made: (i) Loading spikes are evenly spaced over the simulated crack propagation window. (ii) Subsequent loading spikes behave similarly as the first loading spike, and thus the δ-curve corresponding to multiple over-/underloads can be constructed by reusing the single over-/underload curve shifted along a. The existence of cumulative effects can be examined via the finite element model.

The effect to the number of withstood load cycles in the crack propagation interval, as a function of the number of over-/underloads within said interval is schematically shown in Fig. 1(b). If a mean growth rate is known, the result may be presented in terms of a percentage of over-/underload cycles in the loading. Overloads commonly cause initial acceleration followed by delayed deceleration, and finally an asymptotical recovery to the constant-amplitude growth rate. Underloads, on the other hand, are reported to cause acceleration followed by an asymptotical recovery. For occasional over- and underloads, this behavior should correspond to a respective increase and decrease of fatigue life, but repeated occurrence of either loading spike should shorten fatigue life, in line with [3]. In the case of overloads, where a delayed increase in crack closure is predicted, a local maximum in fatigue life can be found for a specific overload frequency.

Key words: Variable amplitude loading, Crack closure, Fracture mechanics, Fatigue strength, Numerical modeling

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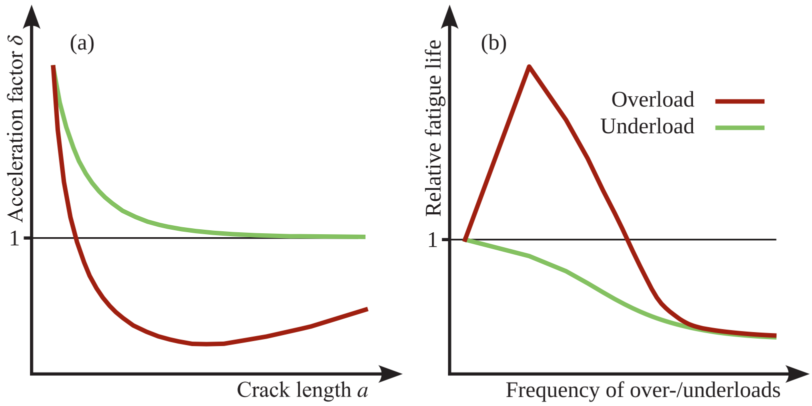

Figure 1. Schematic illustration of the expected effect of (a) single over- and underloads on crack propagation rate and (b) repeated over- and underloads on fatigue life.

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Finnish Mechanics Days 2024

Bayesian approach to uncertainty quantification in ultrasonic non-destructive testing

Saana Bergman[1], Joona Vaara, Miikka Väntänen and Tero Frondelius

Abstract Information about defects in components is necessary for reliable fatigue design. In critical components it is also vital that the uncertainty in the estimation of a flaw characteristic is considered and quantified. Currently information about internal defects is obtained with ultrasonic non-destructive evaluation (NDE) combined with amplitude-based sizing methods or decibel drop methods [2], which only work for ideal flaws and largely ignore the uncertainties in the size estimates. In the present study flaw characterization is considered as an inverse problem. Bayesian methods are used to infer the inclusion characteristics and to quantify the uncertainties related to them. In literature, Bayesian inference has been used successfully to estimate parameters of different NDE measurement systems and characteristics of simple flaws from simulated or measured NDE results. However, there are only a few published articles in which Bayesian inference is applied specifically to ultrasonic NDE.

In Bayesian inference all parameters of interest θ are defined as random variables with probability distributions, which ensures that the uncertainty in all parameter estimations is considered. The parameter posterior distribution is obtained by the Bayesian rule:

$$p(\theta|\hat{v}) \propto p(\hat{v}|\theta)p(\theta) \tag{1}$$

where $p(\hat{v}|\theta)$ is the likelihood function, $p(\theta)$ is the parameter prior distribution and $\hat{v}$ is ultrasound measurement data. When the measurement noise is assumed to be normally distributed and additive, the likelihood is defined as

$$p(\hat{v}|\theta) = \mathcal{N}(\hat{v} - v(f,\theta), \sigma) \tag{2}$$

where $v(f,\theta)$ is a model of the physical process generating the measurement data, i.e. a forward model, and σ is a scale parameter [5]. A suitable forward model in case of immersion or angle beam ultrasound measurement is the Thompson-Gray ultrasound measurement model given in [1] as

$$v(f,\theta) = s(f)V(f,\theta)^2 A(f,\theta)\frac{4\rho_2 c_2}{-ik_2 a^2 \rho_1 c_1} \tag{3}$$

where *s(f)* is a system function, ρ_i and c_i are the densities and sound velocities of materials $i = 1, 2$, k_2 is the wave number in material 2 and a is the radius of the transducer. The coefficient *V(f)* calculated with the Multi-Gaussian Beam model given in [4] considers the wave propagation in the materials along the wave path and transmission through material interfaces. Coefficient *A(f)* calculated with the Modified Born Approximation given in [3] considers the wave scattering of reflecting from the surface of an inclusion.

Preliminary results from inference performed on simulated A-scan measurements of spherical inclusions are shown in figure 1. Uncertainties in the parameter estimates vary significantly depending on the parameter in question: inclusion location x_3 can be estimated with high accuracy and certainty, dispersion in the inclusion density ρ posterior distribution has reduced slightly, while uncertainty in inclusion size a_1 is significant. Prior and posterior distributions of the inclusion position ϕ are nearly identical, i.e. the measurement data does not provide any information about the inclusion position, as is expected in case of a spherical inclusion. More

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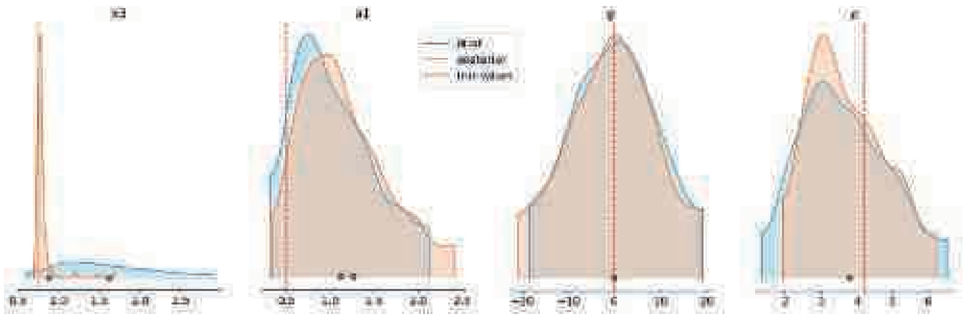

Figure 1. Prior and posterior distributions for inclusion location x_3, size a_1, position ϕ and density ρ.

informative B- or C-scan data should be used in further development to fully take advantage of this method's capabilities.

