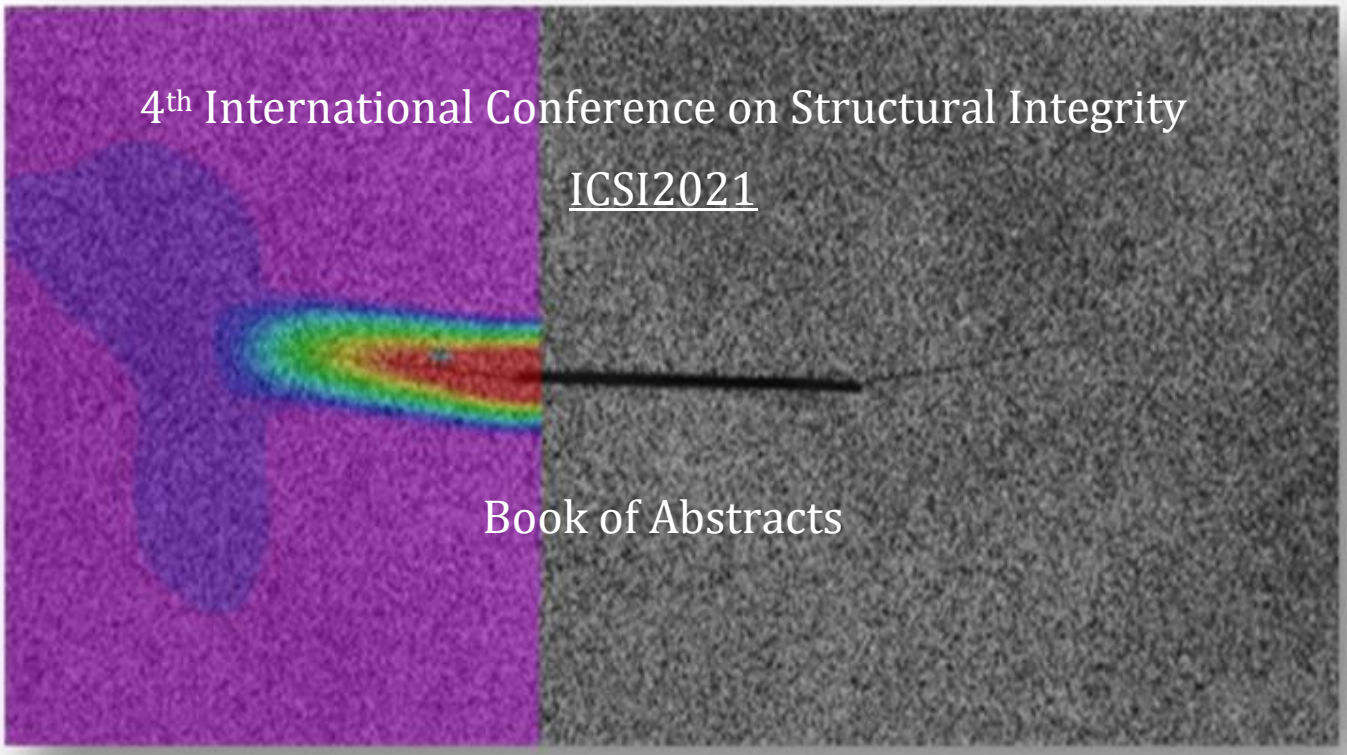
Active thermography for the investigation of corrosion in steel surfaces

4th International Conference on Structural Integrity

ICSI2021



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4th International Conference on Structural Integrity

Funchal, Madeira, Portugal

30 August - 1 September, 2021

https://www.icsi.pt/

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Technical Program

August 27th, 2021 version

Monday, 30nd August 2021		
MON, 08:15 - 08:30	OPENING SESSION	Room A
Welcome to Participants **(Conference Co-Chairs)** Welcome Address		

MON, 08:30 - 09:00	**PLENARY LECTURE I**	**Room A**
Beyond Hopkinson's bar: the IB test series **Prof. Fabrice Pierron** University of Southampton, UK Chair: Pedro Moreira (INEGI, Portugal)		

Prof. Fabrice Pierron

Faculty of Engineering and Physical Sciences
School of Mechanical Engineering
University of Southampton

Professor Fabrice Pierron has been a Professor of Solid Mechanics at the University of Southampton (UoS) since June 2012, having spent the first part of his career in France. His research specialization concerns the development of novel identification strategies based on full-field deformation measurements and data-rich inverse identification. He has been instrumental in the development of the Virtual Fields Method (VFM), which has now gained widespread international recognition and is commercialised as part of a dedicated software platform marketed by the MatchID company (www.matchid.eu), of which he is a founding member. He has published over 140 international journal articles and co-authored the only existing book on the VFM. He was awarded a Royal Society Wolfson Research Merit Award in May 2012 as part of his relocation to the UoS, and has been Editor-in-Chief of Strain (Wiley) between 2010 and 2020. In 2014, he was granted a £1.2M EPSRC Established Career Fellowship that extended his main research interest to high strain rate testing using high-speed imaging (www.photodyn.org). This effort has also been supported by a stream of US Air Force EOARD grants totalling 700k+ USD since 2013. He is part of a group of researchers who have recently been awarded a £6.1M EPSRC programme grant. His role in this project is using ultra-high speed imaging and novel ultrasonics deformation procedures to elucidate mechano-transduction processes at the scale of cells and tissues when submitted to ultrasonic deformation (20 Hz to 1 MHz).

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Topic: Modelling **Chair: Behzad Farahani**		
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034	Interfacial damage in flexible electronics on collagen substrate: effect of environmental conditions Shirsha Bose, Simin Li, Elisa Mele, Vadim V. Silberschmidt	
156	Geometrical study of adhesively-bonded T-joints by cohesive models J.P.M. Lopes, R.G.S.G. Campilho, R.J.B. Rocha, F.J.G. Silva	
120	Innovative processing for ceramic ball manufacturing: analytical estimation, experimental testing and numerical simulation Raffaella Sesana, Irene Pessolano Filos, Sebastiano Rizzo, Rocco Lupoi	
224	Effect of Voids Shape on Deformation of 3D Printed Closed-Cell Porous Structures Mikhail Tashkinov, Yulia Pirogova	

Mon	Session 1B 09:00-10:30	Room B
TOPIC: Symposium E - Mechanical behaviour and modelling of wood and timber structures **Chair: Almudena Majano-Majano and José Xavier**		
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073	CLT-concrete composite slab optimization Carlos Martínez-Criado, José-Ramón Aira	
085	Influence of the connector shape parameters in the structural behaviour of the adhesive-free timber floor panels Gonzalo Moltini, Vanesa Baño	
089	Mechanical behavior of tropical Glued Laminated Timber (GLT) beams with fingers joints Cédric Horphé Ndong Bidzo, Rostand Moutou Pitti, Claude Feldman Pambou, Nziengui, Samuel Ikogou, Beat Kaiser	
097	Impact of mechano-sorptive loading on crack propagation of notched beams of White-fir and Okume Martian Asseko Ella, Samuel Ikogou, Giacomo Goli, Rostand Moutou Pitti, Joseph Gril, Eric Fournely, Gaël Godi	
099	Direct evaluation of Mode I cohesive law of eucalyptus bonded joints Almudena Majano-Majano, Antonio José Lara-Bocanegra, José Xavier, Fábio Pereira, José Morais	

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044	Investigation of Web Buckling of Pultruded GFRP Bridge Deck Subjected to Concentrated Load Yun Sun, Haohui Xin, Yuqing Liu	
076	Comparison between design guidelines in predicting FRP contribution to shear capacity of strengthened RC beams Haya H. Mhanna, Rami A. Hawileh, Jamal A. Abdalla	
077	Evaluation the effect of FRP anchor embedment depth on the flexural bond capacity of concrete prisms Ghusoon S. Alshami, Rami A. Hawileh, Jamal A. Abdalla, Haya H. Mhanna	
092	An approach for assessment of concrete deterioration by surface waves Alexey Tatarinov, Aleksandrs Sisojevs, Gennady Shahmenko, Viktors Kurtenoks	
111	Failure Analysis and Prevention of a Cyclone located in a Cement Production Line Alexandre Fragoso, Rui F. Martins, António Soares	
135	Behavior of R/C Beams Strengthened in Flexure using Externally Bonded Aluminum Alloy Plates Jamal A. Abdalla, Rami A. Hawileh	
018	Mechanical Behavior Analysis of a Galvanized Corrugated Steel Concrete Composite Arch Bridge Structure by FEM Lei Xiao, Yang Zegang, Zhang Shicheng, Ye Tairu, Zheng Yuhan	

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066	Influence of the mesh size on plastic CTOD J. Sanchez-Mancera, D. Camas, P.A. Prates, F.V. Antunes	
141	Crack Closure Analysis Using Digital Image Correlation Behzad V. Farahani, Frederico Direito, Pedro J. Sousa, Pedro M. G. P. Moreira	
199	Crack growth rate deceleration effect in constructional caused by artificial crack closure effect (ACCE) Lesiuk G., Nykyforchyn H., Zvirko O., Duda Sz., Zielonka P., Correia J.A.F.O, Seitl S., de Jesus A.M.P	
057	Numerical simulation of fatigue crack growth in aircraft structure with a honeycomb mesh M. Dinulović, A. Grbović, S. Sedmak, M. Aranđelović, T. Mijatović	
058	Analysis of fatigue behaviour of a bridge welded structure Z. Burzić, A. Sedmak, S. Sedmak, S. Perković, I. Čamagić	
121	Experimental study on the mechanism of wheel-rail steels crack initiation and wear growth under rolling contact fatigue Junpeng Li, Yu Zhou, Zheng Wang, Zhechao Lu, Zhongning Cheng, Shiye Wang	

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119	Effects of long-term loading on Moabi timber beams in the tropical environment of Gabon: spatial variability of mechanical parameters in 3-point bending and axial compression tests Valérie Nsouami, Nicaise Manfoumbi Boussougou, Emilio Bastidas-Arteaga, Rostand Moutou Pitti	
128	Security determination in timber structures Miguel Tortoriello, Luis Lima, Ana Clara Cobas	
129	Notched Connection Design in Timber-Concrete Composite Floors Lei Zhang, Jianhui Zhou, Ying Hei Chui	
148	Identification of material properties of green laminate composite plates using bio-inspired optimisation algorithms A. F. F. Rodrigues, J. V. Araújo dos Santos, H. Lopes	
153	Load-bearing and aseismic mechanism of traditional Chinese timber structures Qingshan Yang, Pan Yu, Ke Liu	

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054	Analysis of cyclic properties of additive vs. conventionally produced material AlSi10Mg Vladimír Chmelko, Igor Berta, Matúš Margetin	
055	Fatigue lifetime of a bicycle frame made additively from AlSi10Mg Róbert Ďurka, Marek Gašparík, Pavel Žlábek	
124	Static and fatigue properties of maraging steel X3NiCoMoTi18-9-5 Miloslav Kepka, Ivana Zetkova, Miroslav Zetek, Ludmila Kucerova	
131	SLM process parameters effects on the fatigue strength of AMed Inconel 718 G. Macoretta, B. D. Monelli	
009	In Situ Full-Field Deformation Measurements on Advanced Manufacturing Processes Filipa G. Cunha, Telmo G. Santos, José Xavier	

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MON, 13:30 - 14:00	PLENARY LECTURE II	Room A
The coexistence of hydrogen embrittlement mechanisms in steel: HELP + HEDE model **Prof. Milos B. Djukic** University of Belgrade, Serbia Chair: Daniel Braga (INEGI, Portugal)		

Prof. Milos Djukic

University of Belgrade, Faculty of Mechanical Engineering, Department of Engineering Materials and Welding, Belgrade, Serbia.

Dr. Milos B. Djukic, Associate Professor is a specialist in the field of hydrogen embrittlement, materials and corrosion science, and the mechanical behavior of materials. He has more than 20 years of teaching and research experience and is the author/co-author of 4 books, 5 book chapters, 1 patent, 72 refereed scientific papers and 120 papers published in conference proceedings and journals.

His new book (co-authored with Prof. Branko Popov) entitled: “Hydrogen Embrittlement Theory and Prevention of Hydrogen Damage in Metals and Alloys, 1st Edition” will be published in 2021 by Elsevier. The book chapter (co-authored with Prof. Branko Popov and Prof. Jong Won Lee), entitled: “Hydrogen Permeation and Hydrogen-Induced Cracking” in the “Handbook of Environmental Degradation of Materials, 3rd Edition” was published by Elsevier in 2018.

Since 2014 he is an external peer reviewer for scientific projects for the following European scientific agencies: Research Foundation Flanders, Belgium, National Science Centre, Poland, and the Dutch Research Council, Netherlands. He was a keynote speaker – topic hydrogen embrittlement at the Materials Science and Engineering 2018 Conf., Germany. He was also an invited speaker on the 13th Int. Conf. on Diffusion in Solids and Liquids in Austria, and on the CORROSION 2015 Conf., USA. Recently, in 2021, he gave an invited talk on the HYDROGENIUS, I2CNER and HydroMate Joint Research Symposium on Hydrogen Materials Interactions 2021, Japan. He was an external Ph.D. thesis examiner at the University of Queensland, Australia, and ISAE-ENSMA, Université de Poitiers, France. He is a member of the editorial board of seven international journals: International Journal of Hydrogen Energy, Frontiers in Materials, Metals, Coatings, Journal of Pipeline Science and Engineering, Frattura ed Integrità Strutturale, and Structural Integrity and Life. He has 217 verified editor records and 111 reviews for 40 international journals including Science, Acta Materialia and Scripta Materialia.

In 2019, he was a Managing Guest Editor of Engineering Fracture Mechanics journal, SI titled: “Recent Advances on Hydrogen Embrittlement Understanding and Future Research Framework”. In 2020/2021 he is a Guest Topic Editor of Frontiers in Materials journal, Research Topic: “Hydrogen Embrittlement in Metals: Characterization, Mechanism and Prevention”.

Mon	Session 3A 14:00-15:30	Room A
TOPIC: Symposium C - Structural Health Monitoring Chair: Hernani M. R. Lopes, José V. Araújo dos Santos		
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150	On the use of finite differences for vibration-based damage localization in laminated composite plates T. Oliveira, J. V. Araujo dos Santos, H. Lopes	
155	Health indicator development for damage monitoring of composite panels utilizing SHM sensors Georgios Galanopoulos, Dimitrios Milanoski, Agnes Broer, Dimitrios Zarouchas, Theodoros Loutas	
164	Pipeline Bending Strain Assessment from IMU Data – A Comprehensive Approach Enyang Wang, Rick Gailing, Aaron Dinovitzer, Francisco Bernal, Juan Mora	
169	Analytically based time reversal damage imaging in plate-like structures with a sparse piezoactive sensor network Artem Eremin, Ilia Bareiko, Evgeny Glushkov, Natalia Glushkova	
200	Damage detection and localization in imperfect bolted joints Reza Soleimanpour, Sayed Mohamad Soleimani, Naser Khaled Mahmoud Mohammad	

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176	A risk-based approach for timber building decay prediction Andrea Gaspari, Ivan Giongo, Maurizio Piazza	
182	Impact of moisture content on tropical wood under opening mode Stanislas Malfait, José Xavier, Rui F. Martins, Rostand Moutou Pitti, Claude Nziengui	
Topic: Fracture and Fatigue I Chair: Behzad Farahani		
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206	Review and synthesis of stress intensity factor (SIF) solutions for circular inner cracks in round bars under tension loading Jesús Toribio, Beatriz González, Juan-Carlos Matos	

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028	A method for determining the distribution of carbon nanotubes in nanocomposites by electric conductivity Dayou Ma, Ali Esmaeili, Claudio Sbarufatti, Marco Giglio, Andrea Manes	
047	Dynamic Fracture Behaviour of Additively Manufactured Polymers and Composites under Ballistic Impact Md Niamul Islam, Konstantinos P. Baxevanakis, Vadim V. Silberschmidt	
109	Structural Integrity of Polymeric Components Produced by Additive Manufacturing Rui F. Martins, Ricardo Branco, Filippo Berto, Nuno Santos, Sebastião Bandeira	
143	Compression fatigue behaviour of extrusion-based 3D printed PLA R.A. Cláudio, R.A Baptista, J. Dupont, M. Leite, L. Reis	
194	Creep and stress relaxation behaviour of 3D printed nanocomposites P.N.B. Reis, S. Valvez, J.A.M. Ferreira	

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040	Hardware proposal for SHM in airborne vehicles Josu Etxaniz, Gerardo Aranguren, José Miguel Gil-García, Jesús Sánchez	
061	Ultrasonically assisted turning of SiCp/Al composites Jin Kim, Lorenzo Zani, A Abdul-Kadir, Marcelo L Ribeiro, Anish Roy, Konstantinos P Baxevanakis, Lewis Jones, Vadim V Silberschmidt	
074	Proof of concept for impact and flaw detection in airborne structures Gabriel Vivas, Jon González, Josu Etxaniz, Gerardo Aranguren	
091	Ship Model Structural Health Monitoring using FBGS to obtain internal forces M.González-Gallego, F.Terroba, J.L. Martinez, R.Atienza, M.Frövel	
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Ref:	Title and Author (s)	
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093	Fracture Mechanics Based Approach for Fatigue Assessment of Ultra-High Strength Steels I. Varfolomeev, T. Straub, M. Luke, A. Kleemann	
197	Autofrettage of component-like ultra high Strength Steel Specimens with intersecting Holes Carl Fällgren, H. Thomas Beier, Michael Vormwald	
036	The Evaluation of Quenching Temperature Effect on Microstructural and Mechanical Properties of Advanced High Strength Low Carbon Steel After Quenching Partitioning Treatment Ehsan Entezari, Hamid Mousalou, SasanYazdani, Jorge Luis González-Velázquez	
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168	Solution for consolidation and retrofitting an historical steel bridge Dorin Radu, Radu Băncilă, Dorel Bolduș, Simon Sedmak, Mihajlo Aranđelović	

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166	Stiffness optimization through a modified greedy algorithm Iulian Constantin Coropețchi, Alexandru Vasile, Ştefan Sorohan, Cătălin Radu Picu, Dan Mihai Constantinescu	
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185	A simulated annealing algorithm for stiffness optimization Alexandru Vasile, Iulian Constantin Coropețchi, Ştefan Sorohan, Cătălin Radu Picu, Dan Mihai Constantinescu	
159	Annealing effect on mechanical properties of 3D printed composites S. Valvez, Abílio P. Silva, P.N.B. Reis, F. Berto	
035	Structural integrity of 3D-printed prosthetic sockets: Experimental study for paediatric applications Theodoros Marinopoulos, Simin Li, Vadim V. Silberschmidt	
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Tuesday, 31st August 2021

TUE, 08:30 - 09:00	PLENARY LECTURE III	Room A
Fracture toughness of advanced materials at different length scales **Prof. Sabrina Vantadori** University of Parma, Italy Chair: Paulo Tavares (INEGI, Portugal)		

Prof. Sabrina Vantadori

Department of Engineering and Architecture, University of Parma, 43124 Parma-Italy

Sabrina Vantadori is a Professor in Structural Mechanics at the Department of Engineering and Architecture of the University of Parma. She is the TC3 President (Technical Committee No.3 “Fatigue of Engineering Materials and Structures”) of ESIS (European Structural Integrity Society) since October 2020, and Vice Head of the Laboratory “Prove Materiale e Strutture” of the University of Parma since February 2021.