Key words: Bayesian methods, Uncertainty quantification, NDE, Ultrasonics, Defect characterization

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Chapter 14

Contributed papers 6: Vibration and stability

October 4, Friday at 10:00 - 11:30. Room: F304 Chair: Pekka Neittaanmäki

Finnish Mechanics Days 2024

Wind-induced vibration control in high-rise buildings

Jussi Jalkanen[1], Jari Toijonen, Camilla Lipponen ja Mikko Malaska

The topic of this presentation is the vibration induced by gusty wind in tall and slender buildings (Figure 1) and the mitigation of vibration with specially designed dampers. In practice passive tuned mass damper (TMD) or tuned liquid damper (TLD) are applicable. The vibration caused by gusty wind is not the only wind-induced vibration phenomenon in structural engineering, but other cases are not addressed in this context.

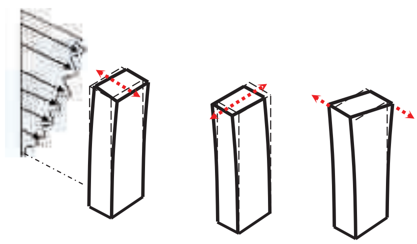

Figure 1. Gusty wind causes a tall and slender building to vibrate. The vibrations can occur in along-wind direction, cross-wind direction or torsional vibration.

Traditionally wind-induced vibration has not been a problem in building design in Finland except for a few rare cases. However globally, and also in Finland, the trend is towards increasingly slender buildings which are inherently more susceptible to wind-induced vibration. In the future we may also need to add separate dampers in domestic tall buildings, which have previously only been used in specialized structures such as chimneys, masts, and towers. Dampers like TMD and TLD are widely used in high-rise buildings abroad.

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Wind-induced vibrations are rarely a significant concern for the strength of structure in ultimate limit state (ULS) and it is more about the comfort of people in the upper floors. Gusty wind causes the building to vibrate, resulting in acceleration that can become uncomfortably high in the upper floors. The perception of acceleration is subjective matter and there are not always clear threshold values for the maximum acceleration in mandatory design standards (e.g. Eurocode). However there are guidelines for the maximum allowable acceleration as a function of natural frequency for buildings in different uses (e.g. ISO 10137:2007).

In a tuned mass damper (Figure 2) a small separate damper mass m_d (approximately 1 - 2 % of the structure's mass m) is connected to the structure which is prone to vibration due to the excitation force.

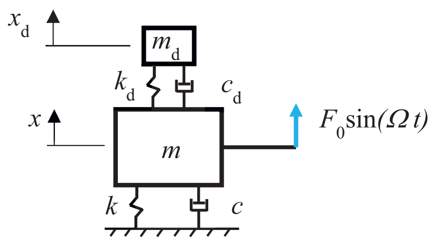
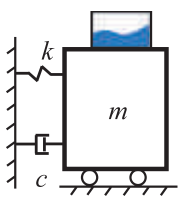


Figure 2. Two degrees of freedom calculation model for a tuned mass damper (TMD).

The calculation model of the system is a simple two degrees of freedom model. A tuned mass damper does not actually increase the magnitude of damping but it changes the dynamic behavior of the system so that the amplitude of vibration decreases. The decrease in amplitude can be interpreted as a increase in damping. In order to work properly the parameters of mass damper m_d, k_d and c_d must be appropriately selected in relation to the structure meaning that the damper is tuned to match the vibrating structure.

In a tuned liquid damper the mass of damper is replaced by sloshing liquid in a container (Figure 3). The behavior of a liquid damper can be analyzed in the same way as a mass damper.



$$f_D = \frac{1}{2\pi}\sqrt{\eta \frac{g}{a} \tanh\left(\eta \frac{h}{a}\right)}$$

a container length
h_w liquid depth
$\eta = \pi$ for a rectangular container

Figure 3. Tuned liquid damper (TLD) and the fundamental frequency of sloshing liquid f_D.

Tuned liquid damper is a very simple and economic solution. Tuning can be done straightforward by changing the liquid level. However, the mass of the liquid does not work as effectively as the solid mass in a TMD.

Finnish Mechanics Days 2024

Numerical analysis of in-Plane static and dynamic behavior of triangular lattices in a curved beam structure

Zeinab Soleimani Javid[1], Jarkko Niiranen

Abstract.

The current work focuses on modeling of size-dependent static and dynamic behavior of 2D triangular lattices in a curved beam structure. The study begins by deriving the corresponding generalized Euler–Bernoulli curved beam models. The calculation of governing equations is done using the Hamilton principle, the basic concept of classical mechanics, which provides a consistent method for calculating equation and boundary conditions [1]. The final equations are solved using a numerical solution technique, specifically the differential quadrature method (DQM), it is chosen for its efficiency and precision in processing differential equations [2]. Numerical experiments are conducted using commercial Finite Element software Abaqus, which ensures that the numerical solutions exhibit good convergence properties, enhancing the reliability of the results. Effective elastic modules are analytically defined for a unit triangular cell, and the in-plane vibration result is validated by matching the curved beam response to the standard problem of free vibration [3], [4]. Based on the figures and tables presented, there is a close agreement between previous studies and this work. A periodic cell geometry is described for the structure design. The triangular unit cell model for this curved structure is generated using two approaches: one with an empty initial state and the other with a full initial state as previous studies have highlighted [5]. The findings of this study indicate that both design approaches are equivalent, resulting in the same final geometry. Additionally, it is important to note that in this case, the results do not differ whether the chords at the top and bottom of the lattice cell are considered to be straight or curved, both configurations produce the same final results. The results are presented and discussed in detail. The implementation of a triangular lattice cell in a curved beam demonstrates significant effects on the vibration response compared to a homogenized solid curved beam. Consequently, the results of this figure can help design more efficient structures with the desired characteristics in structural engineering.

Keywords: Triangular lattice cell, curved beam, Differential quadrature method (DQM), Numerical experiments

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Finnish Mechanics Days 2024

Design of a non-linear wire-rope tuned mass damper; linearized model based approach.

Samuli Rytömaa[1], Sampo Laine

Abstract Wire ropes springs are used in vibration isolation applications due to their inherent energy dissipation properties, low cost and operational robustness. The dynamic behavior of the wire rope springs is characterized by the relative sliding of the wire strands inside the ropes [1, 2]. Friction between the wire strands converts vibration energy to heat under mechanical deformations and the sliding alters the stiffness of the spring. These properties are heavily non-linear depending on the vibration amplitude, making the mechanical modeling challenging. No clear standard means for design exist.

In this paper, a linearization framework for design and dimensioning of the wire rope tuned-mass-dampers is proposed. An amplitude based linearization for the behavior of the wire rope spring is used to model the non-linearity [3]. It is shown, that slightly modified standard vibration isolator measurements can be applied to create a linearized model of the energy dissipation and stiffness of the wire rope TMD and applied to calculation of dynamic responses in the end application. An examplary dimensioning process for the TMD is showcased applying the proposed framework.

Key words: Structural Dynamics, Wire Rope Damper, Frequency Response

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Figure 1. Wire rope spring consists of two metal blocks jointed together using steel wire rope.

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Chapter 15

IFME Session 3rd: Industry, innovation and infrastructure

October 4, Friday at 10:00 - 11:30. Room: D148 Chairs: Anneli Kakko and Gia-Khanh Pham

Finnish Mechanics Days 2024

gH2ADDVA – Adding Value by Clean Hydrogen production

Kati Valpe-Ojala[1], Jamk University of Applied Sciences

Abstract

Objective of gH2ADDVA project is to develop, highlight and apply the special expertise of the Central Finland region, especially in the following areas: 1) New, efficient ways of electrolysis and bio-based production, storage and use of green hydrogen. 2) New material technology solutions related to renewable green energy production and its use. 3) AI methods and tools enhancing the creation of value chain analyses and models (e.g., digital twins, DT). 4) RDI and business networking related to hydrogen technology.

The research of the project reinforces the goals of the industry renewal of Jamk and the City of Jyväskylä. It is carried out multidisciplinary together with the Institute of New Industry and the Institute of Bioeconomy of Jamk and the Department of Physics of the University of Jyväskylä. The project is connected to the ecosystem agreement between the City of Jyväskylä and the Ministry of Economic Affairs and Employment, which aims to build an ADDVA RDI environment in the area to meet the needs of the industry renewal.

The main target group of the project is the companies in the manufacturing industry in Central Finland, especially SMEs. The project will be carried out during the period 1 January 2024 - 30 June 2026 and it is co-funded by the European Union from the Just Transition Fund (JTF).

There are five work packages in the project:
WP1: Efficiency of hydrogen use, application of new bio-based green hydrogen production methods and further refining of hydrogen into synthetic fuels using biological methods.
WP2: Green energy and hydrogen storage and transfer solutions.
WP3: Measurement and sensoring solutions required for the efficiency and safety of hydrogen production and use.
WP4: The digital implementation of the hydrogen production and use value chain.
WP5: Hydrogen technology network and international activities.

Keywords: hydrogen; green hydrogen; hydrogen production

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Finnish Mechanics Days 2024 / IFME2024

Simulation of Hydrogen Induced Failure in High-Strength Steel

Stefan Lampenscherf[1,a], Gia Khanh Pham[b]

[a] Lightsharp UG: Technology & Innovation Consulting, Munich, Germany
[b] Department of Applied Sciences and Mechatronics, Munich University of Applied Sciences, Munich, Germany

Abstract.

When exposed to hydrogen, many metallic materials experience a significant loss of ductility, toughness and fatigue crack growth resistance [1, 2, 3]. This phenomenon, known as hydrogen embrittlement, is a major challenge for the development of advanced high-strength steel applications (e.g. in construction, transport and energy) due to the ubiquity of hydrogen and the higher susceptibility of modern high-strength alloys [4, 5].

Hydrogen ingress into a metal can occur during manufacturing operations, such as casting, welding, machining or electroplating, and through exposure to hydrogenous environments such as water vapor, aqueous electrolytes or hydrogen-containing gas. Following ingress, atomic hydrogen resides at either interstitial lattice sites or microstructural trapping sites (e.g. dislocations, grain boundaries, voids, carbides and interfaces) and diffuses through the lattice driven by several effects.

The hydrogen diffusion flux is induced by the gradient of the chemical potential, which depends on the hydrogen distribution in the lattice and the hydrostatic stress. Tensile hydrostatic stresses extend the volume of the interstitial lattice sites, whereas compressive stresses lead to the lattice sites volume reduction. As a result dissolved hydrogen atoms tend to move to areas of tensile hydrostatic stress (e.g. crack tips) where damage takes place by means of mechanisms that are still being debated [6, 7, 8, 9].