Her research field is fatigue and fracture mechanics of traditional and innovative materials at different length scales.

She received 7 Scientific International Awards. She was the chairperson of 3 International Conferences, member of International Scientific Advisory Committee of several International Conferences, and keynote speakers of 6 International Conferences. She was editor of 11 Special Issues of International Journals. She is committee member of 3 international journals with peer-review. She is author of more then 130 publications on international peer-reviewed journal with impact factor.

Tue	Session 5A 09:00-10:30	Room A
TOPIC: Symposium H - Damage identification and prediction of structural response **Chair: Andrzej Katunin**		
Ref:	Title and Author (s)	
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060	Crack identification in tungsten carbide using image processing techniques Kafayat E Hazzan, Manuela Pacella	
062	Effectiveness of damage identification in composite plates using damage indices based on smoothing polynomials and curvelet transform: A comparative study Andrzej Katunin, Sandris Ručevskis	
083	Prospects of Structural Damage Identification Using Modal Analysis and Anomaly Detection Deniss Mironovs, Sandris Ručevskis	
125	The influence of high temperature on dynamic response of concrete beams reinforced with GFRP rods Beata Zima	
056	Structural integrity analysis of a Kaplan turbine cover Aleksandar Sedmak, Miodrag Arsić, Mirjana Opačić	

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031	Mechanical behaviour of friction stir butt welded joints under different loading and temperature conditions L. Pinto, C. Vidal, M.A. Machado, D. Braga, V. Infante	
067	Effect of primer and sealant in refill friction stir spot welded joints on strength and fatigue behaviour of aluminium alloys Petr Homola, Roman Růžek, Anthony R. McAndrew, Jeroen De Backer	
075	Effect of specimen configuration and notch root angle on fatigue behavior of novel dissimilar resistance spot welds of AA5754 to HSLA steel Liting Shi, Jia Xue, Jidong Kang, Amberlee S. Haselhuhn, Blair E. Carlson	
102	Microstructure and mechanical properties of laser beam-welded AA2198 using Al-Si filler wire under post-weld heat treatment T.N. Examilioti, V. Ventzke, N. Kashaev, B. Klusemann, N.D. Alexopoulos	
223	Friction based spot joining method for thermoplastic based materials Shayan Eslami, Pedro J. Sousa, Pedro M. G. P. Moreira	

Tue	Session 5C 09:00-10:30	Room C
TOPIC: Symposium I - Structural Integrity of steel/FRP & concrete composite structures **Chair: Xin Haohui, Jose Correia, Jun He, Rong Liu and Zhihua Xiong**		
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136	Strengthening of RC Columns using NSM-CFRP Strips and CFRP-Fabric Wraps Jamal A. Abdalla, Raed Abokwiek, Rami A. Hawileh	
014	A prefabricated MVFT composite girder suitable for small-span bridge Zhihua Xiong, Meng Li ,Tianqi Wang, Yang Meng	
214	Fatigue life estimation of CFRP reinforced puddle iron structural details using fatigue local approach Anis Mohabeddine, João Arrojado, José Correia, Abilio de Jesus, José Miguel Castro, Rui Calçada, Filippo Berto	
215	Comparison between rigid and ductile adhesives in CFRP/Steel bonded joints Anis Mohabeddine, Ghassan Malik, José Correia, Nciholas Fantuzzi, Abilio de Jesus, José Miguel Castro1, Filippo Berto	
008	Flexural behavior of prefabricated composite beams with twin I-girders Rong Liu, Hao Zhao	

Tuesday, 10:30 - 10:45	COFFEE-BREAK	

Tue	Session 6A 10:45-12:15	Room A
TOPIC: Symposium H - Damage identification and prediction of structural response **Chair: Andrzej Katunin**		
Ref:	Title and Author (s)	
004	Index Combination for Damage Localization using Genetic Algorithm Elizabeth K. Ervin, Chuangshuo Zeng1	
032	Frontal impact on a coach, door sub-system pseudo-dynamic (PSD) test Rogério Lopes, Francisco Barros, Francisco Q. de Melo, Nuno V. Ramos, P.M.G.P. Moreira, Rafael Cunha, Ricardo Maia, Rui Rodrigues	
041	Experimental investigation of factors influencing the transmission capabilities of a low cost, side-polished evanescent wave absorption plastic optical fiber sensors Grzegorz Wójcik, Piotr Przystałka	
042	Damage classification in composite structures based on X-ray computed tomography scans using features evaluation and deep neural networks Tomasz Rogala, Piotr Przystałka, Andrzej Katunin	
043	A reverse engineering approach for modeling of barely visible impact damage by combining results of non-destructive testing and numerical simulations Angelika Wronkowicz-Katunin, Andrzej Katunin, Wojciech Danek, Krzysztof Dragan, Marek Wyleżoł	
005	Experimental Investigations on Stiffened and Web-core Sandwich Panels Made for Steel under Quasi-Static Penetration Jani Romanoff, Mihkel Kõrgesaar, Pauli Lehto, Kennie Berntsson, Heikki Remes	

Tue	Session 6B 10:45-12:15	Room B
TOPIC: Symposium N - Corrosion and Degradation of Materials **Chair: Nikolaos Alexopoulos**		
Ref:	Title and Author (s)	
162	Corrosion characterisation of solid and lattice AlSi10Mg manufactured by laser powder bed fusion Carlien Taute, Heinrich Möller, Anton du Plessis	
167	A constitutive equation for the kinetics of high temperature hydrogen attack and its use for structural life prediction R.J. Mostert, T. W. Mukarati, C.C.E. Pretorius, VM Mathoho	
183	Effect of different hostile solutions on mechanical properties of composite materials M.P. Silva, P. Santos, J.M. Parente, S. Valvez, P.N.B. Reis	
195	The effect of artificial ageing on the corrosion-induced mechanical properties degradation of aeronautical aluminum alloy 2198 Christina Margarita Charalampidou, Dimitris Georgoulis, Angeliki Proiou, Stavros K. Kourkoulis, Nikolaos D. Alexopoulos	
078	Modelling the impact of climate change on a novel Irish Concrete Bridge David R. Wallace, Paraic C. Ryan	
147	Experimental and theoretical study of a laser beam-welded Al-Li AA2198 alloy under different artificial ageing conditions A. Germanou, T. N. Examilioti, P. Papanikos, N. Kashaev, B. Klusemann, N. D. Alexopoulos	
207	Environmentally-assisted microstructural integrity of commercial cold drawn pearlitic steel wires Jesús Toribio, Francisco-Javier Ayaso, Antonio Fernández-Viña	
179	Mechanism of fireside corrosion deteriorating creep rupture life of Super304H in simulated coal-fired power plant environment Yaxin Xu, Xiaofeng Yang, Jintao Lu, Zhiqi Guo, Wenya Li	

Tue	Session 6C 10:45-12:15	Room C
Topic: Polymers **Chair: Rui Martins**		
Ref:	Title and Author (s)	
012	Experimental study on fatigue crack propagation of octet-truss lattice Yifan Li, Martyn Pavier, Harry Coules	
013	Fracture behaviour of octet-truss lattices in different orientations Yifan Li, Martyn Pavier, Harry Coules	
079	Mechanical Characterization of PDMS with Different Mixing Ratios Flaminio C. P. Sales, Ronaldo M. Ariati, Verônica T. Noronha, João E. Ribeiro	
144	Fatigue Behavior of PLA Material and the Effects of Mean Stress and Notch: Experiments and Modeling Mohammed Algarni	
149	Numerical Simulation of Deformation Behavior of Additively Manufactured Polymer Lattice Structures with a Porosity Gradient Mikhail Tashkinov, Natalia Elenskaya	
103	Strain measurements by FBG-based sensors embedded in various materials manufactured by different technological processes Matveenko V.P., Kosheleva N.A., Serovaev G.S.	

Tuesday, 12:15 - 13:30	LUNCH	

Tue	Session 7A 13:30-15:00	Room A
TOPIC: Symposium H - Damage identification and prediction of structural response Chair: Andrzej Katunin		
Ref:	Title and Author (s)	
130	On the transmission of non-Gaussian random loading through linear structures Arvid Trapp, Fabian Hollweck, Peter Wolfsteiner	
161	Multiple Damage Detection of Cantilever Wing using Classification Machine Learning and Neural Network Architecture Zia Ur Rehman	
138	Active thermography for the investigation of corrosion in steel surfaces M. M. Dugand, F. Curà, R. Sesana, S. Lazzaro	
139	Signal to noise ratio in active thermography for metals characterization Francesca Curà, Raffaella Sesana, Irene Pessolano, Luca Corsaro, Luca Santoro	
140	Lock-in thermography for residual stresses investigation in steel welded joints Francesca Curà, Raffaella Sesana, Luca Corsaro, Irene Pessolano, Luca Santoro	
216	Application of Sandwich Panels in Steel Structures Aditya Vidwans, José A.F.O. Correia	

Tue	Session 7B 13:30-15:00	Room B
Topic: Fatigue I Chair: Luís Borrego		
Ref:	Title and Author (s)	
020	Fatigue crack propagation direction under different loading conditions using MTS and MSS criteria R. Baptista, V. Infante	
029	Mechanical characterization and fatigue assessment of wire and arc additive manufactured HSLA steel parts Nicolae Rodideal, Carla M. Machado, Virgínia Infante, Daniel F.O. Braga, Telmo G. Santos, Catarina Vidal	
126	Effect of elliptical defect orientation on the durability of specimens subject to cyclic bending Zbigniew Marciniak, Ricardo Branco, Rui F. Martins, Dariusz Rozumek, Wojciech Macek	
113	Fatigue peculiarity of metals treated by laser shock impact Prokhorov A., Vshivkov A., Plekhov A., Kashaev N., Zherebtsov S.	
117	Energy balance and acoustic emission in titanium Grade 2 under fatigue A. Vshivkov, A. Iziumova, V. Mubassarova, A. Prokhorov, I. Panteleev, O. Plekhov	
094	Cyclic deformation behaviour of AlSi10Mg aluminium alloy fabricated by laser powder-bed fusion R.F. Fernandes, J. Jesus, R. Branco, L.P. Borrego, J.A. Martins Ferreira	

Tue	Session 7C 13:30-15:00	Room C
Topic: Composite and nanomaterials Chair: Nikolaos D. Alexopoulos		
Ref:	Title and Author (s)	
095	Mechanical, electrical and piezoresistive properties of hydraulic lime paste reinforced with modified carbon nanotubes Angeliki Eirini Dimou, Zoi S. Metaxa, Stavros K. Kourkoulis, Ioannis Karatasios, Nikolaos D. Alexopoulos	
098	Optimization of the graphene reinforcement in cement-based materials Anastopoulos G Stylianos, Givannaki Th Faidra, Zoe S Metaxa, Paraskevas. Papanikos, Alexopoulos D Nikolaos	
178	Effect of graphene nanoparticles on suspension viscosity and mechanical properties of epoxy based nanocomposites J.M. Parente, R. Simões, P.N.B. Reis	
196	Mechanical, electrical and piezoresistive properties of a ternary cement-based restoration paste with incorporated carbon-based nanomaterials Christina Margarita Charalampidou, Angeliki Eirini Dimou, Zoi S. Metaxa, Stavros K. Kourkoulis, Ioannis Karatasios, Nikolaos D. Alexopoulos	
175	Estimation of residual fatigue life of polymer composites after preliminary low-velocity impact Oleg Staroverov, Dmitrii Lobanov	
064	Eigenstrain Reconstruction from Contaminated Data using Inverse-EIM Arun Agrawal	

Tuesday, 15:30 - 15:45	**COFFEE-BREAK**	

TUE, 15:45 - 16:15	PLENARY LECTURE IV	Room A
Establishing specimen property to part performance in additive manufacturing **Prof. Nima Shamsaei / Prof. Shuai Shao** Auburn University, United States of America Chair: Paulo Lobo, University of Madeira		

Prof. Nima Shamsaei

Philpott-WPS Distinguished Professor and NCAME Director
National Center for Additive Manufacturing Excellence (NCAME)
Samuel Ginn College of Engineering
Auburn University

Nima Shamsaei is currently the Philpott-WestPoint Stevens Distinguished Professor in the Department of Mechanical Engineering at Auburn University, where he is also the founding director of the National Center for Additive Manufacturing Excellence (NCAME), a NASA and NIST funded research center focused on advancing the additive manufacturing (AM) technology. NCAME is also one of the two U.S.-based founding partners of the ASTM International Additive Manufacturing Center of Excellence (AM CoE). Prior to joining academia, Dr. Shamsaei spent many years in industry, including leadership positions, specializing in fatigue analysis and durability test development. Dr. Shamsaei then took his skillset to Mississippi State University in 2013 and initiated a research track in the AM field. The focus of his research was on the structural integrity of AM metallic materials, which is his continued primary area of interest at Auburn University. His research work has resulted so far in publishing over 200 peer-reviewed journal articles and conference proceedings as well as 70+ technical presentations including 40+ invited talks or keynote/plenary speeches in the areas of fatigue, fracture, mechanics of materials, and AM part qualification and certification. Several government agencies and private companies sponsor many of his research projects in order to advance AM technology for faster industrial adoption. He has served as the guest editor for the International Journal of Fatigue 1st and 2nd special issues on Additive Manufacturing in 2017 and 2019 and continues to organize multiple AM-related symposia and conferences in ASTM, TMS, and ASME.

Tue	Session 8A 15:45 -17:15	Room A
TOPIC: Symposium B - Innovations in Crack Detection Methods **Chair: Jürgen Bär**		
Ref:	Title and Author (s)	
072	Investigation of Crack Formation and Propagation in AA7475 using Multiple Potential Drop Measurement Jürgen Bär, Mike Nahbein	
104	On the exploitation of multiple 3D full-field pulsed ESPI measurements in damage location assessment Alessandro Zanarini	
187	Crack Tip Monitoring by Multiscale Optical Techniques Frederico Direito, Behzad V. Farahani, Pedro J. Sousa, Paulo J. Tavares, Pedro M. G. P. Moreira	
063	Quantitative Thermometry: A Revived Simplified Approach to Fatigue Strength Determination Florian Schäfer, Jan Rosar, Michael Marx, Haoran Wu, Peter Starke	
030	Hot spot stress analysis on steel 316L(N)-IG welded joints for nuclear applications Catarina Vidal, João Milheiro, Raul Luís, Virgínia Infante, Paulo Varela, Bruno Soares Gonçalves	

Tue	Session 8B 15:45 -17:15	Room B
Topic: Fatigue II **Chair: Luís Reis**		
Ref:	Title and Author (s)	
163	Influence of easy repair using plasma sintering and alumina particle on fatigue crack growth Daisuke Sasaki, Tomokazu Kiyonaga, Yuki Obukuro, Yuji Kawakami	
186	Combined approach for fatigue crack characterisation in metals J. M. Robles, J. M. Vasco-Olmo, A. S. Cruces, F. A. Diaz, M. N. James, P. Lopez-Crespo	
202	On the use of the plastic component of the CTOD for fatigue analysis in austenitic stainless steel M. Ajmal, C. Lopez-Crespo, A. S. Cruces, F. V. Antunes, P. Lopez-Crespo	
TOPIC: Symposium G - Multiaxial fatigue and VHCF: experimental, theoretical and numerical approach **Chair: Luís Reis, Manuel Freitas, Vitor Anes**		
065	Fatigue Damage Assessment in a Welded Tubular Joint Under Random Loading C. Ronchei, S. Vantadori, Andrea Carpinteri, Scorza Daniela, Andrea Zanichelli	
151	VHCF under biaxial loading of a mold tool steel Pedro R. da Costa, Luís Reis, Manuel Freitas	

Tue	Session 8C 15:45 -17:15	Room C
Topic: Concrete and Civil Structures I **Chair: Paulo Lobo**		
Ref:	Title and Author (s)	
096	Numerical modeling of a masonry arch structure Khalil Naciri, Issam Aalil, Ali Chaaba, Muzahim Al-Mukhtar	
122	Assessment of potential alkali-silica reactivity of aggregates for concrete João Custódio, Dória Costa, António Santos Silva, António Bettencourt Ribeiro	
134	Estimation of maximum temperature attained during concrete cure for internal sulfate reaction prevention in structures João Custódio, Manuel Vieira, António Bettencourt Ribeiro, António Mesquita, Rodrigo Santos	
172	Modelling superelastic SMA bars using OpenSees Mariana Jesus, Paulo Silva Lobo, Rui Marreiros	
204	Structural integrity of hot bituminous mixtures for road pavements: mechanical and environmental factors governing fatigue & fracture Jesús Toribio, Rubén Tino, Beatriz González, Juan-Carlos Matos	

Wednesday, 1st September 2021

WED, 08:30 - 09:00	PLENARY LECTURE V	Room Lisboa
Differences in Mechanical Behavior between Additively and Conventionally Manufactured Metallic Materials **Prof. Youshi Hong** Chinese Academy of Sciences, China Chair: Pedro Moreira, INEGI		

Prof. Dr. Youshi Hong

Institute of Mechanics, Chinese Academy of Sciences, Beijing 100190, China

Youshi Hong is a Professor in the Institute of Mechanics (IMECH), Chinese Academy of Sciences (CAS). He was the Director of IMECH-CAS between 1998 and 2006. He has been the Editor-in-Chief for Fatigue & Fracture of Engineering Materials & Structures (FFEMS) since 2012. He was elected as an academician of Asia Pacific Academy of Materials Science in 2017.
His research fields are mechanical behavior of materials, fracture mechanics and structure mechanics. His main research achievements are related to: high-cycle and very-high-cycle fatigue behavior of metallic materials; effects of second phase particles on deformation, fracture and stress corrosion cracking of steels; analyses of stress intensity factors and plastic zone sizes for notch-cracks and fatigue crack growth from a circular notch under biaxial stress; mechanism and modeling of collective damage evolution process of initiation and propagation for short fatigue cracks; mechanical behavior of nano-crystalline metallic materials; and dynamic response and prototype design of submerged floating tunnels. He has published 330 papers in academic journals and conference proceedings, and obtained 17 Chinese patents. He received a First Grade Award of Natural Science of CAS, a National Second Grade Award of Natural Science, a Second Grade Award of Natural Science of Chinese Society of Theoretical and Applied Mechanics, and a First Grade Award of Science and Technology of China Highway & Transportation Society.