In this paper we present a coupled chemo-mechanical and fracture mechanics-based model to cover the complexity of hydrogen uptake, transport and capable of predicting macroscopic crack growth as a function of material, loading and environmental variables. The model is implemented using the multi-physics simulation package COMSOL and solved as a coupled deformation–diffusion problem to define a fracture criterion as a function of residual and externally applied loads and hydrogen concentration. The local

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hydrogen induced material damage is approximated by a parametric dependency of local fracture toughness on hydrogen concentration in the hydrostatic process zone near the crack tip (strain concentrator).

As an example we demonstrate a ductile-brittle transition in the failure pattern of a double-notch specimen under tension w/o hydrogen loading. The presented modelling and simulation approach for the fracture mechanics-based assessment of hydrogen-sensitive applications could enable a controlled use of high strength alloys, accelerate material certification, and govern inspection planning and fitness-for-service assessment.

Keywords: Hydrogen embrittlement, hydrogen transport model, fracture mechanics based failure model, hydrostatic process zone, COMSOL multi-physics, ductile brittle transition

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Finnish Mechanics Days 2024

Oscillating viscous flow around a circular cylindrical post confined between two parallel plates

Francisco Moral-Pulido[1], Antonio J. Bárcenas-Luque, Francisco J. Parras-Martos, Cándido Gutiérrez-Montes, Wilfried Coenen and Carlos Martínez-Bazán

Abstract Inspired by the effect of the micro-anatomy in the spinal subarachnoid space on the cerebrospinal fluid motion, the present work investigates analytically and experimentally the oscillating flow around a cylindrical post of radius a confined between two parallel plates, separated each other a distance $2h$. The oscillatory flow, which has been considered to be both harmonic and anharmonic, is characterized by its velocity amplitude U_∞ and its angular frequency ω, with associated stroke lengths U_∞/ω similar to the post radius a, which yield a dimensionless parameter $\varepsilon = (U_\infty/\omega)/a \leq 1$. The theoretical analysis evaluates the harmonic flow in the limit $\varepsilon \ll 1$, varying the aspect ratio of the post $\lambda = h/a$, as well as the associated Womersley number, $Wo = \left(a^2\omega/\nu\right)^{1/2}$, being ν the kinematic viscosity of the fluid. Under these conditions, the fluid particle motion, composed by a purely oscillatory motion (leading-order), together with two steady components (steady-streaming and the so-called Stokes-drift), is found to be three-dimensional due to the wall confinement. Moreover, steady recirculating vortices are induced in the symmetrical mid-plane. These vortices, attached to the wall post, decrease as Wo increases for values of the latter below a critical one, Wo_c. For $Wo > Wo_c$, a second, outer vortex is induced. The formation of this second vortex depends on the aspect ratio of the post, reducing the critical value of Wo_c as λ increases [1]. The analysis has been experimentally validated considering a fixed aspect ratio, $\lambda = 2$, for different values of Wo, ε and oscillating waveforms. Results of the experiments present similar flow patterns when the stroke is increased from the asymptotic limit $\varepsilon \ll 1$ to $\varepsilon \simeq 1$. In addition, when anharmonic waveforms of the oscillating flow are considered, the transversal symmetry of the steady flow is lost, only remaining the symmetry along the streamwise axis. The experiments have also been extended to describe the flow around a linear equidistant array of posts along the axial direction. In this configuration, the induced vortices are confined by the posts, for which a net stream appears far away from the array for the anharmonic flow (see Figure 1), which is similar to what seen in previous works [2].
This work has been supported by the coordinated project, PID2020-115961RB-C31, PID2020-115961RB-C32 and PID2020-115961RA-C33, financed by MCIN/AEI/10.13039/501100011033.

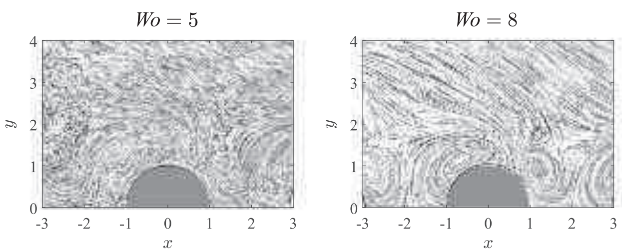

Figure 1. Steady flow patterns around a linear array of cylindrical posts at different values of Wo, induced by an anharmonic, patient-specific waveform.

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Key words: Biological fluid dynamics, oscillating flow, steady streaming, experimental fluid mechanics

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Chapter 16

Contributed papers 7: Finite element analysis 2

October 4, Friday at 12:30 - 13:30. Room: D148 Chair: Tero Tuovinen

Finnish Mechanics Days 2024

Design space exploration of manufacturability and mechanical performance of foldable Miura-ori origami structures

Tomi Kankkunen[1], Petteri Kokkonen, Jarkko Niiranen, Jarmo Kouko

Abstract. This study explores the simulation-based prediction of how variations in geometry and material affect the manufacturability and mechanical performance of origami structures. Utilizing advanced modeling techniques, including detailed geometric representations of origami and parametric finite element analysis for design exploration, this research aims to identify design parameter values that ensure successful fabrication and meet functional requirements for the final product. Parametric finite element simulations predict the impact of changes in origami geometry and material properties on performance metrics such as structural integrity, flexibility, and durability. The findings advance the fields of lightweight design manufacturing and origami mechanics by providing insights into the efficient production of high-performance origami structures. This paves the way for innovative, sustainable applications and end-products in engineering and design.

Keywords: Miura-ori, foldable structures, finite element analysis, material variation, design exploration

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Finnish Mechanics Days 2024

Damage Updating in Finite Element Models by Using Computer Vision and Phase Field Method

Youqi Zhang[1], Jarkko Niiranen

Abstract. Accurate updating of the damage in finite element models (FEM) are crucial for understanding the reliability and safety of the deteriorated structures. Therefore, we present a novel approach that works as the interface to integrate computer vision techniques and the phase field method to enhance damage update and evaluation processes in FEM. Computer vision is employed to analyze visual data and extract the geometric features of the damage, while the phase field method provides a robust numerical solution for representing the damage and further simulating the progression of damage. The integration of these methods allows for automated and precise updates of damage states in FEM, improving model accuracy and reducing manual intervention. Case studies on a paper board and a steel cross beam on a bridge demonstrate the effectiveness of the proposed approach, highlighting its feasibility for real-time monitoring and assessment in various engineering applications.