Wed	Session 9A 09:00 -10:30	Room A	Wed	Session 9B 09:00 -10:30	Room B	Wed	Session 9C 09:00 - 10:30	Room C
TOPIC: Symposium F – Failure Analysis **Chair: Virginia Infante and Manuel Freitas**			**Topic: Fracture and Fatigue I** **Chair: José Correia**			**Topic: Concrete and Civil Structures II** **Chair: Paulo Lobo**		
Ref:	Title and Author (s)		Ref:	Title and Author (s)		Ref:	Title and Author (s)	
016	Fracture analysis of a leaf spring of a wagon railway car M. Freitas, V. Infante, M. Fonte		189	Experimental evaluation of the stress intensity factors, T-stress and higher order coefficients of the Williams series expansion by digital photoelasticity method and finite element analysis Larisa Stepanova, Oksana Belova		070	NLFEA based design optimization of GFRP stirrups in partially confined concrete Djenad Sonia, Ait Taleb Souad, Si Salem Abdelmadjid, Bouzidi M. Amin	
017	Failure analysis of a parabolic spring belonging to a railway wagon V. Infante, M. Freitas, R. Baptista		021	High Resolution Crack Tip Displacement Field Applications Using Numerical Methods R. Baptista, V. Infante, M. Garcia, C. Esteves, D. Braga, B. Farahani, P. Moreira		026	Analysis and Construction of Transfer Structures: a Case Study Gonçalo Ribeiro, João Almeida, Paulo Silva Lobo	
045	In service failure of a signal-support bridge structure for traffic signaling Mihaela Iordachescu, Andrés Valiente, Maricely de Abreu		048	Integrity evaluation of a reactor pressure vessel based on a sequential Abaqus-FRANC3D simulation method M. Annor-Nyarko, Hong Xia		069	3D simulation models for developing digital twins of heritage structures: challenges and strategies A. Shabani, M. Skamantzari, S. Tapinaki, A. Georgopoulos, V. Plevris, M. Kioumarsi	
046	Graphite debonding in compacted graphite iron under thermal loading: 3d microstructure-based modelling Evangelia Nektaria Palkanoglou, Konstantinos P. Baxevanakis, Vadim V. Silberschmidt		081	Global and local fracture behavior in a brittle solid with a set of pre-existing small-scale cracks Koji Uenishi, Kunihiro Nagasawa		087	Study of rock dilation effect on oil recovery during steam-assisted gravity drainage A. Kostina, M. Zhelnin, O. Plekhov	
049	Failure Analysis of FRP Composites Exposed to Real Marine Environment Goran Vizentin, Goran Vukelić		191	Nonlinear eigenvalue problems arising from nonlinear fracture mechanics problems Larisa Stepanova, Ekaterina Yakovleva		173	Accuracy of models of concrete in circular columns using different proposals for the prediction of failure of the confining FRP Paulo Silva Lobo, Mariana Jesus	
084	Effect of testing frequency on fatigue behavior of base materials AA2024, Ti-6Al-4V and Inconel 718 Ruslan Kuliiev, Stefan Riekehr, Volker Ventzke, Nikolai Kashaev		208	Micro- and nano-structural integrity of cold drawn pearlitic steels: drawing-induced evolution of intracolonial micro-defects Jesús Toribio, Francisco-Javier Ayaso, Antonio Fernández-Viña				
152	Effect of WC-Co Grade on Heading Die Performance in Cold Forging M. Burak Toparli, İlhan Burak Özhan							

Wednesday, 10:30 - 10:45	COFFEE-BREAK	

Wed	Session 10A 10:45 -12:15	Room A
Topic: Symposium F – Failure Analysis Chair: Virginia Infante and Manuel Freitas		
Ref:	Title and Author (s)	
088	Damage assessment of CFRP laminate plate subjected to close-range blast loading: hydrocode methodology validation and case study A. Vescovini, L. Lomazzi, M. Giglio, A. Manes	
110	Failure Analysis of a Ball Mill located in a Cement's Production Line Alexandre Fragoso, Rui F. Martins, António Soares	
123	Oil transmission pipelines with corrosion defects reinforced by two types of sleeves: comparison efficiency of sleeves Jan Kec, Ivo Černý, Adam Poloch, Barbora Kyselá, Miloslav Poupa, Přemysl Kuchař	
165	A Study on Tensile Strain Limit Evaluations Using Failure Assessment Diagrams for IMU Pipeline Bending Strain Assessment Enyang Wang, Rick Gailing, Aaron Dinovitzer, Francisco Bernal, Juan Mora	
112	Cyclic compression behavior of multilayered polymeric nanostructured foams: FEM simulation and experimental testing Ignacio Gutiérrez Montero, Raffaella Sesana, Sebastián D'hers, Fabrizio Scarpa	
160	Probabilistic Method to estimate the Scatter of the Fatigue Strength of Shafts in the HCF-region Sebastian Vetter, Alexander Hasse	
052	Failure behavior of human trabecular bone Ekaterina Smotrova, Simin Li, Mikhail Tashkinov, Vadim V. Silberschmidt	

Wed	Session 10B 10:45 -12:15	Room B
TOPIC: Symposium K – Impact and High Strain Rate Testing of Engineering Materials and Structures Chair: Giuseppe Catalanotti, José Xavier, and Fabrice Pierron		
Ref:	Title and Author (s)	
033	Frontal impact on a coach, door sub-system numerical modelling Rogério Lopes, M. P. L. Parente, P.M.G.P. Moreira, Rafael Cunha, Ricardo Maia, Rui Rodrigues	
145	Dynamic delamination resistance of electrically modified composites Sahand P. Shamchi, Marcelo F.S.F. de Moura, Zhongjie Zhao, Xiaosu Yi, Pedro M.G.P. Moreira	
201	On material identification of Pinus pinaster Ait. at high strain rate loading by the image-based inertial impact test F.G. Cunha, R. Nunes, L.C. Fletcher, J. Xavier, F. Pierron	
082	The effect of confinement and material heterogeneities on the dynamics of a granular medium subjected to impact loading Koji Uenishi, Dongyun Xi	
180	Custom control system for Split Hopkinson Pressure bars Pedro J. Sousa, Rogério Lopes, Pedro M. G. P. Moreira	
181	Impact characterization of bio-based sandwich panels with cork core P. Santos, N. Bouhemame, P.N.B. Reis, A. Bezazi	

Wed	Session 10C 10:45 -12:15	Room C
Topic: Monitoring Chair: Paulo Tavares		
Ref:	Title and Author (s)	
038	Displacement monitoring of crossbeams in an airport runway extension using digital image correlation Francisco Barros, Susana Aguiar, Pedro J. Sousa, António Cachaço, Nuno V. Ramos, Paulo J. Tavares, Pedro M. G. P. Moreira, Min Xu, L. Oliveira Santos, Elsa Franco	
039	Structural monitoring of a breakwater using UAVs and photogrammetry António Cachaço, Pedro J. Sousa, Francisco Barros, Paulo J. Tavares, Pedro Moreira, Rui Capitão, Maria Graça Neves, Elsa Franco	
188	Displacement monitoring of a pedestrian bridge using 3D digital image correlation Francisco Barros, Susana Aguiar, Pedro J. Sousa, António Cachaço, Paulo J. Tavares, Pedro M. G. P. Moreira, D. Ranzal, N. Cardoso, N. Fernandes, R. Fernandes, R. Henriques, P.M. Cruz, A. Cannizzaro	
174	Evaluation Framework for Tensile Measurements, based on Full-Field Deformation Measurements and Digital Twins Fekete, Tamás	
068	Acousto-Ultrasonic Investigation of corrosion in CORTEN steel by Deep Learning Neural Network approach Claudia Barile, Caterina Casavola, Giovanni Pappalettera, Vimalathithan Paramsamy Kannan	
114	Method of Coaxial Accelerometers Correlation for Quality Assessment of Structural Joints D. Serdjuks, V. Kurtenoks, A. Tatarinov, V. Mironovs, V. Lapkovskis, K. Buka-Vaivade, A. Macevičs, K. Topcijs, M. Vilnitis	
115	Non-model vibration analysis methods for health monitoring of structural joints V. Lapkovskis, V. Kurtenoks, K. Buka-Vaivade, D. Serdjuks, V. Mironovs, A. Tatarinov, A. Podkoritovs	

Wednesday, 12:15 - 13:30	**LUNCH**	

WED, 13:30 - 14:00	PLENARY LECTURE VI	Room A
More Steps Towards an Innovative Concept of Structural Integrity: Between Leonardo da Vinci and Galileo Galilei **Prof. Prof. Jesús Toribio** University of Salamanca, Spain Chair: José Correia, INEGI		

Prof. Jesús Toribio

University of Salamanca, Spain

Professor Jesús Toribio graduated in Civil Engineering in 1982 and then in Mathematics in 1986. In 1987 he was awarded his PhD in the Polytechnic University of Madrid (UPM) and turned into Associate Professor in that Institution. In 1992 he became Full Professor and Head of the Materials Science Department of the University of La Coruña (at the age of 32, thus being the youngest Full Professor in the area of Materials Science in Spain). In 2000 he moved to the University of Salamanca (USAL) where is currently Full Professor of Materials Science and Head of the Fracture and Structural Integrity Research Group (FSIRG) of that Institution.

His research work is mainly concerned with fatigue and fracture mechanics, environmentally assisted cracking, stress corrosion cracking and hydrogen embrittlement/degradation/damage of metals and alloys (mainly cold drawn pearlitic steel wires for civil engineering and austenitic stainless steels for nuclear engineering and energy applications), covering theoretical, computational and experimental aspects. He actively participates in International Conferences, very often being member of the International Advisory Committee, organising Special Sessions/Symposia, being Session Chairman or delivering Plenary/Keynote/Invited Lectures. Professor Dr. Jesús Toribio has published more than 500 scientific papers, most of them in international books and journals.

He is the Chairman of the Technical Committee 10 (TC10): Environmentally Assisted Cracking of the European Structural Integrity Society (ESIS) and has been Director (2013-2017) of the International Congress of Fracture-The World Academy of Structural Integrity (ICF-WASI), being responsible of launching the Ibero-American Academy of Structural Integrity (IA2SI). Prof. Toribio has been awarded a variety of scientific research prizes and awards including: (i) UPM Young Scientist Award of the Polytechnic University of Madrid; (ii) METROTEC Award for the best Technological Research Project; (iii) Honour Medal of the Spanish Group of Fracture (GEF/SEIE) in recognition of his research achievements in the field of fracture mechanics; (iv) Fellow of the Wessex Institute of Technology (WIT) in recognition of leadership and outstanding work in engineering sciences; (v) Top Reviewer 2011 in recognition of an outstanding contribution to the quality of the Elsevier International Journal Engineering Fracture Mechanics; (vi) Fellow of the European Structural Society (ESIS Fellow) for his outstanding contributions to the art, science, teaching or practice of fracture mechanics and his service to the society; (vii) Honorary Member of the Italian Group of Fracture (IGF) in acknowledgement and appreciation of his outstanding achievements in the research field of fracture mechanics; (viii) Best Paper and Presentation Award in the International Conference on Energy Materials and Applications (ICEMA 2017) held in 2017 in Hiroshima, Japan, with a paper entitled: Numerical Simulation of Hydrogen Diffusion in the Pressure Vessel Wall of a WWER-440 Reactor; (ix) María de Maeztu Scientific Award of the University of Salamanca (800th anniversary during 2018) in recognition of academic trajectory and excellence in scientific and technological research.

Wed	Session 11A 14:00 -15:30	Room A	Wed	Session 11B 14:00 -15:30	Room B			
Topic: Testing **Chair: Luís Borrego**			**TOPIC: Sponsors Technical session** **Chair: Paulo Tavares**					
Ref:	Title and Author (s)		Ref:	Title and Author (s)				
080	PU tensile tests: conventional and digital image correlation analysis Flaminio C. P. Sales, Ronaldo M. Ariati, Verônica T. Noronha, Romeu R. C. da Costa, João E. Ribeiro		219	Fatigue Testing at 1000Hz Testing Frequency Markus Berchtold				
198	Influence of ester on the mechanical hysteresis characteristic of power transformer insulation components Daniel F.O. Braga, E. E. Almeida, Shayan Eslami, Ricardo Lopes, Pedro M.G.P. Moreira		220	An Automatic System for Residual Stress Measurements by Hole Drilling Alessio Benincasa, Emilio Valentini, Simone Gulisano, Enrico Boccini				
158	Development of a small-scale testing machine for use with interferometric monitoring methods Pedro J. Sousa, Shayan Eslami, Frederico Direito, Pedro M. G. P. Moreira		221	High-speed imaging options in material and component testing Tim Nicholls				
157	Adherend effect on the peel strength of a brittle adhesive J.P.O. Pereira, R.G.S.G. Campilho, F.J.G. Silva, D.C. Gonçalves		222	Advanced Mechanical Surface Characterization João Cascalheira				
211	Review and synthesis of stress intensity factor (SIF) solutions for elliptical surface cracks in round bars under tension loading: A Tribute to Leonardo Torres-Quevedo Jesús Toribio, Beatriz González, Juan-Carlos Matos							
212	Review and synthesis of stress intensity factor (SIF) solutions for elliptical surface cracks in bolts under tension loading: A Tribute to Juan de la Cierva Jesús Toribio							

Wednesday, 15:30 - 15:45	COFFEE-BREAK	

Wed	Session 12A 15:45 -17:15	Room A	Wed	Session 12B 15:45 -17:15	Room B			
Topic: Fracture Mechanics II **Chair: Pedro Moreira**			**Topic: Large Structures** **Chair: Francisco Melo**					
Ref:	Title and Author (s)		Ref:	Title and Author (s)				
071	Overloading effect on transient fatigue crack growth of TiAl6V4 parts produced by Laser Powder Bed Fusion L. Borrego, J. Jesus, J.M. Ferreira, C. Capela, J.D. Costa		171	The Fundaments of Structural Integrity of Large-Scale Pressure Systems Fekete, Tamás				
192	An effective scheme for solving a class of nonlinear boundary value problems of stress concentration through quasilinearization approach Larisa Stepanova, Ramil Zhabbarov		024	Numerical and Theoretical Modal Analysis of Transit Buses Rogério Lopes, Behzad V. Farahani, Francisco Q. de Melo, Nuno V. Ramos, P. M. G. P. Moreira				
209	A fracture criterion for cold drawn pearlitic steel cracked wires with elliptical surface cracks of different aspect ratios: A Tribute to Eduardo Torroja Jesús Toribio		025	A Numerical Dynamic Analysis of a Multi-Body Bus Rogério Lopes, Behzad V. Farahani, Francisco Q. de Melo, Nuno V. Ramos, P. M. G. P. Moreira				
210	A fracture criterion for cold drawn pearlitic steel notched wires with circumferentially-shaped notches of different geometries: From Eduardo Torroja to José Antonio Torroja Jesús Toribio, Francisco-Javier Ayaso		142	A Study on the Passive Safety Solution on Transit Buses According to Regulation No. 66 of UN/ECE Behzad V. Farahani, Nuno V. Ramos, Pedro M. G. P. Moreira, Rafael Cunha, André Costa, Ricardo Maia, Rui. M. Rodrigues				
193	Constraint effect on fracture toughness resistance curves of an X60 pipe steel Cheng Qian, Jie Liang, Yifan Huang, Jidong Kang, Jim Gianetto		218	A review of fatigue damage in offshore wind turbine structures D. Haselibozchaloe, P. Mendes, J.A.F.O. Correia, M. Correia, A.M.P. Jesus, Filippo Berto				
			217	Effects of normalizing heat treatment on the mechanical and magnetic properties of an ancient iron bridge Lucas Benini, Iara Oliveira, Juan Pardal, Leosdan Noris, José Correia, Filippo Berto				

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ICSI 2021 The 4th International Conference on Structural Integrity

Editorial

Pedro Moreira, Paulo J. Tavares

INEGI – Institute of Science and Innovation in Mechanical and Industrial Engineering, Porto, Portugal

Research activity in Structural Integrity has seen an uprise in recent years and spread throughout a number of exciting areas. ICSI focuses on all aspects and scales of structural integrity, ranging from basics to future trends, with special emphasis on multi-scale and multi-physics approaches, and applications to new materials and challenging environments. Current research topics targeted by ICSI include, but are not limited to Fatigue and Fracture, Stress Analysis, Damage Tolerance, Durability, Crack Closure, Joining Technologies, Nanomechanics and Nanomaterials, Ageing, Coatings Technology, Environmental Effects, Structural Health Monitoring, New materials, Surface Engineering, Structural Integrity in Biomechanics and many other exciting research topics.

In 2021, in spite of the pandemic which affected the entire R&D community and forced ICSI to go online, an effort was made to keep the momentum generated in the previous editions, increasing the visibility to the conference and its scientific impact. ICSI2021 invited a number of prominent researchers which accepted to lecture on their own fields, such as Prof. Sabrina Vantadori from the University of Parma, Prof. Fabrice Pierron from Southampton University, Prof. Milos Djukic from the University of Belgrade, Profs. Nima Shamsaei and Shuai Shao from Auburn University, Prof. Youshi Hong from the Chinese Academy of Sciences and our dear friend Prof. Jesus Toribio from the University of Salamanca.

ICSI2021 has been organized into a general track and thematic symposia, as in previous editions. Apart from the publication of the proceedings in Procedia Structural Integrity, special issues were also arranged in Engineering Failure Analysis and the International Journal of Fatigue, both highly relevant in the field of Structural Integrity.

The response to the organization efforts has been outstanding: Fourteen symposia were proposed and accepted; the number of submissions was kept at a similar level to 2019, with 206 approved oral communications out of 224 submissions, from 38 countries; approximately 25% of the approved communications were submitted by students, an important landmark for the organizers, who strived to create favourable conditions for greater student involvement.

The biennial ICSI conferences, at the end of summer, were planned to be a reference source of inspiration for the researchers in the field that want to keep abreast current R&D results and the outstanding response of the delegates in times of turmoil didn’t let us down. The conference has seen a steady growth in quality and we welcome the reader to judge the excellence of the conference by himself and whether he should attend ICSI in 2023.

Above all, the organizers believe the ICSI conferences disseminate excellent research and share important knowledge for the enhancement of science and the prosperity of our society, and therefore actively contribute to the preservation and sustainability of our world.

The Conference Chairs,
Pedro M. G. P. Moreira
Paulo J. S. Tavares

, Index Combination for Damage Localization using Genetic Algorithm

Elizabeth K. Ervin[1], Chuangshuo Zeng[1]

[1]*Civil Engineering, University of Mississippi,106 Carrier Hall, Box 1848, University, MS 38677, USA, eke@olemiss.edu*

Structural Health Evaluation *Damage Detection Index* *Genetic Algorithm*

Abstract Inspection on infrastructure has a set return period to ensure structural integrity over time. In order to reduce time, cost, and error, vibration data can be analyzed to reveal internal changes, perhaps including defects. Modal properties extracted from acquired structural responses, such as acceleration or velocity, strongly correlate with structural health status. Literature has reported single quantitative measures that are useful for certain structures with particular damage, but publications rarely focus on using three-dimensional data in their metrics. Due to the variety of civil infrastructures, damage mechanisms can vary widely such that a single index will be insufficient.

This paper establishes a genetic algorithm (GA)-based damage detection scheme (Figure 1) to address current issues regarding damage indices. The use of directional index resultants is also introduced to provide inputs for a GA framework that optimizes detection accuracy of both location and severity. Synchronous or asynchronous time histories of measured responses are acquired for two states (e.g. baseline and subsequent inspections, pre- and post-event, as-built and aged). Modal analysis is independently performed for both states, and matched dynamic modal properties are used to generate 51 directional Damage Indices (DIs). These uni-axial DIs are used to generate the 24 tri-axial resultant DIs. Then the genetic algorithm (GA) fits the normalized resultant DIs to a binary target vector to optimize the damage detection result. The critical threshold is found by three rounds of analysis, and the outputs are both best DI and optimized damage locations. Multiple criteria are used to evaluate this novel methodology's performance both quantitatively and qualitatively.

As proof-of-concept, a steel frame's model output is analyzed when Young's modulus E is reduced. The damaged member is successfully identified (a 60% E reduction showing a 94% change), and the most effective DI is Z-score resultant strain energy ZjR. Detection thresholds are found as a variation of 36% between the undamaged and damaged nodes and an average fitness value of 2.3%. Here, the limit of undetectable damage level was an E reduction of 0.001% due to the modeled time histories with 5% Gaussian noise.

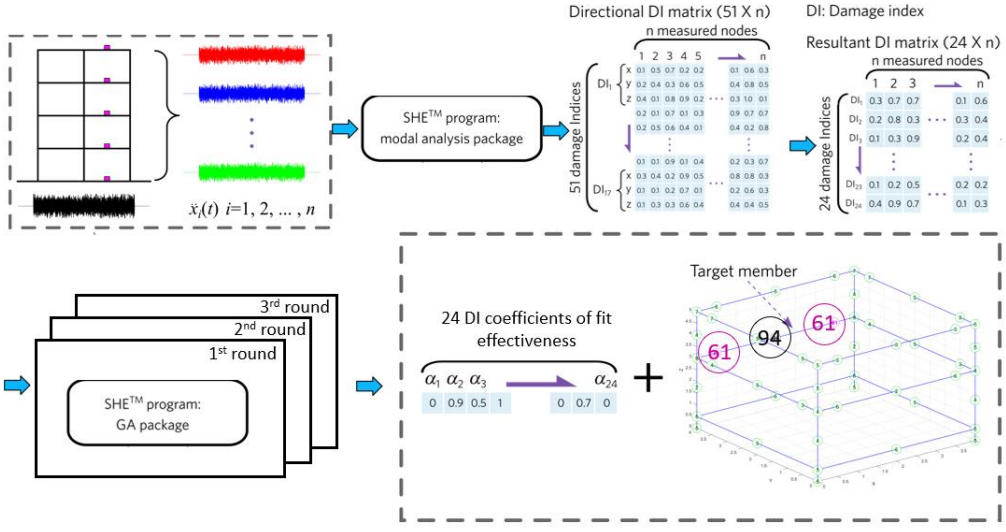

***Figure 1** – optimized change detection methodology*

Experimental Investigations on Stiffened and Web-core Sandwich Panels Made for Steel under Quasi-Static Penetration

Jani Romanoff[1], Mihkel Kõrgesaar[2], Pauli Lehto[1], Kennie Berntsson[1] and Heikki Remes[1]

[1] Marine Technology, Department of Mechanical Engineering, Aalto University, Finland

[2] Estonian Maritime Academy, Tallinn University of Technology, Tallinn, Estonia

Steel panels *Crashworthiness* *Large Structure*

Abstract Analysis of the dynamic response of ships in collisions requires a realistic idealization of environmental and operational conditions by models suitably idealizing external and internal mechanics in which the interaction between these two is modelled through contact force -penetration relationship. This paper investigates experimentally this relationship with quasi-static experiments on single-sided stiffened and double-skinned steel sandwich panels. These two structures were exposed to variety of boundary and load-conditions. In addition, the effect of as-produced curvature of the panels was considered. Three repetitions were carried out per test and experiment was carried out until fracture occurred resulting in dramatic drop in the contact force. Results reveal the importance of uncertainties associated with the loading, material and structural gradients of the panels. When physical variations on these gradients occur at the same location geometrical location in the panel, dynamics prevail in seemingly quasi-static load case. This leads to drastic changes in the resulting load-carrying mechanism and energy dissipation. It is therefore concluded that spatial and temporal discretization may influence dynamic response when for example Finite Element Simulations of these experiments are carried out

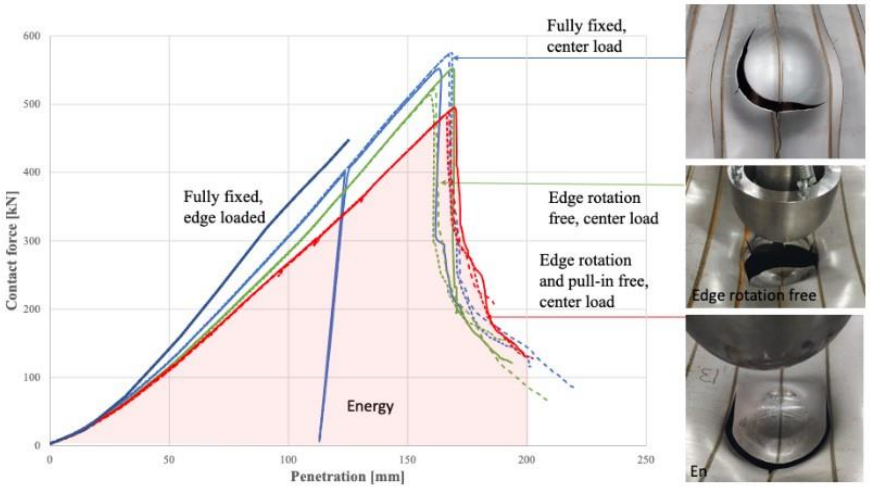

***Figure 1** – Test results on stiffened steel panels.*

, Identification of orthotropic elastic properties of wood by digital image correlation and finite element model updating techniques

J. Henriques[1] *, J. Xavier[2], A. Andrade-Campos[1]

[1]*Department of Mechanical Engineering, Centre for Mechanical Technology and Automation, University of Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal*

[2]*UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, NOVA University Lisbon, 2829-516 Caparica, Portugal*

**joaodiogofh@ua.pt*

Wood *Digital image correlation* *Inverse identification*

Abstract Wood and wood-based products have been gathering relevance across the globe due to policies of sustainability and green economy. Wood can be modelled as a hierarchical material. Despite the mechanical characterization of several major species at the macro and structural scales, information addressing material properties at the mesoscale of the annual growth rings is still very scarce in the literature. Computer-aided engineering systems rely on constitutive models and their material parameters to describe the material behaviour. Moreover, the simulation of processes by finite element analysis (FEA) is well established. However, the calibration of the material constitutive models is still facing open challenges. This identification process grows in complexity for more elaborated material models, increasing the number of experimental tests needed, which proves to be a time-consuming process due to exhaustive experimental campaigns. To tackle this issue, it is required to use inverse identification techniques that can simplify the experimental campaign without compromising the accuracy of the models. Recently, with the improvement of digital image technology, there has been a growing interest in the use of full-field measurements techniques, such as digital image correlation (DIC) and the grid method. This fact has highlighted a new methodology on inverse identification techniques such as the Virtual Fields Method (VFM) and Finite Element Model Updating (FEMU) method. This work aims to identify linear elastic constitutive parameters of *Pinus Pinaster* Ait. wood using uniaxial compressive experimental tests, under quasi-static loading conditions, with on-axis rectangular specimens oriented in the radial-tangential (RT) plane. Several images of the experimental tests were recorded by a digital camera, further processed by DIC. As a result, heterogenous full-field displacement and strain maps with strain gradient fields at the wood growth ring scale were obtained and used to identify the material parameters, such as modulus of elasticity, *Poisson*'s ratio, and shear modulus. The identification was done using FEMU by the minimization of a cost function that describes the difference between the experimental and FEM results, including the load and strain fields. This work was carried out considering wood as an orthotropic homogeneous material, resulting in four material parameters to be identified. In this study, the elastic properties of wood were determined for the RT plane.

, Flexural behavior of prefabricated composite beams with twin I-girders

Rong Liu, Hao Zhao

College of Civil and Transportation Engineering, Hohai University, Nanjing 210098, China

Composite bridge structure *Accelerated bridge construction* *Finite element analysis*

Abstract: Composite beams composed of a reinforced concrete slab and I-shaped steel girders are competitive for short and medium-span bridges due to the higher strength, the lighter self-weight, and the fewer economic cost. A new generation of prefabricated composite Π-shaped beams, consisting of beam modules with the concrete slab supported by twin I-girders, is developed for city viaducts built by the accelerated bridge construction (ABC) method. The beam module is prefabricated in factories by casting concrete slab and concrete cross beams at the supporting sections to connect the twin steel girders. The I-shaped steel girder is designed without web stiffeners and inter-span cross beams which are crucial components in normal composite beams.

Since few design specifications for the prefabricated composite Π-beams are available and limited numbers of the beams have been tested, this paper conducts a full-scale numerical analysis to predict the bearing resistance and deformation performance of the beams. The non-linear finite element model is verified by literature-reported test results. The elastoplastic behavior of the beam subjected to four-point bending is studied. The influences of material strength, plate thickness, flexible interface connection, and transverse supporting are discussed.

Results have shown that the initial design without intermediate cross beams shows elastic behavior under the adverse maximum load combination, as shown in **Fig. 1**. The bending moment is about 20% lower than the elastic limit for the middle beam, and 15% lower for the side beam. The plastic failure is obtained, as shown in **Fig. 2**. The composite Π-beams have sufficient safety margin for practical use.

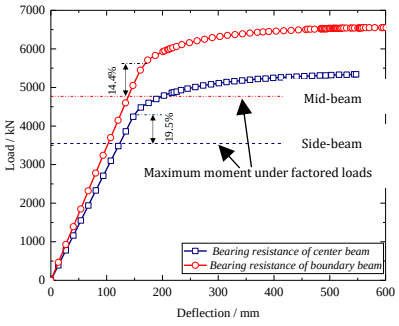

Fig. 1. Load-displacement curve of composite Π-beams

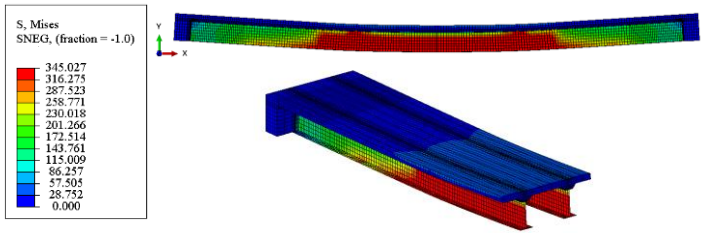

Fig. 2. Failure mode of composite Π-beams (MPa)

In situ monitoring of wire and arc additive manufacturing by digital image correlation: a case study

Filipa G. Cunha, Telmo G. Santos, José Xavier

UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, NOVA University Lisbon, 2829-516Caparica, Portugal, fa.cunha@campus.fct.unl.pt (F.G.C.); telmo.santos@fct.unl.pt (T.G.S.); jmc.xavier@fct.unl.pt (J.X)

Digital image correlation *In situ Additive manufacturing*

Abstract

This paper presents a case study addressing in situ monitoring during wire and arc additive manufacturing (WAAM) by means of digital image correlation (DIC).

WAAM is an additive manufacturing (AM) process that requires the deposition of consecutive layers of molten material. This creates several non-homogeneous thermal cycling that affects underneath layers. For this reason, high residual stress can be developed, generating distortions in the parts. In addition, manufacturing defects may occur in the produced parts. Non-destructive testing can be employed to assist the WAAM process. Among them, DIC can be used for in situ monitoring during the technological process. Nevertheless, several adverse conditions must be properly addressed [1]: (1) high-intensity electromagnetic radiation; (2) high temperature reached in the inspection surface; (3) sparks and projection of melted metal.

A sample was firstly produced by WAAM using a Metal Active Gas (MAG) welding power source PRO MIG 3200 from KEMPY. The wire feed speed was about 4 m/min, the travel speed was about 350 mm/min and the length of the produced samples was 130 mm, using a 1 mm wire diameter AISI316L stainless steel as a feedstock material. The voltage and the electric current prescribed were 20 V DC and 120 A, respectively. A speckled pattern was painted on the base part. The optical system consisted of a Manta G-1236 Allied Vision CMOS camera with a Nikon AF Nikkor 28-105 mm lens. The DIC analysis was carried out using the MatchID software. In this study, the following DIC setting parameters were used: subset size of 41×41 pixels; subset step of 10×10 pixels; ZNSSD correlation criterion; bicubic splines image grey level interpolation; affine shape functions; strain window of 5×5 control points; displacement approximation using bilinear (Q4) Lagrange polynomials; Green-Lagrange strain calculation algorithm.

In this case study, the problems of high-intensity electromagnetic radiation and melted metal projections were solved by placing a metallic bulkhead in front of the electric arc. This metallic bulkhead allowed radiation and projections not to damage the images captured quality by the DIC camera. This study shows that DIC optical technique evidence feasibility to be used in the future for in situ monitoring of WAAM process.

References

[1] Cunha, F.G.; Santos, T.G.; Xavier, J. In Situ Monitoring of Additive Manufacturing Using Digital Image Correlation: A Review. *Materials* **2021**, *14*, 1511. https://doi.org/10.3390/ma14061511

, Experimental study on fatigue crack propagation of octet-truss lattice

Yifan Li, Martyn Pavier, Harry Coules

Department of Mechanical Engineering, University of Bristol, Queens Building, University Walk, Bristol BS8 1TR, UK, ***yifan.li@bristol.ac.uk***

Octet-truss lattice *Different orientations* *Fatigue crack growth*

Abstract Octet-truss lattice materials are widely used as lightweight structures because of the superior mechanical properties like high strength-to-density ratio. Deeply and extensively studies have been done on its static mechanical properties. While, lattice structures in real applications are frequently subjected to cyclic mechanical or thermal loadings, so fatigue failure is one of the most common failure modes of lattice structures. It is important to understand the fatigue crack growth of octet-truss lattices in different orientations. In this research, octet-truss lattices were fabricated in three different orientations (see in Figure 1(a)) by stereolithography additive manufacturing. Octet-truss lattices were printed in CT specimen type (see in Figure 1(b)) to conduct tensile fatigue experiment with clip gauge. The displacement-cycle diagram of octet-truss lattice is similar to corresponding curves of lattice under compression-compression fatigue load, showing three-stage fatigue behavior. The crack lengths of specimens were calculated using compliance method sugessested by ASTM E647. The polynomial fitting method was used to reduce unsmoothness and fluctuation in the curves (Figure 1(d)). Finally, the fatigue crack growth rates of different orientation lattices were obtained by secant method shown in Figure 1(e). The fitted curves of crack growth rates of different orientation lattices were nearly horizontal, but crack in orientation-Y lattice grows fastest under the same ΔK and orientation-Z lattice has the excellent resistance to fatigue crack propagation.

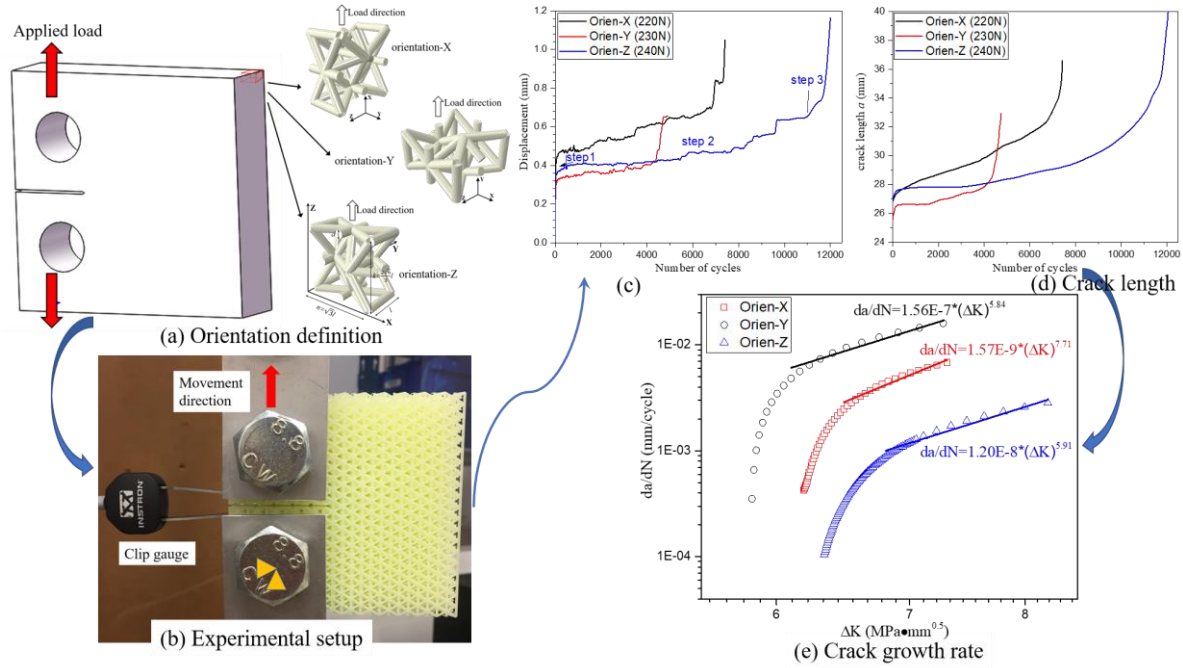

Figure 1 - *Definition of specimen orientations, test setup and results*

, **Fracture behaviour of octet-truss lattices in different orientations**

Yifan Li, Martyn Pavier, Harry Coules

Department of Mechanical Engineering, University of Bristol, Queens Building, University Walk, Bristol BS8 1TR, UK, ***yifan.li@bristol.ac.uk***

Octet-truss lattice *Different orientations* *Fracture behaviour*

Abstract The octet-truss lattice structure is a typical stretching-dominated lattice, with a unit cell of a nodal connectivity equal to 12. Comparing with bending-dominated lattices, stretching-dominated lattices have advantages in load bearing. Therefore, octet-truss lattice has great potential in lightweight structural applications. Recently, different studies have revealed the influence of orientations on mechanical behaviour, including strength and fracture toughness. However, there are few studies on the effects of different orientations on the fracture properties of octet-truss lattice, especially in experimental research. It is important to understand the fracture response of octet-truss lattices with different orientations under tensile load. The present research aims to investigate the mechanical behaviour and fracture response of octet-truss lattice in three different orientations (see in Figure 1(a)) by using both experimental and FE methods. Several octet-truss lattices in CT specimen type (see in Figure 1(b)) manufactured by stereolithography printing were investigated in three orientations. The fracture mechanisms and crack paths in three orientations were described in detail and compared with each other. The fracture resistances of orientation X, Y and Z lattices are 5.72, 8.52 and 8.49 $MPa\sqrt{mm}$, respectively. The crack paths for orientation X and Z specimens were almost horizontal. While, crack path of the orientation Y structure fluctuated up and down with 30° inclination. The numerical results also suit well with the test results including the load reaction and crack paths.