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Finnish Mechanics Days 2024

Engineering the micro-architecture of triangular lattice improving the resistance against crack propagation

Milad Omidi[1], Jarkko Niiranen

Lightweight structural materials are crucial to the transport industry as they offer an efficient option to reduce their CO_2 emissions. For example, reducing the mass of a Boeing 787 by 20% decreases its fuel consumption by 12% [1]. This industrial demand for lightweight materials can be fulfilled by a range of solutions, which among them, lattice materials have become increasingly popular in engineering because their architecture can be tailored to achieve desired properties [2]. Lattice materials are made from tessellation of an interconnected unit-cell of struts or cell-walls filling 2D (planar lattices) or 3D (spatial lattices) spaces [3]. They are frequently manufactured with polymers, ceramics, or metals providing stiff, strong, tough, and lightweight materials. Albeit the theoretical upper bound for strength and stiffness are reached by conventional planar lattices, there is no limitation in improving toughening behavior [4, 5].

Enhancement in toughness and resistance against crack propagation in lattice materials is crucial because it increases the reliability and lifespan of structures. Triangular lattice is a planar lattices presenting high fracture toughness among conventional lattices [6]. However, there is a room to enhance the resistance of triangular lattice against crack propagation (R-curve) by controlling their toughening mechanisms. Since the micro-architecture of lattices can be altered, **the concepts of changing the thickness of struts is employed to investigate the possibility of R-curve improvement in triangular lattice.**

The crack propagation in lattices was predicted using Finite Element (FE) simulations rely on a boundary layer method introduced by [7, 8]. For each tessellation, we used a square domain with a side length of 1600ℓ, where ℓ is the length of a cell wall. The domain contained an initial crack in the negative x_1 direction, as shown in Fig. 1a. The ratio of the thickness of bars aligned in x_2 direction to the inclined bars $T = t_2/t_1$ was altered so that maintain the constant relative density with that of triangular lattice with uniform thickness. The effect of T on propagation was examined for a brittle and ductile materials.

Results show that increasing amount of T up to 2 could significantly enhance rising of R-curve, especially for ductile materials. For the ratio of $T > 2$ the orthotropic effect changes the direction of propagation in comparison with that of isotropic triangular lattice. Also, brittle triangular lattice gets mutually tougher and stronger in x_2 with increasing T. This study provides insight into tailoring the micro-architecture of conventional lattices to improve their damage-tolerance in industries.

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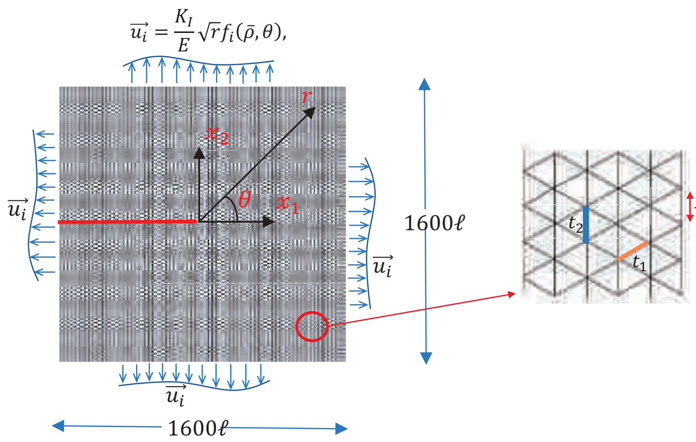

Figure 1. Schematic of boundary layer method.

Key words: Lattice materials, Triangular lattices, Finite Element Method, Crack propagation

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Chapter 17

Contributed papers 8: Additive manufacturing

October 4, Friday at 12.30 - 13.30. Room: D149 Chair: Heidi Piili

Finnish Mechanics Days 2024

Fundamental Thermoelastic Behavior Modeling for L-PBF Additive Manufacturing

Juha Jeronen[1], Tero Tuovinen and Matti Kurki

Abstract We investigate the 3D printing process of laser powder bed fusion (L-PBF), commonly used for metals, from the viewpoint of the theory of axially moving materials.

Key words: additive manufacturing, 3D printing, laser powder bed fusion (L-PBF), selective laser melting (SLM), mathematical modeling, coupled problem, multiphysics, thermomechanical analysis, viscoelasticity, axially moving materials

Description of the research

In the last decade, additive manufacturing has risen in popularity in industrial applications. A key aspect is that there are very few or no geometric restrictions. Particularly, the 3D printing of metals allows one to make complex, durable, custom parts. [2]

Our group has investigated [1] the thermomechanical behavior of 3D printing of metals in the laser-based powder bed fusion (L-PBF) process, also known as selective laser melting (SLM). Here we highlight the main results of the research.

We construct a thermoviscoelastic continuum model for the case where a thin fin is being printed at a constant velocity. We use a coordinate frame that moves with the printing laser, applying an Eulerian perspective to the moving solid. We consider a steady state similar to those used in the analysis of production processes in the process industry, in the field of research known as axially moving materials.

As our main result, we obtain the steady-state deformation shape in the wake of the laser in a two-dimensional setting, using a primal formulation and standard C^0 FEM elements. Another important result are nondimensional parameters derived from a one-dimensional model, which, like the Reynolds number of a flow, govern the behavior of the printing process. We demonstrate the model with parameter values for 316L steel.

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Finnish Mechanics Days 2024

3D chiral metamaterial unit cell capable of two deformation mechanisms under compression

Mohammaderfan Khodabakhshi[1], Sergei Khakalo

Abstract Metamaterials, distinguished by their engineered unit cells, possess exceptional mechanical and physical properties beyond those of conventional materials. This study presents a novel 3D chiral metamaterial unit cell design capable of dual deformation mechanisms under compression. Finite element method (FEM) simulations, validated by experiments on 3D-printed samples, reveal the design's ability to toggle between semi-achiral deformation without twisting and super-chiral behavior with combined twisting and compressing. This tunability showcases the advanced functionality of the metamaterial unit cell.

Key words: Metamaterial, FEM, Additive Manufacturing, Chiral, Deformation Mechanism

Description

Metamaterials are engineered structures whose properties primarily derive from their cellular architecture rather than chemical composition [2]. These materials exhibit unique behaviors not found in natural materials, such as compression/twist coupling [1], negative compressibility [4], negative Poisson's ratio [5], and tunable stiffness [3]. Significant advancements have been made in both theoretical and experimental aspects of 3D chiral metamaterials. Our unit cell design is defined by six geometrical parameters, as shown in Figure 1. Finite element analysis (FEA) was conducted using COMSOL Multiphysics 6.0 under quasi-static assumptions to avoid dynamic effects. The structures were discretized with quadratic tetrahedral elements. The boundary conditions include a fixed movement without any rotation condition for the bottom surface and a predefined longitudinal displacement on the upper surface of the structure. To validate the FEM simulations, samples were fabricated using a 3D SLS printer with Nylon 12 material. These samples were tested using a Zwick Roell+korthaus uniaxial testing machine. A custom-built rotating plate mechanism allowed accurate measurement of the twisting angle during compression. Simulation results showed a high correlation with experimental data, confirming the FEM simulation's accuracy. A parametric study was performed to determine the relationship between each design parameter and the twisting angle, stiffness, and deformation mechanism of the structure. The study identified the unit cell structure with the highest twist/compression ratio. For small values of θ, two deformation mechanisms were observed: super-chiral unit cell with a twist/strain ratio of 3.7, and semi-achiral which is a new finding for a chirally designed cell. When the infill ratio h tends towards 0, resulting in a thinner star-shaped body, the deformation mechanism shifts from compression-torsion

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coupling (CTC) to a semi-achiral mechanism, meaning the structure compresses without rotation.

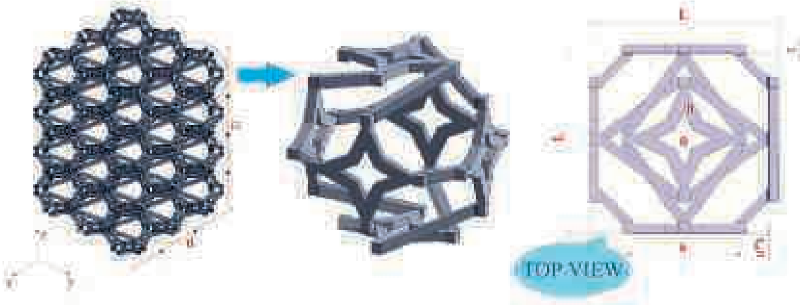

Figure 1. Geometrical parameters of designed structure's unit cell.

Figure 2 illustrates two cells with h values of 0.1 and 0.9. The left one is super-chiral with a twist/strain ratio of 3.7, while the right one behaves like an achiral unit cell with a near-zero twist/strain ratio. In semi-achiral structures, under compressive loading, the less stiff star plate parts bend symmetrically until deformation limits, causing compression without rotation. These findings pave the way for advanced metamaterials with potential applications in sensors, actuators, and multifunctional devices.

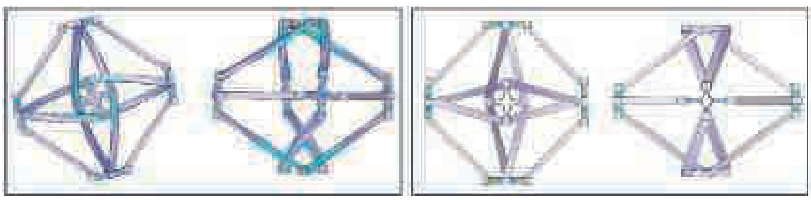

Figure 2. Two unit cell configurations with different deformation mechanisms.

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Finnish Mechanics Days 2024

LPBF Additive Manufacturing; Modeling and Material Test Results

Matti Kurki[1]

Abstract. This presentation combines experimental and computational approaches to investigate the mechanical properties and performance of 316L stainless steel and Inconel 718 produced via Laser Powder Bed Fusion (LPBF), a one of the leading additive manufacturing technologies today. The target is to explore the impact of key process parameters, including body orientation and printing patterns on the mechanical properties of the printed materials. Experimental methods such as static and fatigue testing are employed alongside a thermomechanical computational model to provide a comprehensive understanding of the LPBF process.

One-dimensional computational model simulates the temperature and stress distributions during the LPBF process, providing insights into the thermal gradients and resulting residual stresses that influence the mechanical behaviour of the printed parts. These simulations are validated against experimental data, demonstrating the model's capability to predict critical factors such as thermal distortions and stress concentrations.

For 316L stainless steel, the study reveals that body orientation and printing patterns significantly affect tensile strength and elongation, with computational simulations explaining the underlying thermal and mechanical phenomena. Fatigue testing results, supported by computational temperature predictions, highlight the necessity of a custom cooling unit to manage thermal loads during high-stress conditions. Modelling assists in understanding these trade-offs by illustrating the evolution of microstructural phases and residual stresses during the heat treatment process.