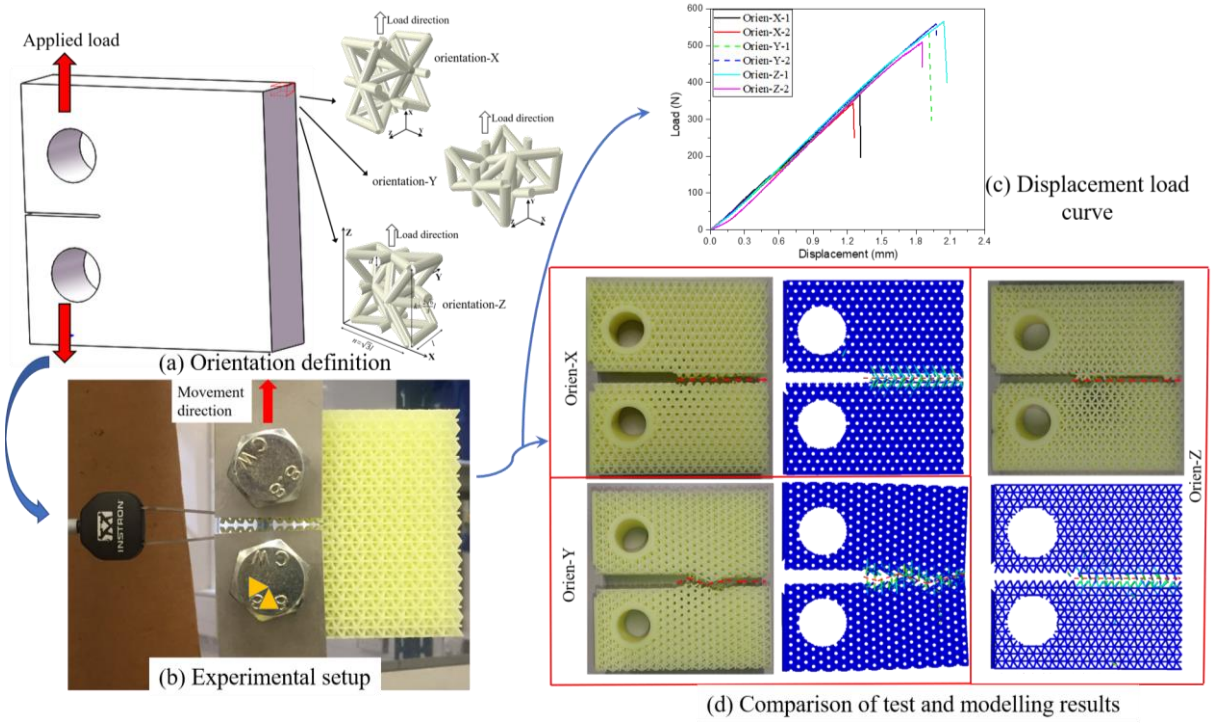

Figure 1 - *Definition of specimen orientations, test and modelling results*

' A prefabricated MVFT composite girder suitable for small-span bridge

Zhihua Xiong[1], Meng Li[1], Tianqi Wang[1], Yang Meng[1]

[1]College of Water Resources and Architectural Engineering, Northwest A&F University, Yangling, Shaanxi, China, zh.xiong@nwsuaf.edu.cn

MVFT *bridge* *girder*

Abstract Modified VFT (MVFT) girder is suitable for the bridge with a span range between 20~40m. The author has proposed the girder in the previous work in an arch bridge. The MVFT girder is evolved from VFT girder applied in bridge construction in German and other European countries. The advantages of MVFT girder compared with traditional concrete-steel composite girder include: accelerated construction speed, integral prefabricated etc. The construction analysis was carried out in this paper. Taking the bridge structure stiffness and steel cost into consideration, the live load structure index (LLSI) was introduced to evaluate the application efficiency of the steel bridge under different structural schemes.

, Aluminium to GFR Polymer Composite Joining through Friction Stir Welding

F. Dias[1], V. Infante[1], G. Cipriano[1], D. Braga[2], A. Correia[1], S. Eslami[2], P.M.G.P.Moreira[2]

[1]IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001

Lisbon, Portugal, virginia.infante@tecnico.ulisboa.pt

[2]INEGI, University of Porto, Rua Dr. Roberto Frias, 400, Porto, 4200-465, Portugal

Friction Stir welding *Dissimilar materials* *Composite/aluminium*

Abstract Joining of dissimilar structures or parts with tailor-engineered properties, in provision of the aerospace industry, is still a challenge concerning the achievement of sound joint quality and high productivity for cost-efficient manufacturing. Technologies currently established to join dissimilar structures are either too expensive, limited in performance or environmentally detrimental. The DisFri project aims at the development of technological solutions for dissimilar materials (composite/aluminium) joining on aerospace industry structures applying advanced mechanical welding technologies. The joining process selected is an important breakthrough welding technology: Friction StirWelding (FSW). FSW is a mechanical process delivering high quality assurance when technological conditions are correctly set-up. This welding process is clean, ecological, do not depend on operator skills and produce weld seams of the highest quality, while offer further advantage of being suitable for joining dissimilar materials that were previously impossible to weld by fusion methods. This paper presents the results obtained on aluminium to GFR polymer composite joining through Friction Stir Welding in order to provide indication on the correct welding procedure to be applied during production of dissimilar structures. Detail metallographic characterization of weld zone, hardness distribution at different zones of the weld region and the fracture surfaces are presented.

,

Fracture analysis of a leaf spring of a wagon railway car

M. Freitas[1], V. Infante[1], M. Fonte[1,2]

[1]IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisbon, Portugal, manuel.freitas@tecnico.ulisboa.pt

[2]Escola Superior Náutica (ENIDH), Av. Eng. Bonneville Franco, 2770-058 Paço de Arcos, Portugal

Metallographic analysis *Leaf spring* *Wagon railway car*

Abstract This abstract describes the study of a fractured leaf spring belonging to a two-axle wagon suspension system. In order to determine the causes of the failure, a material analysis was performed, followed by a detailed study of the fracture's surface both visually and using optical and scanning electron microscopies. The material analysis revealed that the high carbon steel was quenched and tempered; uniaxial tensile tests along the width of the leaf spring and hardness measurements were carried out and revealed that the material is under the specifications requested for the leaf springs. The observations of fracture surfaces of the leaf spring revealed that the fracture began in the central zone near the clamping system where the bending stress are maximum and between the leaf springs. The cause of the spring fracture was a fatigue process. The propagation of fatigue cracks is clearly observed through several beach marks in the fractured surface of the leaf spring. Several crack initiations were observed but only one crack caused the fracture of the leaf spring. The observation of crack initiation revealed that a process of surface corrosion was at the origin of some cracks but also cracks had the origin in the interior clearly after the initiation at the surface.

, Failure analysis of a parabolic spring belonging to a railway wagon

V. Infante[1], M. Freitas[1], R. Baptista[1,2]

[1]IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisbon, Portugal, virginia.infante@tecnico.ulisboa.pt

[2]CDP2T, Departamento de Engenharia Mecânica, Escola Superior de Tecnologia de Setúbal, Instituto Politécnico de Setúbal, Setúbal, 2910-761, Portugal

Numerical simulations *Parabolic spring* *Railway wagon*

Abstract This paper describes the study of three fractured parabolic springs belonging to a two-axle wagon suspension system. In order to determine the causes of the failures, a material analysis was performed, followed by a detailed study of the fracture's surface both visually and using optical and scanning electron microscopies. The observations of fracture surfaces of the three springs revealed that the fractures began in the contact zones between the leaf springs. The cause of the springs fracture was a fatigue process. The propagation of fatigue cracks is more pronounced and extensive in one of the leaf springs. Finite element analyses were also performed taking into account the service conditions in order to determine the stress and strain distribution along the leaf springs. From the numerical simulations it can be concluded that the maximum stresses occur in two different zones: in the central section of the leaf spring and along the distance to the central section, in the sections where the relationship between the thickness reduction of the leaf spring and the resulting bending moment is most unfavourable. The Goodman's criterion shows a safety factor of approximately 1 and it can be concluded that this value is not enough to prevent the fatigue failure.

Mechanical Behavior Analysis of a Galvanized Corrugated Steel Concrete Composite Arch Bridge Structure by FEM

Lei Xiao[1], Yang Zegang[1], Zhang Shicheng[1], Ye Tairu[1], Zheng Yuhan[1]

(1. College of Civil and Transportation Engineering, Hohai University, 1 Xikang Road, Nanjing 210098, China;)

Abstract: Galvanized corrugated steel sheet has been widely used in small span bridges and culverts in recent years. This paper introduced a design scheme and technical difficulties in construction about a galvanized corrugated steel concrete composite arch bridge. The mechanical properties of corrugated steel concrete composite arch under different loads were studied. The failure mode and bearing capacity of corrugated steel-concrete composite members under different compression-bending ratios, the strain distribution and development of corrugated steel plates at different positions were studied by finite element method, and the structural forms of corrugated steel were analyzed. The results provide theoretical support for the use of galvanized corrugated steel concrete composite arch bridge and contribute to the popularization of this new structure.

Keywords: Corrugated steel-concrete composite structure, Compression bending combination condition, Finite element simulation, Parameter analysis

Fatigue Crack Growth on Modified CT Specimens Using Artificial Neural Networks

R. Baptista[1,2], P. Moita[2,3], V. Infante[2]

[1]CDP2T, Departamento de Engenharia Mecânica, Escola Superior de Tecnologia de Setúbal, Instituto Politécnico de Setúbal, 2910-761 Setúbal, Portugal, ricardo.baptista@estsetubal.ips.pt

[2]IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

[3]CENTEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

Artificial Intelligence *Mixed Mode* *Crack Propagation*

Abstract The purpose of this paper is to analyze fatigue crack growth (FCG) under mixed mode conditions using artificial neural networks (ANN). Mixed mode conditions on a compact tension (CT) specimen are introduced using different diameter holes, placed on different positions. Initial crack length can also influence FCG creating an expensive problem to solve, due to the number of experimental or numerical simulations needed to be performed. To solve this problem an ANN was trained to predict FCG based on the specimen dimensions, hole location, initial crack length and material behavior. Finite element analysis (FEA) simulations were used to train the ANN, using the vector crack tip displacement (VCTD) propagation criterion. The crack propagates under proportional loading conditions, with R = 0.1, by calculating the crack propagation angle for each 0.5 mm crack length increment. The VCTD criterion has proven to be more accurate when predicting initial crack propagation angles, by using the crack tip normal and lateral displacements. Different ANN input and output variable combinations are tested for FCG prediction accuracy. Crack tip location can be directly predicted by the ANN or calculated using the predicted normal and lateral crack tip displacement values [1]. Once fully trained, the ANN was able to predict FCG paths under mixed mode conditions, using the VTCD criterion. The initial crack length, hole diameter and position affect FCG paths, but the trained ANN was able to predict their influence, reducing the overall number of FEA simulations necessary.

[1] Wang B, Xie L, Song J, Zhao B, Li C, Zhao Z. Curved fatigue crack growth prediction under variable amplitude loading by artificial neural network. Int J Fatigue 2021;142:105886. https://doi.org/10.1016/j.ijfatigue.2020.105886.

Fatigue crack propagation direction under different loading conditions using MTS and MSS criteria

R. Baptista[1,2], V. Infante[2]

[1]CDP2T, Departamento de Engenharia Mecânica, Escola Superior de Tecnologia de Setúbal, Instituto Politécnico de Setúbal, 2910-761 Setúbal, Portugal, ricardo.baptista@estsetubal.ips.pt

[2]IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

Maximum Tangential Stress *Maximum Shear Stress* *Fatigue Crack Growth*

Abstract Fatigue Crack Growth (FCG) plays a major role on structural integrity. When mixed mode fatigue crack propagation is introduced by complex geometry or loading conditions, numerical methods are essential for fatigue life determination. This paper explores the differences between two crack propagation models. Using an automatic fatigue crack growth algorithm and the finite element method (FEM), crack propagation on CTS and four-point bending specimens was simulated. Both specimens allow for pure mode I, mixed mode and pure mode II loading conditions. According to the maximum tangential stress criteria, fatigue crack propagation occurs along the direction where tangential stress is maximized. Comparing crack propagation results with literature, it was possible to conclude that this criterion can be used under pure mode I or mixed mode loading conditions. The maximum tangential stress (MTS) criterion was also compared to the maximum shear stress criterion (MSS), where crack propagation occurs along the direction that maximizes shear stress. Crack propagation directions between these criteria were compared and it was possible to conclude that the maximum shear stress criterion should be used for pure mode II loading conditions. Overall, this methodology allows for fatigue crack growth simulations under complex loading conditions.

, **High Resolution Crack Tip Displacement Field Applications Using Numerical Methods**

R. Baptista[1,2], V. Infante[2], M. Garcia[2], C. Esteves[2], D. Braga[3], B. Farahani[3], P. Moreira[3]

[1]CDP2T, Departamento de Engenharia Mecânica, Escola Superior de Tecnologia de Setúbal, Instituto Politécnico de Setúbal, Setúbal, 2910-761, Portugal, ricardo.baptista@estsetubal.ips.pt

[2]IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisboa, Portugal

[3]INEGI, University of Porto, Rua Dr. Roberto Frias, 400, Porto, 4200-465, Portugal

Crack tip *Displacement field* *Numerical methods*

Abstract Under monotonic and cyclic loading conditions, crack propagation is influenced by the elastic-plastic displacement field around the crack tip and the material behavior model. Both experimental and numerical approaches can be used to characterize and predict the strain and stress distributions when a crack is present. Photoelasticity has been used to characterize elastic stress fields around crack tips, but plastic and anisotropic effects are neglected by this technique. Displacement measurement-based analysis, like digital image correlation (DIC), allow for full elastic-plastic strain field determination. Finally, numerical methods, like the finite element analysis (FEA), provide full stress and strain fields, based on a given material model. This paper gives an overview on the development of a FEA model, able to calculate a high-resolution displacement, strain and stress fields, around a crack tip. In order to achieve a high-resolution field, the mesh should be extremely refined. This is achieved using a sub-modeling technique around the crack tip. Different material behavior models are used, both linear elastic and elastic-plastic. The crack is modeled based on real fatigue cracked specimen, and the model is used to predict the stress intensity factors, T-Stress and crack closure effect, based on different materials models. Both stress and strain fields were compared with analytical and experimental results.

SHM of a Foot Bridge in a Virtual Reality Environment

Furkan Luleci[1], Liangding Li[2], Jiapeng Chi[2],
Carolina Cruz-Neira[2], and F. Necati Catbas[1*]
[1]Department of Civil, Environmental, and Construction Engineering
[1]Department of Computer Science
University of Central Florida, Orlando, FL 32816, USA
catbas@ucf.edu

Keywords: VR, LiDAR, Photogrammetry, SHM

Abstract

In civil engineering, aging infrastructures require imminent attention before any failure mechanism forms on the structure. To that end, structural engineers, contractors, and inspectors work together during the Structural Health Monitoring (SHM) process of the structure. This often needs arranging an on-site meeting to better analyze the structure, which is both time-consuming and costly. Also, most of the time, being present on the real structure poses danger and requires personal protective equipment. This particularly holds true during the visual inspection of the unreachable areas of the structure. For this purpose, our Virtual Reality (VR) model aimed to bring the structure into the office. In this work, we present an SHM system in a VR environment that includes all the technical and visual information necessary to the engineers and inspectors and other related parties related to the footbridge we chose on campus at the University of Central Florida. In this VR model, for the visualization stage, UAV photogrammetry and LiDAR (Light Detection and Ranging) methods are used to capture the real asset. For the technical assessment stage, Finite Element Analysis (FEA) and Operational Modal Analysis (OMA) from collected operational acceleration data are performed. To better visualize the dynamics of the structure, the operational behavior from FEA is reflected on the LiDAR point cloud model immersivity. Lastly, our VR environment also supports multi-user feature that allows teams to collaborate simultaneously. In conclusion, our VR model is very promising and has great potential to provide beneficial features with further automated improvements on the model for the SHM field.

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Numerical and Theoretical Modal Analysis of Transit Buses

Rogério Lopes[1], Behzad V. Farahani[1], Francisco Q. de Melo[1], Nuno V. Ramos[1], P. M. G. P. Moreira[1]

[1]INEGI, Institute of Science and Innovation in Mechanical Engineering and Industrial Engineering, Campus da FEUP, R. Dr. Roberto Frias 400, 4200-465 Porto, Portugal.
rflopes@inegi.up.pt, bfarahani@inegi.up.pt, fmelo@inegi.up.pt, nviriato@inegi.up.pt, pmoreira@inegi.up.pt,

FEM *Long Vehicle Dynamics* *Modal Analysis*

Abstract The transportation sector demands high important technological improvements strived for high safety standards and environmental sustainability. This study is dealing with the dynamic behavior of a passenger bus subjected to different loading conditions. Therefore, a simplified dynamic model of a single body bus is considered as a case study and then the natural vibrational frequencies are calculated through developed theoretical formulations. The obtained results show that the behavioral variation is mainly caused by the induction of the suspension flexible behavior and unforeseen external loads, mostly wind gusts. Numerically, the model was solved using the Finite Element Method (FEM) simulated in Abaqus©. Therefore, more complex vibrational modes have been numerically obtained. In this work, the suspension features and the behavior between the road and tire contact was studied in detail. A reasonable agreement has been verified amongst the results acquired on the natural frequencies from the developed theoretical and the FEM solutions.

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A Numerical Dynamic Analysis of a Multi-Body Bus

Rogério Lopes[1], Behzad V. Farahani[1], Francisco Q. de Melo[1], Nuno V. Ramos[1], P. M. G. P. Moreira[1]

[1]INEGI, Institute of Science and Innovation in Mechanical Engineering and Industrial Engineering, Campus da FEUP, R. Dr. Roberto Frias 400, 4200-465 Porto, Portugal.
rflopes@inegi.up.pt, bfarahani@inegi.up.pt, fmelo@inegi.up.pt, nviriato@inegi.up.pt, pmoreira@inegi.up.pt,

FEM *Multibody Vehicles* *Natural Frequencies* *Modal Analysis* *Dynamics*

Abstract The usage promotion and enhancing the performance of passenger transportation vehicles is a goal of governmental entities, aiming a better environmental and sustainable life of communities. Current trends of vehicle design and construction imply high safety requirements, as well as reduction of the environmental impact through lower energy consumption. This study aims at investgation of the dynamic behavior of a multi-body passenger bus articulated by a damping joint. The dynamic behavior of components upon loading will be numercially described and thereby the potential damage to the bus structure and passenger safety will be therefore evaluated. The numerical study is performed on a single-joint articulated urban bus model using the Finite Element Method (FEM). So, several computational analyses are studied in order to assess the influence of external loads on the natural frequencies of the structure.

Analysis and Construction of Transfer Structures: a Case Study

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Gonçalo Ribeiro[1,*], João Almeida[2], Paulo Silva Lobo[2,3]

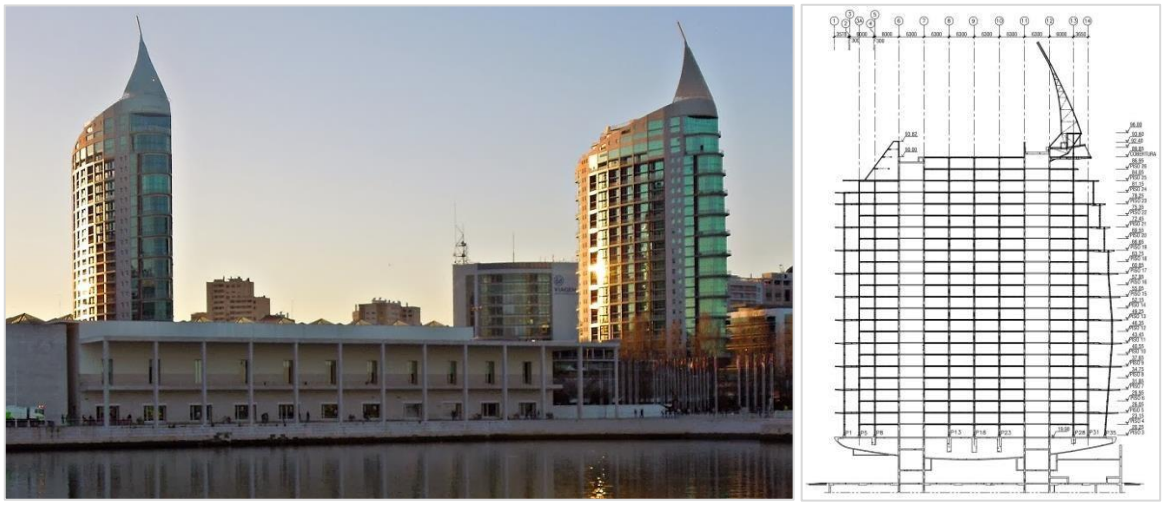
[1] *Department of Civil Engineering, Architecture and Georesources, Instituto Superior Técnico, University of Lisbon, Av. Rovisco Pais, 1049-001 Lisbon, Portugal*
** E-mail address: goncalo.x.ribeiro@gmail.com*

[2] *Department of Civil Engineering, Architecture and Georesources, CERIS, Instituto Superior Técnico, University of Lisbon, Av. Rovisco Pais, 1049-001 Lisbon, Portugal*

[3] *Faculty of Exact Sciences and Engineering, University of Madeira, Campus Universitário da Penteada, 9000-390 Funchal, Madeira, Portugal*

Transfer structure *Design* *Construction*

Abstract A transfer structure of a building is a structure that alters the load path of the gravity loads, shifting the line of thrust laterally to a different vertical alignment. They usually represent major elements of a structure and their impact on building cost and construction time can be substantial. The design for deflection control is frequently the primary consideration when defining the geometry of a transfer element, given their usual long spans and the high magnitude of the forces involved. Considerations of robustness and disproportionate collapse may also be key for the design of transfer structures as these are often regarded as critical elements for the overall stability of the building. Furthermore, the sequence of construction should be modelled through a construction-staged analysis, as it greatly affects deflections as well as final forces distribution. This paper provides guidance and highlights the key aspects that are likely to determine the structural design of transfer structures, as well as typical construction methods and challenges. It also presents a comparative study between two different types of transfer structures for the same building: an alternative composite scheme for the post-tensioned concrete transfer grid of the St. Gabriel Tower (Lisbon) was designed and the most relevant factors are highlighted.



(a) (b)

Figure 1 *- (a) Saint Gabriel and Saint Rafael Towers, Lisbon, Portugal; (b) Structural elevation*

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Fracture studies of 3D-printed PLA-wood composite

Mohammad Reza Khosravani*, Tamara Reinicke

Chair of Product Development, University of Siegen, Paul-Bonatz-Str. 9-11, 57068 Siegen, Germany

Corresponding author: mohammadreza.khosravani@uni-siegen.de

Additive manufacturing *Fracture behavior* *PLA-wood composite*

Abstract Additive manufacturing (AM) has shown extraordinary growth over the past few years and revolutionizes the rapid manufacturing. In this three-dimensional (3D) printing, the final products are made by adding material layer-upon-layer. Fused deposition modeling (FDM) is the most commonly utilized 3D printing technique due to its simplicity, material availability, and reliability. Polylactic acid (PLA) filament is one of the most popular materials for FDM process. Although PLA composites have been investigated in several research works, there are a few studies on the mechanical characterization of 3D-printed PLA-wood composites. In the present study, fracture behavior of intact and defected PLA-wood composite specimens were investigated. To this aim, wood-reinforced PLA material was used to print test coupons based on the FDM technique. It should be pointed out that the missing extrudates were considered as an intentional defect in the defected specimens. In this study, both groups of intact and effected composite specimens were printed with different raster directions. Based on a series of tensile tests, mechanical properties such as elastic modulus, tensile strength, and toughness of the examined parts were determined. Moreover, effects of raster orientations on the fracture behavior of the intact and defected parts were investigated. In this study, the obtained results were compared with results of tests on 3D-printed PLA parts. This comparison indicated effects of wood in fracture behavior of additively manufactured composite. The documented results are beneficial for the next material development and future computational models of 3D-printed components.

, **A method for determining the distribution of carbon nanotubes in nanocomposites by electric conductivity**

Dayou Ma[1], Ali Esmaeili[2], Claudio Sbarufatti[1], Marco Giglio[1], Andrea Manes[1]

[1]Politecnico di Milano, Department of Mechanical Engineering, via la Masa, 1, 20156, Milan, Italy dayou.ma@polimi.it
[2]Department of mechanical and industrial engineering, College of Engineering, Qatar University, Doha, Qatar

Mechanical properties *Electrical properties* *Health monitoring*

Abstract Nanocomposite with carbon nanotube (CNT) is one of the most promising materials due to its remarkable mechanical properties as well as the electrical conductivity, which offers the capability of monitoring the deformation and damage of composite structures by measuring the related conductivity variations. However, quantifying the distribution of CNTs inside the material remains a challenge with respects to both experimental and numerical works. In the current study, we applied our previously-proposed methods [1], about using electrical conductivity to replicate the microstructure of aligned-CNT-reinforced polymer in general cases, without aligning CNTs. By introducing a modified parameter related to the polar angle of CNTs, the mechanical properties as well as the electrical conductivity changing with deformation of nanocomposites can be replicated. After validated by experimental data from the multi-wall CNT/polymer nanocomposites under tensile loading as presented in Figure 1, the capability of the current method with respects to various weight fraction were then studied.

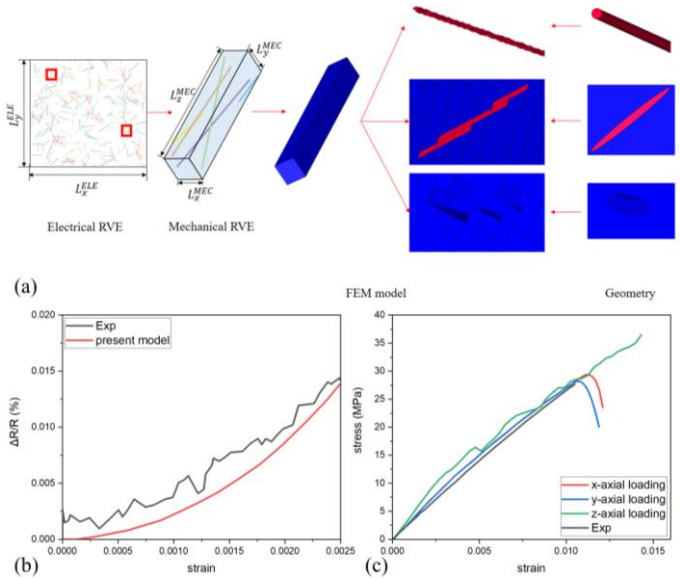

Figure 1: *(a)Methodology description; agreement on conductivity changing (b) and mechanical response (c) of nanocomposite between experiments and simulations*

Reference:

[1] Ma D, Giglio M, Manes A. An investigation into mechanical properties of the nanocomposite with aligned CNT by means of electrical conductivity. Compos Sci Technol 2020;188:107993.

, Mechanical characterization and fatigue assessment of wire and arc additive manufactured HSLA steel parts

Nicolae Rodideal[1], Carla M. Machado[2], Virgínia Infante[3], Daniel F.O. Braga[3], Telmo G. Santos[2], Catarina Vidal[2,*]

[1] *NOVA School of Science and Technology, NOVA University Lisbon, 2829-516 Caparica, Portugal*

[2] *UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, NOVA University Lisbon, 2829-516 Caparica, Portugal*

[3] *LAETA, IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisbon, Portugal*

[*] *Corresponding author: c.vidal@fct.unl.pt*

Additive manufacturing *HSLA steel* *Fatigue*

Abstract Additive manufacturing (AM) is one of the main key technologies of Industry 4.0. It aims, particularly, to increase productivity, reducing material waste and bringing many advantages that overcome the conventional manufacturing processes. Wire and Arc Additive Manufacturing (WAAM) is an AM process that employs an electric arc as heat source to melt and add material. It shows great versatility to fabricate parts using a layer-by-layer method of deposition. Despite its clear advantages, further scientific and technological progress is still needed to make it more industrially relevant. One of the main challenges it faces is studying the mechanical properties bet on the desired geometry, type of material and manufacturing parameters before employing these components in critical operational loading conditions.

In this work, the mechanical properties and fatigue resistance of HSLA steel parts manufactured by WAAM were assessed. Therefore, two type of samples were produced – low heat-input and high heat-input – in which the changing variable was the travel speed.

After manufacturing, samples' waviness was measured and three different regions were detailed analysed – bottom, middle and top via optical microscopy, electrical conductivity, microhardness, uniaxial tensile and fatigue testing at room temperature, with subsequent fracture surface observation through SEM.

It was found that processing conditions have a determinant effect on mechanical properties. Samples experienced different thermal cycles presented changes in microstructure, microhardness and properties such as ductility and/or toughness. Electrical conductivity as well as magnetic permeability were uniform along height, despite the heat accumulation. Overall, low heat-input parts yielded improved mechanical properties due to shorter thermal cycles that lead to a smaller grain size and a harder microstructure. In addition, these parts provide higher productivity given the faster travel speed during manufacturing. Fatigue results were consistent along height and a fatigue strength of 263 MPa, at 10^6 cycles, was determined based on the mean curve.

, Hot spot stress analysis on steel 316L(N)-IG welded joints for nuclear applications

Catarina Vidal[1, 2, *], João Milheiro[3], Raul Luís[2], Virgínia Infante[4], Paulo Varela[2], Bruno Soares Gonçalves[2]

[1]*UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, NOVA University Lisbon, 2829-516 Caparica, Portugal*

[2]*Instituto de Plasmas e Fusão Nuclear, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal*

[3]*Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisbon, Portugal*

[4]*LAETA, IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisbon, Portugal*

[*]*Corresponding author: c.vidal@fct.unl.pt*

ITER *Hot spot stress analysis* *Fatigue*

Abstract Diagnostic systems, to be installed in the International Thermonuclear Experimental Reactor (ITER) to provide in-service monitoring, will be subjected to inertial, electromagnetic, pressure, thermal and pretension loads. A standard approach, based on pre-designed attachments welded on the vacuum vessel (VV) inner shell wall, will be used to fasten the diagnostic components to be installed in-vessel. These attachments will be subjected to interface loads induced by the VV and to external loads transferred by the diagnostic components. Additionally, some of the in-vessel components will be directly exposed to the plasma and, therefore, subjected to high radiation doses, which will contribute to increase the thermal loads and may cause irradiation induced changes in the material properties. Both, the attachments and the in-vessel components, are made of ITER-grade steel 316L(N) IG.

This work presents the fatigue assessment of the welded attachments, performed to demonstrate whether the structural integrity of the VV is compromised in terms of fatigue crack propagation.

The loads applied on the attachments' welds by diagnostic components were determined by carrying out nuclear and thermo structural analyses. These loads will be then used as input to determine whether the attachments are compliant with the fatigue limit requirements. The fatigue assessment was based on the Pressure Equipment Directive (PED) Harmonized Standard EN 13445-3. Two different failure modes were assessed for a specific operation scenario by conducting finite element analysis (FEA) and then calculating the structural hot spot stresses on the weld toe using three different extrapolation schemes. The advantages and disadvantages of each scheme are discussed herein as well as the structural integrity of the VV. At last, to improve the fatigue behaviour of the welded attachments, the application of a fatigue life improvement technique is recommended.

, Mechanical behaviour of friction stir butt welded joints under different loading and temperature conditions

L. Pinto[1], G. Cipriano[1], C. Vidal[2], M.A. Machado[2], D. Braga[3], V. Infante[1]

[1]IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisbon, Portugal

[2]UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, NOVA University Lisbon, 2829-516 Caparica, Portugal

[3]INEGI, University of Porto, Rua Dr. Roberto Frias, 400, Porto, 4200-465, Portugal

c.vidal@fct.unl.pt

Friction stir welding *Stress ratio influence* *Temperature influence*

Abstract The nature of welding in the aeronautic industry is characterized by low unit production, high unit cost, extreme reliability, and severe service conditions. Nevertheless, it is known that welding can provide cost savings of up to 30% and weight savings of up to 10% for a typical airframe structure by replacing the actual mechanical fastening of subcomponents used to produce most of the primary structural components in airframe. Moreover, mechanical fastening suffers from difficulty of automation, problems with corrosion and the requirement for sealants. Therefore, the potential for the use of Friction Stir Welding (FSW) in airframes is extremely large. In this paper, results of FSW aluminium butt-welded joints are presented. The influence of the stress ratio for R=0.1 and 0.5 and the test temperature (room temperature and 70ºC) was assessed. The as-welded parts were subjected to Eddy current nondestructive testing. Microstructural analysis and mechanical static characterization of the welded joints, including residual stress measurements, were carried out. S-N data was obtained with respective fractographic analysis, and experimental curves were compared against the base material fatigue curve.

, Frontal impact on a coach, door sub-system pseudo-dynamic (PSD) test

Rogério Lopes[1], Francisco Barros[1], Francisco Q. de Melo[1], Nuno V. Ramos[1], P.M.G.P. Moreira[1], Rafael Cunha[2], Ricardo Maia[2], Rui Rodrigues[2]

[1] *INEGI, Institute of Science and Innovation in Mechanical Engineering and Industrial Engineering, Campus da FEUP, R. Dr. Roberto Frias 400, 4200-465 Porto, Portugal.* rflopes@inegi.up.pt, fbarros@inegi.up.pt, fmelo@inegi.up.pt, nviriato@inegi.up.pt, pmoreira@inegi.up.pt

[2] *Caetanobus – Fabricação de Carroçarias, Avenida Vasco da Gama 1410, 4430-247 Vila nova de Gaia.* rafael.cunha@caetanobus.pt, ricardo.maia@caetanobus.pt, ruirodrigues@caetano.bus.pt

Pseudo-dynamic techniques *Crash analysis* *Image correlation*

Abstract Testing automotive structures represents a very important procedure for its certification, and safety evaluation. In this work, a pseudo-dynamic procedure was used to assess the deformation energy of a coach door structure when subjected to a virtual impact of a swinging striker. Currently, passenger vehicles are tested for its resilience when subjected to an impact of a swinging striker hitting the vehicle frontal surface at a prescribed velocity. This procedure represents some investment, mainly in instrumentation and complex test rig kinematics. As a first step for the full structure validation, in this work the vehicle door structural behavior under impact was analyzed using a pseudo-dynamic method. For this test, only a fraction of the mass striker is considered to hit the door structure, once the front pillar approximately receives the majority of the striker kinetic energy. The door is instrumented using 6 uniaxial strain gauge strategically placed. In addition, the deformation and strain fields of the main front panel were measured using 3D digital image correlation.

A pseudo-dynamic (PSD) test is an experimental practice with the advantage of providing accurate and reliable results. The dynamic model associated to the structure can be approached as a single degree of freedom (SDOF) model. The deformation evolution with time (virtual time) can usefully inform about the structure behavior due to its modes of damage propagation.

a) *b)*

***Figure 1** - Experimental setup of the PSD method. a) Back view of the door, b) Front view of the door*

, Frontal impact on a coach, door sub-system numerical modelling

Rogério Lopes[1], M. P. L. Parente[1,2], P.M.G.P. Moreira[1,2], Rafael Cunha[3], Ricardo Maia[3], Rui Rodrigues[3]

[1]INEGI, Institute of Science and Innovation in Mechanical Engineering and Industrial Engineering, Campus da FEUP, R. Dr. Roberto Frias 400, 4200-465 Porto, Portugal. rflopes@inegi.up.pt, pmoreira@inegi.up.pt

[2] Department of Mechanical Engineering, Faculty of Engineering, University of Porto, 4200-465 Porto, Portugal. mparente@fe.up.pt

[3] Caetanobus – Fabricação de Carroçarias, Avenida Vasco da Gama 1410, 4430-247 Vila nova de Gaia. rafael.cunha@caetanobus.pt, ricardo.maia@caetanobus.pt, ruirodrigues@caetano.bus.pt

FEM *Crash analysis* *Bus transportation*

Abstract A coach is a heavy load vehicle used for long distances. It is a passenger transport defined as a M3 Class III vehicle. When developing new coach structures, the study of each sub-systems becomes fundamental in order to pre-validate the structure for improved the driver and currier safety. In particular, a coach needs a careful study mainly due to the higher travelling speed. Currently there are few available standards to be followed. R-29 is an obligated regulation for trucks but can be considered for a coach. Thus, when considering a frontal impact, R-29 regulation must be followed. Since in this study will be focused on the passenger door sub-system, it will be assumed that 3% of the total impact energy from an external mass weighting 1500 kg is transmitted to the door. It is expected that the coach front pillar will absorb the largest quantity of energy.

The Finite Element Method (FEM) can be used to predict crash test results and improve the driver and currier safety. The Pam Crash FEM software, provided by ESI Group was used. This software is intensively used for crash simulation in the automotive industry. A dynamic study using the explicit method was performed. In the simulation, a $45kg$ equivalent mass strikes the door frame at a speed of approximately 31 km/h. The FEM mesh consisted of Belytschko-Tsay shell elements with uniform reduced integration. The door is considered to be manufactured with three different materials. The tubular frame uses an S355 J2H steel alloy and the smaller components an EN 10130 DC01 steel alloy. The large frontal panel is manufactured in the EN AW 5754 H111 aluminum alloy.

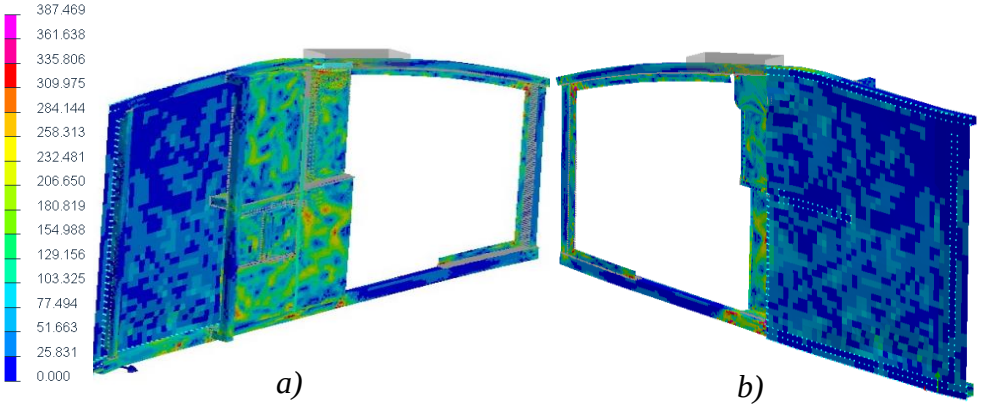

***Figure 1** - Contour field of the von Mises stresses* $[MPa]$*: a) Back door view, b) Front door view.*

, Interfacial damage in flexible electronics on collagen substrate: effect of environmental conditions

Shirsha Bose[1], Simin Li[1], Elisa Mele[2], Vadim V. Silberschmidt[1,3]

[1] *Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Loughborough, Leicestershire LE11 3TU, UK*

[2] *Department of Materials, Loughborough University, Loughborough, UK*

[3] *Laboratory of Mechanics of Biocompatible Materials and Devices, Perm National Research Polytechnic University, Perm 614990, Russia*

V.Silberschmidt@lboro.ac.uk

Collagen *Interfacial properties* *Damage evolution*

Abstract Polymeric films such as polyethylene terephthalate, polyimide and polyether sulfone are increasingly used as substrates for implantable sensors and flexible-electronics devices since they induce less tissue damage due to the mismatch in mechanical properties than hard substrates. Collagen films as substrate is a modern concept (Moreno *et al*., 2015) thanks to their biocompatibility, biodegradability, flexibility and piezoelectric behaviour. Such devices are prone to failure at the interface between the soft substrate and metallic devices. Thus, there is a need to investigate the damage evolution for collagen-metallic wearable devices to predict their in-service performance, especially in various environments.

Flexible-electronics devices were modelled with Abaqus employing a 3d finite-element formulation as a composite with the collagen substrate (50/100 μm) and gold film (170 nm). A thin adhesive layer of chromium (30 nm) was placed between the collagen and gold. The size effect of the metallic layers was considered; they were modelled as elastic-perfectly plastic materials while collagen was modelled with the Ogden 3rd order hyperelastic model based on original experimental data. A surface-based cohesive behaviour was applied to the interface between the chromium and collagen layers.