Keywords: LPBF, Additive Manufacturing, Thermomechanical Modelling, Finnish Mechanics Days

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Chapter 18

Contributed papers 9: Analysis

October 4, Friday at 12.30 - 13.30. Room: F304 Chair: Reijo Kouhia

Finnish Mechanics Days 2024

Natural Flame Spectral Analysis and Chemiluminescence Imaging of Diesel Spray Combustion

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Abstract. Natural flame specatral analysis and chemiluminescence imaging, with high temperal and spatial resolution, has been widely applied to study the combustion process and fundamental chemical reaction mechanism under various conditions. To gain an insight into the diesel spray evolution, ignition, flame propagation and pollutants formation, a simulataneous natural flame lumination with a color camera and multiple species (e.g., OH*, CH*, C2*) technique is employed to characterize the diesel spray combustion. In this study, the diesel combustion processes under different conditions, including ambient chamber density (e.g., 9.45kg/m3, 16.37kg/m3, 28.06kg/m3,), temperature (e.g., 900K, 1000K, 1100K) , O2 concentration (e.g., 12%, 15%, 18%) and injection pressure are obtained based on a multiple camera imaging system. The natural flame luminosity is employed to estimate the global flame propagation and soot emission. Meanwhile, the chemiluminescent distributions of OH*, CH*, C2* are obtained to evaluate the ignition delay time, heat release rate and global/local equivalence ratio in diffusion diesel flames under marine engine conditions. The changes in the reaction zones of OH* layer and CH* layer were further compared. The peak intensity ratios of OH* and CH* were used to quantitatively characterize the global equivalence ratio and heat release rate. The results show that variations in the global equivalence ratio and the dilution level do not obviously alter the shape and thickness of the CH* layer. The distribution and intensity changes of the OH* layer are much more significant than those of the CH* layer when the experimental conditions are varied. For the flame with a low dilution level, the CH* layer is located on the inner rim of the OH* layer, and the radial positions of two peaks are not much different. The increase of the dilution level leads to the displacement of the OH* peak, which becomes closer to the flame axis. In addition, due to the narrowing of the OH* layer, the CH* layer eventually becomes at the outer rim of the OH* layer. The peak intensity ratio of OH* and CH* decreases linearly with the rise of the global equivalence ratio, and changes as a power function with the increasing dilution level. Results show that a higher oxygen concentration case features a shorter ignition delay and higher heat release rate. The LTC mode can be realized by decreasing the oxygen concentration and ambient temperature

simultaneously and it features a longer ignition delay, a slower reaction rate, and apparently lower soot radiation heat loss.

Keywords: Diesel spray*, combustion, natural flame luminosity, chemiluminescence*

Opitical System

A simultaneous natural flame luminosity (NFL) combined with OH*, CH*, C2* chemiluminescence are recored by three cameras and a image intensifier in a high speed manner. The incoming light from spray combustion is split by a dichroic mirror with a cut-edge of 400 nm, which passed the ultraviolet light (under 400 nm) and reflected in 45° the visible and near infrared light (above 400 nm). A high speed camera (Phantom T1040) with a Cerco 100-mm f/2.8 lens and image intensifier (HiCATT) and image doubler (Lavision) are employed to capture the OH* and CH* at 100 kHz frames per second and a resolution of 640*400. The OH* chemiluminescence is imaged by a band-pass filter (310 nm centered, 10 nm FWHW) and CH* chemiluminescence is obtained by a band-pass filter (430 nm centered, 10 nm FWHW). Both signals are splitted by the image doubler and imaged in the same camera. The exposure time is controlled by the gate width of the image intensifier which sets to 2 µs in this study. The spatial resolution is 0.117 mm/pixel. The digital resolution is 12 bit for each pixel. The system is illustrated in Fig. 1. A high-speed color camera (Photron SA-Z) is applied to obtain the natural flame luminosity (NFL). The color camera provides a frame rate of 40 kHz with a resolution of 640*640 and exposure time of 90 µs. The C2* chemiluminescence is captured by a monochrome camera (Phantom V2012) . Considering the spectrum of C2* is in the visible range with a wavelength of 515 nm, there is no image intensifier is needed and a band-pass filter is selected accordingly. The C2* imaging sets to a frame rate of 50 kHz with a resolution of 512*512. The exposure times of the all cameras are carefully chosen to avoid the saturation and obtain meaningful signal. Although the frame speeds of two cameras are not exactly same, they are the closest number that can be configured. The imaging is therefore considered as quasi synchronized.

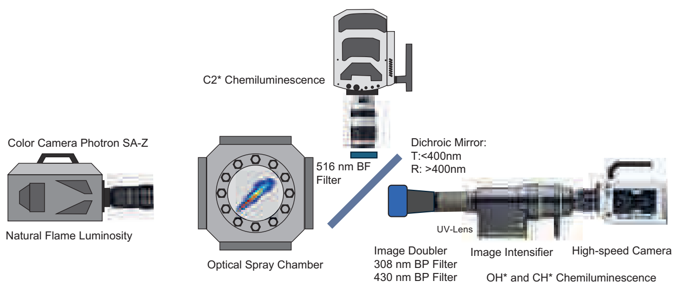

Fig. 1 Schematic of the optical setup

Most important in hydrocarbon combustion is the OH* emission around 310 nm, which originates from the $A2\Sigma^{+}$ to the ground state. The visible emission close to the reaction zone of flames is caused by excited CH*. About 80 % of this emission stems from the A2-state and the residual 20 % from the $B2\ \Sigma^{-}$. In rich flames, emissions in the green spectral range originating from the C2* (d–a) Swan bands can be observed as well. Fig. 1 shows the spectral emissions of three flames with low resolution sample spectra from the center region of maximum luminescence. The CH and especially C2 emissions are very dependent on stoichiometry, and the C2 Swan bands cannot be identified in the lean flame spectrum. Some underlying emission, particularly near 350 nm and to the red of 430 nm, especially for the lean flame, may be because of the CO2* continuum. But it is too faint for analysis here. In the following analysis, we assume light from 280 to 340 nm is from OH(A-X), that between 380 nm and 450 nm is excited CH, and light beyond 450 nm for the standard and rich flames only is from the C2 Swan bands. Note the Δv=+2 Swan bands will contribute to the intensity assigned to CH(A-X) near 430 nm, but little error is introduced the contribution is less than 10% of the Δv=+1 peak at 470nm.