Three important factors were considered in analysis of the damage evolution at the collagen-chromium interface of these devices - effect of hydration, geometry and spatial orientation of devices. Hydration plays an important role in the mechanical response of collagen (Bose *et al.,* 2020) and might significantly affect the damage evolution. The research provides a better understanding of the damage evolution and failure of wearable-electronics devices.

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, Structural integrity of 3D-printed prosthetic sockets: Experimental study for paediatric applications

Theodoros Marinopoulos[1], Simin Li[1], Vadim V. Silberschmidt[1,2]

[1] *Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Loughborough, Leicestershire, UK*

[2] *Laboratory of Mechanics of Biocompatible Materials and Devices, Perm National Research Polytechnic University, Perm 614990, Russia*

T.Marinopoulos@lboro.ac.uk, S.Li@lboro.ac.uk, V.Silberschmidt@lboro.ac.uk

Additive Manufacturing *Prosthetic socket testing* *Structural integrity*

Abstract: Due to unique patient characteristics, a standardised testing protocol cannot be applied to prosthetic sockets like for other major parts of the prosthesis. This makes the mechanical assessment of the socket difficult, still remaining crucial, especially now, when new manufacturing technologies, such as additive manufacturing, are gaining ground in the field. In this study, a prototype testing rig was developed according to BS EN ISO 10328 to recreate the loading conditions of an early stance of an amputee gait for a paediatric transfemoral socket (Fig. 1A). This condition is related to the maximum load that the socket is exposed to at the moment of the heel touching the ground (heel strike). Various designs of above-knee prosthetic sockets of polylactic acid were produced, using a commercial 3D printer. The sockets were tested under compressive load employing a silicone-rubber phantom limb. Silicone was chosen thanks to similarity of its mechanical properties with those of a human tissue. The load requirements suggested in the ISO standard were recalculated for the case of a 14-year-old male user with the weight of 76 kg (98th percentile). After initial design improvements, 3D printed sockets were found capable to sustain loads up to five times the weight of the patient before failure. Despite the different failure load levels, all sockets demonstrated failure at their distal posterior site (Fig. 1B).

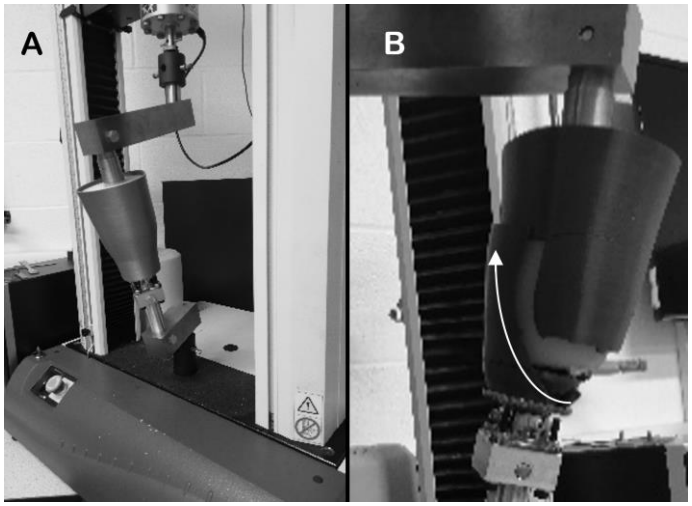

Figure 1 – *(A) Testing setup for transfemoral socket: (B) direction of crack on failed socket (shown with arrow)*

, The Evaluation of Quenching Temperature Effect on Microstructural and Mechanical Properties of Advanced High Strength Low Carbon Steel After Quenching Partitioning Treatment

Ehsan Entezari [1], Hamid Mousalou [2], SasanYazdani [3], Jorge Luis González-Velázquez [4]

J.A. Szpunar[5]

[1] Department of Metallurgy and Materials, Escuela Superior de Ingeniería Química e Industrias Extractivas, Instituto Politécnico Nacional, Mexico City, Mexico, ehsan.entezari2014@gmail.com

[2] Faculty of Materials Engineering, Sahand University of Technology, Tabriz, Iran

[3] Faculty of Materials Engineering, Sahand University of Technology, Tabriz, Iran

[4] Department of Metallurgy and Materials, Escuela Superior de Ingeniería Química e Industrias Extractivas, Instituto Politécnico Nacional, Mexico City, Mexico

[5] Department of Mechanical Engineering, University of Saskatchewan, 57 Campus Drive, S7N5A9 Saskatoon, Saskatchewan, Canada

Advanced High Strength Steel *Quench and temper* *Strengthening mechanisms*

Abstract The influence of quenching temperature on microstructural and mechanical properties of a low alloy steel of the following chemical composition: 0.26C, 1.70Mn, 1.42Si, 1.10Cr, 1.10Ni, 0.94Cu, 0.24Mo, 0.1V, Bal. Fe (Wt.%) was investigated after applying a quenching-partitioning (Q-P) treatment. The steel samples were isothermally quenched at 260, 280, and 300 °C, from the austenitizing temperature and then Q-P treated at 340 °C. After the Q-P treatment, the steel showed a multi-phase microstructure containing bainite, martensite, and retained austenite. It was determined that the tensile strength and Charpy impact energy increased with a decrease in quenching temperature to 1415 MPa and 43 J, respectively. This effect was attributed to an increase of the volume fraction of austenite/martensite micro blocks that introduces a hard phase mixture strengthening factor and the presence of tempered martensite, which is strengthened by fine particle dispersion and moreover, a decrease in thickness of the bainitic-ferrite subunits that refines the microstructure. The fractographic examination of the Charpy tested specimens showed that the sample quenched at 260 °C contained finer and deeper dimples, which indicates that more energy was spent on the nucleation and growth of ductile fracture micro-voids, thus increasing the toughness.

Influence Assessment of Artificial Defects on the Fatigue Behavior of Additively Manufactured Stainless Steel 316LVM

Felix Stern[1], Jonas Grabowski[1], Stefan Kleszczynski[2,3], Daniel Kotzem[1], Arno Elspaß[2], Gerd Witt[2], Frank Walther[1]

[1]TU Dortmund University, Department of Materials Test Engineering, (WPT), Baroper Str. 303, D-44227 Dortmund, Germany

[2]University of Duisburg-Essen, Chair of Manufacturing Technology, Lotharstr. 1, D-47057 Duisburg, Germany

[3]Center for Nanointegration Duisburg-Essen (CENIDE), Carl-Benz-Str. 199, D-47057, Duisburg, Germany

Effects of defects *Fatigue behavior* *Austenitic steel*

Abstract The laser-based additive manufacturing (AM) of metals is one of the most promising techniques to realize lightweight optimized parts and structures. Other possible design elements are internal cooling channels or topology-optimized geometries. However, not only does the process suffers of instabilities causing pores and lack-of-fusion defects but also possible outer and inner surfaces can cause challenges due to the process-inherent surface quality. A further knowledge about these defects and their influence on the mechanical behavior are needed to bring AM parts in applications which are not only of optical use.

In this work, the austenitic stainless steel 316LVM (X2CrNiMo18-13-3) has been processed by laser-based powder bed fusion (PBF-LB/M) to generate cylindrical specimens with a length of 100 mm and a diameter of 10 mm. In total, four different batches were manufactured with specific cubic defects ranging between 0.3 and 1.5 mm edge length and one of the batches having no intended internal defects for reference purposes. The specimens were analyzed by microfocused computed tomography to non-destructively characterize the intended defect geometry. After that the fatigue behavior was evaluated at stress ratio R = -1 and test frequency f = 20 Hz up to 1E7 cycles at stress amplitudes between 260 and 420 MPa. The fracture surface was analyzed by scanning electron microscopy. Additionally, different models for the defectbased description of the fatigue behavior were applied to compare the experimental and modelbased data. In detail, Murakami's model and a modified Kitagawa-Takahashi diagram were used.

The results show that the reference material and specimens with a defect's edge length of 0.3 mm do not fail due to internal defects but because of crack initiation from the surface or other near-surface defects. The specimens with defect sizes of 1.0 and 1.5 mm edge length all failed due to crack initiation and propagation starting from the defects' downskin internal surface. As expected, fatigue life is reduced with increasing defect size and fatigue strength at 1E7 is decreased from 290 MPa (reference batch) down to 210 MPa for the defect size of 1.5 mm. The defect-based models show a more conservative description of the fatigue strength implying a high defect tolerance of the steel. The reason for this is not yet fully understood and, thus, can not be considered in the models.

Displacement monitoring of crossbeams in an airport runway extension using digital image correlation

Francisco Barros[1], Susana Aguiar[1], Pedro J. Sousa[1], António Cachaço[1], Nuno V. Ramos[1], Paulo J. Tavares[1], Pedro M. G. P. Moreira[1], MinXu[2], L. Oliveira Santos[2], Elsa Franco[3]

[1]INEGI, Institute of Science and Innovation in Mechanical Engineering and Industrial Engineering, Campus da FEUP, R. Dr. Roberto Frias 400, 4200-465 Porto, Portugal.
[2]LNEC, National Laboratory for Civil Engineering, Av. Brasil 101, 1700-066, Lisboa, Portugal
[3]ANA- Aeroportos de Portugal, SA, 9100-105 Santa Cruz, Madeira, Portugal
ptavares@inegi.up.pt

Digital image correlation *Beam deflection* *Structural monitoring*

Abstract The structure of the Madeira Airport's runway extension was built above the sea and is composed by a slab supported by frames at heights above 60 m. When landing in the E-W direction, the aircrafts touch this structure, which results in bending of the support beams.

A vision system was installed under the runway in order to evaluate the deflection of the two support beams more directly involved with impact loads upon landing, but otherwise also involved in take-off or taxiing operations. Each system consists of a camera mounted on a beam, directed at the midspan of the following beam, whose displacement is set to be measured. The section captured by the camera has been prepared with a 2 m by 1 m speckle pattern target for displacement tracking using digital image correlation (DIC). A trigger mechanism was developed in order to save only the images obtained upon clear operational events. The camera acquires images continuously onto a buffer and compares them with a reference using DIC. When a displacement is detected, the images on the buffer, along with the frames taken in the next few seconds, are saved for posterior image processing.

This system was successful at obtaining measurements for the monitored areas' displacement fields and the evolution of deflection through time for each event, which were compared to the displacement results obtained through double integration of the signal from vertical accelerometers placed on the same beams. Significant values for strain are yet to be obtained, as they were, most likely, too small for the system's resolution, for the events captured to this date.

Figure 1 – *Image acquisition system installed above one of the pillars supporting the runway*

, Structural monitoring of a breakwater using UAVs and photogrammetry

António Cachaço[1], Pedro J. Sousa[1], Francisco Barros[1], Paulo J. Tavares[1], Pedro M. G.[1], Rui Capitão[2], Maria Graça Neves[2], Elsa Franco[3]

[1]INEGI, Institute of Science and Innovation in Mechanical Engineering and Industrial Engineering, Campus da FEUP, R. Dr. Roberto Frias 400, 4200-465 Porto, Portugal.

[2]LNEC, National Laboratory for Civil Engineering, Av. do Brasil 101, 1700-066 Lisboa, Portugal

[3]ANA- Aeroportos de Portugal, SA, 9100-105 Santa Cruz, Madeira, Portugal

ptavares@inegi.up.pt

Photogrammetry *Unmanned aerial vehicle* *Breakwater monitoring*

Abstract The present project addresses a problem related to the water erosion effects on a breakwater barrier which leads to its degradation and lack of functionality. In the present case, the breakwater acts as a physical barrier between the Atlantic Ocean and the cargo harbour of Leixões, in Matosinhos, Portugal, justifying the needs of health monitoring of the barrier.

To monitor this structure, with a length of roughly 700 m, the need of a fast data acquiring system led to the choice of imaging techniques which allow for a fast acquisition of a diversified data set. The images were acquired making use of a high-resolution camera attached to an unmanned aerial vehicle (UAV), enabling a faster acquisition and a degree of automation leading to the systematization of the process, while being compatible with the difficult accessibility of the structure, which is surrounded by seawater. Point clouds corresponding to the breakwater's geometry were then obtained from the set of images using photogrammetry.

Two image acquisition and processing operations were performed three months apart in order to compare the point clouds acquired in the different instances and identify possible changes in the geometric configuration of the breakwater. By registering the two point clouds and computing the distance between them, it was possible to show that some movement within the structure occurred between the two points in time.

***Figure 1** – Point cloud of the breakwater resulting from the photogrammetry process*

With this detailed and accurate information, it is possible to verify the state of the structure and analyze in detail the area with stability problems, i.e., where blocks either moved from its resting positions or broke. Moreover, by comparing different surveys enables one to verify the evolution of the structure's integrity and determine the areas where an intervention is necessary to maintain the functionality and stability of the structure during its expected lifetime.

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Hardware proposal for SHM in airborne vehicles

Josu Etxaniz[1], Gerardo Aranguren[1], José Miguel Gil-García[2], Jesús Sánchez[2]

[1]Faculty of Engineering, University of the Basque Country, 48013 Bilbao, Spain; josu.etxaniz@ehu.es

[2]Faculty of Engineering, University of the Basque Country, 01006 Vitoria-Gasteiz, Spain

SHM *Ultrasound test* *Airborne vehicles*

Abstract Nowadays, not only must the structures be in good health when they are manufactured and installed, but also their integrity must be monitored during their life cycle. NDT techniques are applied in the beginning of the cycle, and SHM techniques afterwards.

There is a wide literature on how to monitor integrity in large civil structures, where the size of equipment and accessibility for testing are not serious problems. There are studies that deal about the integrity of airborne vehicles, some focused on the inspection technology or the algorithms used. However, the integrity inspection on an aircraft also requires the development of reliable low volume lightweight electronic equipment with high technical capability.

The authors are developing electronic prototypes to satisfy such requirements. The goal of this research is to build an on-board electronic system that monitors the integrity of the airborne throughout its lifetime. The prototype uses ultrasound technology with piezoelectric transducers (PZT) and can emit and acquire waveforms on multiple channels simultaneously (pulse-echo or pitch-catch schedules). It can use many test techniques: simple test, transmission beamforming, fast round-robin (associated with reception beamforming), multiple signal delayed, etc. The prototype can generate steerable beams as required. It can also operate in passive mode, i.e. listening to acoustic emissions. The prototype weights 600 g, includes USB 2.0 connectivity, and compresses the data before uploading them to a computer.

To check the viability of the prototypes, tests on isotropic (aluminum) and anisotropic (composite) specimens were carried out (Figure 1).

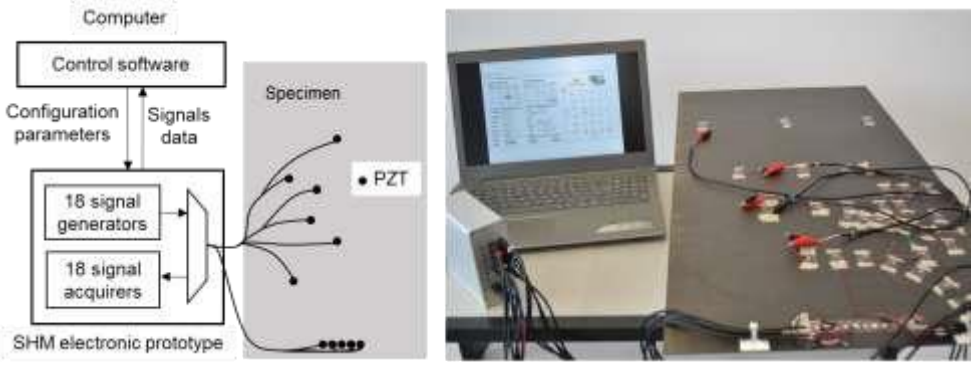

***Figure 1** – Schematic and photography of the setup of the tests.*

The prototype is providing satisfactory results when testing it with different algorithms to detect all kind of damage, and specimens, including real-world aircraft parts.

Experimental investigation of factors influencing the transmission capabilities of a low cost, side-polished evanescent wave absorption plastic optical fiber sensors

Grzegorz Wójcik, Piotr Przystałka

Department of Fundamentals of Machinery Design, Silesian University of Technology, Konarskiego 18A, Gliwice 44-100, Poland, grzegorz.wojcik@polsl.pl; piotr.przystalka@polsl.pl

Plastic optical fiber *Optical sensor* *Refractive index sensors*

Abstract The Plastic Optical Fiber (POF) sensors can be low cost or cost-competitive solutions to other sensing techniques due to their advantages, such as immunity to electromagnetic interference, compactness, lightweight, multiplexing capabilities, higher sensitivity. Scientists and engineers have already developed POF sensors capable of sensing strain, deflection, pressure, refractive index, and more. These make them suitable for structural health monitoring, medicine, environment, chemical applications. The academic community has mainly explored solutions that utilize two fibers and an optical coupler, where one optical fiber is used as a reference to compensate attenuation changes that are caused by low sensor reproducibility, light source fluctuations, and other factors. The cost of the sensor could be lowered significantly by not splitting the light waves into two optical fibers.

This research explores the influence of such attenuation changes, in particular extrinsic losses (introduced by manufacturing procedures), and environmental conditions (ambient temperature) on the transmission capacities of the refractive index (RI) evanescent wave absorption POF sensor. Light sources of the sensors were driven with constant currents. Photodiodes and transimpedance amplifiers were used to convert the returning light intensity into output voltage, allowing to measure the transmission capacities of the POF. Polishing methods were used to produce several side-polished RI evanescent wave absorbance POF sensors.

The performance of the sensors was evaluated by means of transmission capacities and RI sensitivity, at different stages of the POF preparation and at different ambient temperatures. The sensitivity was studied through the characterization with solutions of sucrose of known refractive index in the range of 1.3330 – 1.4958. Findings presented in this paper will be used for further development of POF sensors. In particular the ones using evanescent wave absorption and surface plasmon resonance effects, which can be used e.g. for measuring solution concentration, water contamination, etc.

Damage classification in composite structures based on X-ray computed tomography scans using features evaluation and deep neural networks

Tomasz Rogala, Piotr Przystałka, Andrzej Katunin

Department of Fundamentals of Machinery Design, Silesian University of Technology, Konarskiego 18A, 44-100 Gliwice, Poland, tomasz.rogala@polsl.pl; piotr.przystalka@polsl.pl; andrzej.katunin@polsl.pl

X-ray computed tomography *Damage classification* *Deep neural networks*

Abstract Modern demands on structural safety require periodic inspections of elements and structures being under operation in numerous industrial branches. Such inspections are usually performed with non-destructive testing (NDT) methods. However, such inspections may provide information on damage presence, location, and type only without a possibility of evaluation the structural residual life. The prediction of a structural response, being the last step of structural damage evaluation, is one of the most challenging and still unsolved problems.

The following study is based on NDT results obtained from glass fiber-reinforced composite specimens subjected to fatigue loading using X-ray computed tomography (XCT). The XCT technique was selected, since it provides a possibility to obtain results in the form of a 3D array with high spatial resolution. The initially pre-processed tomograms using the developed image processing algorithm consisted of objects that represent delamination, cracks, and artifacts resulting from XCT scanning and processing procedures. One of the main difficulties of this study is to distinguish mentioned types of damage, even in the cases, when they are merged, and determine a set of features sensitive to their morphology.

The authors considered numerous features, both 2D and 3D, including statistical, morphometric, and other types of features, to evaluate their performance in distinguishability of damage types. Special attention was paid to features that are invariable with respect to scale, translation and rotation. Further, the pre-selected features were used to construct an input set of parameters to a convolutional neural network, being adapted to the investigated problem for automatic classification of damage types. The proposed classification approach might be helpful as the decision supporting tool for NDT inspectors as well as can be used as an input to numerical models for the evaluation of a structural residual life of composite elements.