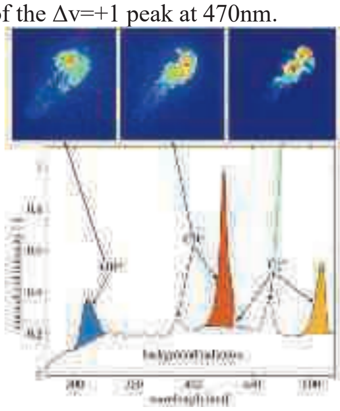

Fig. 2 Typical chemiluminescence spectrum of hydrocarbon fuel flame

Finnish Mechanics Days 2024

Buckling and post-buckling of twisted strips

Jarkko Niiranen[1] and Sergei Khakalo

Abstract This one-page abstract is about a study on the buckling response of columns formed by twisting a flat, straight and narrow material strip having a rectangular cross section; consisting of both experimental results and finite element analysis.

Keywords: buckling, post-buckling, twisting, stability, strip structure, plywood

Introduction

The study in question [1] has its roots in the design of a wooden pavilion relying on finding structurally more efficient geometrical configurations for originally straight and flat birch plywood strips: twisting leads to structural members stiffer in both bending and compression. For a flexible material strip, twisting can be seen as a natural shaping process: forces or kinematical constraints are applied only at the ends of the strip, whereas the strip span takes its form according to the laws of mechanics.

A straight and narrow material strip having a rectangular cross section is first twisted and then compressed – in both real laboratory and virtual simulation environments. The reported experimental results cover flexible birch plywood strips twisted up to 90 degrees. The corresponding finite element analysis covers both the twisting phase and the subsequent compression phase, including a study on the influence of the twisting-induced stresses on the buckling response.

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Finnish Mechanics Days 2024

Kokemuksiani tutkijakoulutuksesta

Pekka Neittaanmäki*

Suomen tavoitteena on parantaa kansainvälistä kilpailukykyä nostamalla tutkimus- ja kehityspanostukset neljään prosenttiin bruttokansantuotteesta vuoteen 2030 mennessä. Tämä vaatii merkittävää lisäystä T&K-henkilöstöön, noin 9000 uutta työntekijää vuosittain, joista 2000 tulisi olla tohtorikoulutettuja.

Opetus- ja kulttuuriministeriö on myöntänyt yliopistoille 255 miljoonaa euroa vuosille 2024–2027 tohtorikoulutuksen uusien käytänteiden pilotointiin. Rahoitus kohdennetaan 1000 väitöskirjatutkijalle, jotka otetaan määräaikaisiin kolmen vuoden työsuhteisiin suorittamaan tohtorintutkintoja. Tämän pilotin avulla pyritään vastaamaan Suomen kasvavaan huippuosaajien tarpeeseen sekä edistämään tutkittuun tietoon pohjautuvien innovaatioiden syntymistä.

Pilotin päätavoitteita ovat tohtoreiden määrän kasvattaminen, joustavampien koulutusprosessien ja sisältöjen pilotoiminen, liikkuvuuden lisääminen eri organisaatioiden välillä sekä valmistuneiden tohtoreiden monipuolisten uramahdollisuuksien tukeminen. Samalla kehitetään ohjausta ja edistetään tohtoreiden työllistymistä yhteiskunnan eri sektoreille.

Esityksessä analysoidaan, kuinka yliopistot ovat menestyneet kansallisessa kilpailussa ja kuinka tutkijakoulutusta tulisi kehittää, jotta asetetut tavoitteet saavutetaan. Lisäksi tarkastellaan tieteen tekemisen muutosta, erityisesti laskennallisten tieteiden nousua perinteisten tutkimusmenetelmien rinnalle, sekä annetaan käytännön neuvoja tutkijanuran eri vaiheisiin yli 30 vuoden kokemuksen pohjalta. [1][2]

Kerron esityksessäni kokemuksistani eri tieteenallilta tutkijankoulutuksesta yli 30 v vuoden ajalta. Miten aihe valitaan? Miten väitöskirjan eri vaiheissa edetään? Mikä on suunnitelma väitöskirjan jälkeen?

Avainsanat: Jatko-opinnot, tutkijankoulutus

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Program

Time	Place	WEDNESDAY Nov 2	Time	Place	THURSDAY Nov 3	Time	Place	FRIDAY Nov 4
9:00	FP05	Registration & Coffee	10:00	FP05	Registration & Coffee	9:30	FP05	Registration & Coffee
9:30 10:00 10:45	FP05 FP05 FP05	**Opening words** **Plenary 1** Rolf Stenberg: **Plenary 2** Fredrik Larsson	10:30	FP05	**Plenary 3** Marcelo Dias	10:00	D148 D149 F304	**Parallel sessions** IFME 3: Industry, innovation and infrastructure MS 3: Fatigue, analysis, experi-ments and design C6: Vibration and stability
11:30		Lunch	11:30		Lunch	11:30		Lunch
12:30	D148 D149 F304 F305	**Parallel sessions** IFME 1: Industry, innovation and infrastructure C1: Finite element analysis 1 C2: Digital twins and artificial intelligence C3: Computation-al fluid dynamics/ C4: Thin structures	12.30	D148 D149 F304 F305	**Parallel sessions** IFME 2: Educa-tion in the digital age and applied research C5: Fracture, da-mage and wear MS 1: Imaging and image-based methods in experimental mechanics MS 2: Industry cases	12:30	D148 D149 F304	**Parallel sessions** C7: Finite element analysis 2 C8: Additive manufacturing C9: Analysis
14:30		Coffee	14:30		Coffee	13:30		Coffee
15:00 16:00 16:30 17:30 18:00 19:30	FP05 Ylistö Aal-to2	**Round Table 1** END Optional: JYU laboratory End of tour Welcome cocktail and tour at Aalto2 museum center	15:00 16:00 16:30 17:30 19.00 22.30	FP05 Jamk Vesi-linna	**Round Table 2** END Optional: Jamk laboratory Dinner, Restaurant Vesilinna	14:00 14:45 15:00	FP05	**Plenary 4** Giovanni Meneghetti **Closing words** END

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