A reverse engineering approach for modeling of barely visible impact damage by combining results of non-destructive testing and numerical simulations

Angelika Wronkowicz-Katunin[1], Andrzej Katunin[1], Wojciech Danek[2], Krzysztof Dragan[3], Marek Wyleżoł[1]

[1]*Department of Fundamentals of Machinery Design, Silesian University of Technology, Konarskiego 18A, 44-100 Gliwice, Poland, angelika.wronkowicz-katunin@polsl.pl; andrzej.katunin@polsl.pl; marek.wylezol@polsl.pl*

[2]*Department of Theoretical and Applied Mechanics, Silesian University of Technology, Konarskiego 18A, 44-100 Gliwice, Poland, wojciech.danek@polsl.pl*

[3]*Airworthiness Division, Air Force Institute of Technology, Ks. Bolesława 6, 01-494 Warsaw, Poland, krzysztof.dragan@polsl.pl*

Low-velocity impact damage *Non-destructive testing* *Structural residual life*

Abstract An evaluation of the structural residual life for composite elements affected by low-velocity impact loading is a challenging task due to the uncertainty of an influence of the resulting damage on the mechanical properties of a structure, which cannot be truly assessed without destructive testing. To overcome this deficiency, an approach based on reverse engineering was developed. Within this approach the results of non-destructive testing (NDT) are considered, namely the results of X-ray computed tomography as well as ultrasonic testing in B- and C-scan modes, for an evaluation of the geometrical properties of damage as well as the results of numerical simulations of impact testing of the composite were used to support the experimental results. Based on the obtained results, the generic shapes of barely visible impact damage (BVID) in composite structures were determined, and based on the generic shapes and the obtained relations between the damage extent and the impact energy, a parametric computer-aided design models were developed. The obtained models allow predicting the structural response, including the estimation of the residual life of composite structures in finite element simulation environments.

The aim of the performed studies was to develop a methodology of a reconstruction of BVID from UT scans with appropriate correction based on reference NDT results and numerical simulations, which can be then used for a simulation of BVID and a prediction of the residual life of polymer matrix composite structures. This study summarizes a recent progress in reaching the goal.

The results of the developed methodology are intended to be used during inspections of PMC aircraft structures as a tool of an enhancement of BVID detection and identification as well as further evaluation of the structural residual life, which is in agreement with the concepts of damage tolerance and condition-based monitoring accepted worldwide by international and national airworthiness authorities.

, Investigation of Web Buckling of Pultruded GFRP Bridge Deck Subjected to Concentrated Load

Yun Sun[1], Haohui Xin[2], Yuqing Liu[1]

[1]Department of Bridge Engineerin, Tongji University, Shanghai 200092, China, sunyun@tongji.edu.cn

[2]Department of Civil Engineering, Xi'an Jiaotong University, Xi'an 710049, China

GFRP bridge deck *Local buckling* *Finite element analysis*

Abstract Experimental and numerical investigation on the stability behavior of a pultruded glass fiber-reinforced polymers (GFRP) bridge deck exposed to wheel loading has been carried out in this paper. The relationship between web local buckling and bearing capacity, the effect of the web-flange junction(WFJ) on web local buckling, as well as loading positions' effect on deck's bearing capacity were discussed. The results showed that the middle web buckling was the dominant failure mode of deck specimen. Due to the structural redundancy, the deck could still carry the load until final failure caused by longitudinal cracks propagated at top flange below loading point. Finite element model with detailed construction of WFJ had obvious improvement in simulation accuracy of web buckling behavior. Through parametric analysis, it was found that as the shear-span ratio decreases, the principal compressive stress is more concentrated and the shear buckling is more pronounced, leading to decrease of GFRP bridge deck's bearing capacity.

In service failure of a signal-support bridge structure for traffic signaling

Mihaela Iordachescu[1], Andrés Valiente[2], Maricely de Abreu[2]

[1]*Materials Science Dpt., E.T.S.I. Caminos, Universidad Politécnica de Madrid, Spain, Prof. Aranguren St., Ciudad Universitaria, mihaela.iordachescu@upm.es*

[2] *Materials Science Dpt., E.T.S.I. Caminos, Universidad Politécnica de Madrid, Spain*

high-strength steel *fracture micro mechanisms* *Fatigue*

Abstract The traffic signals are extensively used all around the world for traffic directing in highways or local roadways and their accurate operation is today a well-recognized issue by the transportation authorities. The structures used for supporting them over major roadways are exposed to fatigue cracking when wind-induced large-amplitude vibrations occur because of severe environmental conditions or wind gusts resulting from the passing trucks.

The present paper describes the research undertaken to analyze the failure detected in the bolted joint that couples the two symmetrical parts of an overhead bridge span structure for traffic signaling during a routine service inspection. The structure, in use for more than 20 years, was located close to a highway entrance into a tunnel. The research is basically a forensic engineering analysis of failure involving the fractographic study and microstructural analysis of the broken bolts in the splice connection of the bridge span. The analysis involves optical and scanning electron microscope (SEM) observations of the in-service fractures (Figure 1) and additional static and cyclic tension tests of bolt material in order to assess its adequacy to the actual design requirements. The fracture analysis indicated a long time service before final failure by overloading, with a previous fatigue cracking covering more than 70% of the fracture surface. The local dissolution and microcracking of the protective Zn layer produced multiple fatigue initiators at steel interface and propitiated the fatigue failure of the bolts.

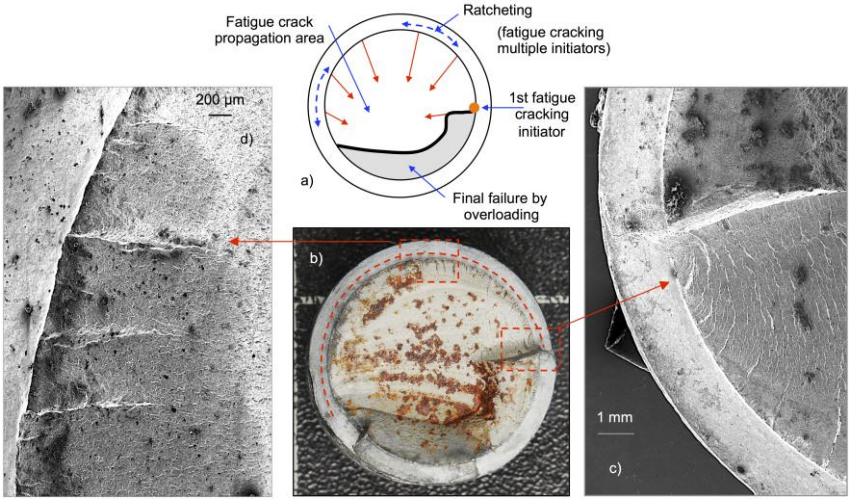

Figure 1 - *Threaded bolt rupture: a) sketch of the macro mechanism of fracture; b) macroscopic image of the surface rupture; c) detail showing the 1st fatigue cracking initiation site; d) detail capturing some of the ratcheting marks formed at bolt surface by multiple fatigue cracking initiators*

,Graphite debonding in compacted graphite iron under thermal loading: 3d microstructure-based modelling

Evangelia Nektaria Palkanoglou, Konstantinos P. Baxevanakis, Vadim V. Silberschmidt

Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, LE11 3TU, UK

K.Baxevanakis@lboro.ac.uk

Graphite debonding *Cast iron* *Thermal load*

Abstract In this work, the thermomechanical and fracture behaviours of compacted graphite iron (CGI) is computationally investigated at microscale, employing a microstructure-based modelling approach. CGI is an engineering alloy used extensively in a vast number of industrial applications thanks to its good combination of thermal and mechanical properties. It is a composite material, comprising a metallic matrix (ferritic/pearlitic) and randomly orientated graphite particles of various shapes and sizes embedded in it [1]. Although considerable research in CGI was conducted in the past, its fracture at the microscale is not yet fully understood, especially for pure thermal loading. Graphite particles are soft and brittle while their coefficient of thermal expansion is an order of magnitude lower compared to that of the matrix. This mismatch in thermal and mechanical parameters triggers graphite decohesion from the matrix, initiating thus fracture at the microscale [2].

To obtain an input for the suggested numerical models, CGI microstructures are characterised with scanning electron microscopy, with the scans quantified using image-processing tools. Following a statistical analysis of the results, representative volume elements are generated with Python scripts. These three-dimensional unit cells, comprising a ferritic/pearlitic matrix and graphite particles of various shapes represented as ellipsoids, are studied using a finite-element approach. An elastoplastic behaviour is assigned to all phases while the graphite-matrix interface region is modelled with cohesive finite elements, with a focus on understanding the onset of graphite decohesion from the matrix. Alongside the use of periodic boundary conditions, a comparison between fully constrained and free volume elements is performed. The methodology allows for a parametric analysis of the problem to identify the effect of different parameters on the response to purely thermal loading. The effects of different matrix phases (pearlite, ferrite) and the interaction between neighbouring particles on the onset of graphite decohesion and matrix plasticisation are investigated. The obtained results are expected to be useful in the design of this engineering alloy.

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, Dynamic Fracture Behaviour of Additively Manufactured Polymers and Composites under Ballistic Impact

Md Niamul Islam, Konstantinos P. Baxevanakis, Vadim V. Silberschmidt

Wolfson School of Mechanical, Electrical and Manufacturing Engineering,

Loughborough University, LE11 3TU, UK

K.Baxevanakis@lboro.ac.uk

Additive Manufacturing *Dynamic Fracture* *Reinforced Composite*

Abstract Recent advances in additive manufacturing (AM) have gained a significant attention of researchers thanks to its notable benefits compared to traditional manufacturing methods. The AM process (also known as *3D printing*) is a layer-by-layer adhesion of the material to fabricate a 3D structure. Different techniques are used to manufacture such structures depending on the type and state of the raw materials. The most common method is fused deposition filament (FDM) using polymers such as poly-lactic acid, acrylonitrile butadiene styrene, polycarbonate, and nylon. The current FDM process is able to fabricate specialised structures of complex geometry but performance of these structures is affected by weak interfaces and porosity associated with 3D printing. Therefore, high-strength fibres (carbon, glass, Kevlar) are added to the polymers to improve the strength of the resultant structures. However, research in such materials was limited mostly to quasi-static conditions. Understanding the fracture behaviour of AM polymers and composites in dynamic regime such as ballistic impact would help create improved high-performance products for applications ranging from prosthetics and protective gear to complex aerospace structures.

The use of destructive experimental methods for dynamic loading conditions is accompanied in this research by development of numerical models for AM polymers and composites to elucidate their dynamic fracture behaviour under ballistic impact. For this purpose, quasi-static tensile and compression tests were conducted to identify suitable printing parameters and the elastic-plastic properties of the material. To study the fracture behaviour of AM composites under impact load, low- and high-velocity ballistic impacts of spherical steel projectiles on 3d-printed plates made of nylon and its composite reinforced with short carbon fibres were performed using an in-house gas gun. Further, micro-CT was used to assess the porosity and fibre distribution as well as to understand the influence of the microstructure on the material strength. Finally, ballistic-impact modelling was implemented using finite-element analysis with a user-defined material behaviour to compare the results with experimental findings.

, Integrity evaluation of a reactor pressure vessel based on a sequential Abaqus-FRANC3D simulation method

M. Annor-Nyarko [1, 2, 3] , Hong Xia[1, 3]

[1] Key Laboratory of Nuclear Safety and Advanced Nuclear Energy Technology, Ministry of Industry and Information Technology, Harbin Engineering University, Harbin 150001, China
[2] Nuclear Installations Directorate, Nuclear Regulatory Authority, Ghana
[3] Fundamental Science on Nuclear Safety and Simulation Technology Laboratory, Harbin Engineering University, Harbin 150001, China

xiahong@hrbeu.edu.cn

pressurized thermal shock *structural integrity* *reactor pressure vessel*

Abstract The safety-risk pressurized thermal shock (PTS) have on a reactor pressure vessel (RPV) is one of the most important study for the lifetime ageing management of a reactor. Several studies have investigated PTS induced by postulated accidents and other anticipated transients. However, there is no study that analyzes the effect of PTS induced by one of the most frequent anticipated operational occurrences - inadvertent operation of the safety injection system. In this paper, a sequential Abaqus-FRANC3D simulation method is proposed to study the integrity status of an ageing pressurized water reactor subjected to PTS induced by inadvertent actuation of the safety injection system. A sequential thermal-mechanical coupling analysis is performed using a three-dimensional reactor pressure vessel finite element model (3D-FE). Then 3D-FE fracture mechanic submodel with a postulated semi-elliptical surface crack is created. Subsequently, the 3D-FE submodel is used to evaluate the stress intensity factors, calculated using the M-integral approach. Subsequently, the ASME method is used to estimate the reactor vessel's steel fracture toughness. Finally, the stress intensity factor obtained with the sequential Abaqus-FRANC3D method is compared with the conventional XFEM approach, and the result shows a good agreement. In addition, the maximal thermo-mechanical stress concentration was observed at the inlet nozzle-inner wall intersection. This work serves as a critical foundation for further studies on RPV crack growth analysis and fatigue life prediction

,Failure Analysis of FRP Composites Exposed to Real Marine Environment

Goran Vizentin[1], Goran Vukelić[1,2]

[1]*University of Rijeka, Faculty of Maritime Studies, Marine Engineering Department, Studentska 2, Rijeka, Croatia; vizentin@pfri.hr*

[2]*University of Rijeka, Faculty of Maritime Studies, Center for Marine Technologies, M. Baraca 18, Rijeka, Croatia; gvukelic@pfri.hr*

Failure analysis *Composites* *Marine environment*

Abstract Fiber reinforced polymer (FRP) composites find ever growing application possibilities in marine structures. Due to harsh environmental operational conditions, failure prediction of such structures is an imperative in this industry sector. For this reason, samples of epoxy/glass and polyester/glass with various fiber layout configurations have been submerged under the sea for prolonged periods (6 and 12 months). On contrary to usual accelerated laboratory experiments, these type of tests in real sea environment and for prolonged periods are rarely done. They are useful to obtain more realistic environmental input parameters for structural modeling of marine structures. Changes in mass, marine microbiology growth, tensile strength and morphological structures were analyzed after submersion and compared with samples exposed to room environment. All samples exhibited an increase in mass due to seawater absorption and microorganism growth in the organic resins used as matrix materials. The dynamic and level of decrease in tensile strength showed dependency on the fiber layout configuration. Optical and scanning electron microscopical investigation showed significant matrix morphological changes primarily due to salt crystal formation and the impact of sea microorganisms embedding in the resin. Results of this experimental work will be used as realistic input parameters for subsequent failure analysis numerical tool that can be applied for life-time behavior predictions of marine structures.

, The Demonstrator of Structural Health Monitoring System of Helicopter Composite Blades

Aleksey Mironov [1], Pavel Doronkin [2]

[1] D un D centrs, Jasmuizas 12-16, Riga, LV-1021 Latvia, info@ddcentrs.lv

[2] D un D centrs, Riga, LV-1021 Latvia

helicopter's structural health monitoring *operational modal analysis* *modal passport*

Abstract The health and usage monitoring systems (HUMS) are widely used for the monitoring of vibrations of power plant units on helicopters. At the same time critical helicopter structures like main and tail rotors or tail boom are still out of permanent monitoring. Practically all non-destructive techniques (NDT), like ultrasound, eddy current, X-ray and others make the inspection of structural components available on the ground only, during the maintenance check or overhaul. The article considers the promising technique for structural health monitoring (SHM) of rotating composite blades of a helicopter in flight. Actively developing methods of modal analysis, especially operational, open a new opportunity for structural features estimation, and become the basis for the novel concept of "modal passport" for monitoring of helicopter's composite blades. The basic principles of modal passport based on the theory of experimental and operational modal analysis techniques are introduced. The trial application of modal passport to the helicopter composite blades is demonstrated. The paper discusses the problems associated with practical application of modal passport (MP) to rotating helicopter blades and ways to overcome it. As an operating platform for experimental study and the demonstrator of the MP application to rotating blades the light coaxial helicopter Ka-26 was chosen. Description of equipment and transducers preparation on the blades for experimental stage is presented. The research was aimed at determining the resolution of the demonstrator and the paper discusses the results of analytical phase of the study, including FE modelling and comparative analysis with the results of experimental study. The conclusions of the paper summarize the results of the research stage, outline the novelties and its practical application. The tasks of further works for SHM research stages using the demonstrator are formulated.

Figure 1 *– The demonstrator of SHM based on operating helicopter*

, Penetration of thin aluminium targets with non-axisymmetric projectiles: Numerical study

Theodosios Stergiou[1], Konstantinos P. Baxevanakis[1], Anish Roy[1], Nickolay A. Sazhenkov[2], Mikhail Sh. Nikhamkin[2], and Vadim V. Silberschmidt[1]

[1] *Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University, Leicestershire, LE11 3TU, UK*
[2] *Aircraft Engines Department, Perm National Research Polytechnic University, Perm, Russia*

Non-axisymmetric projectile *Impact* *Finite-element analysis*

Abstract: Up to now, studies on impact with non-axisymmetric projectiles having high cross-sectional aspect ratios are limited, yet such cases can occur in a wide range of civilian and military applications. A target response to projectiles of such geometry differs from the extensively studied case of impact with axisymmetric projectiles. The aim of this study is to examine the penetration capabilities of plate-like projectiles upon impact on thin metallic targets. So, the focus of this analysis is on the projectile's geometrical parameters and their effect on penetration characteristics. An experimentally validated model was developed within the finite-element framework to study the projectile-induced fracture in the target (Fig. 1), the projectile's velocity profiles, and force histories, in order to get a better understanding of the dissipation mechanisms and assess the contribution of key geometrical parameters. A change in the expected target's fracture response was reported, while a drop of a linear section of the projectile's velocity was associated with a half-cone angle of the projectile.

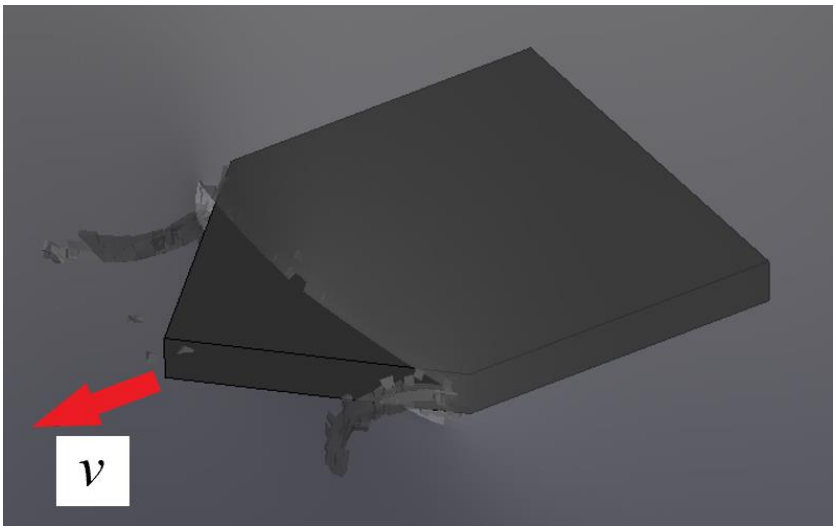

Figure 1 *– Target penetration*

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Failure behavior of human trabecular bone

Ekaterina Smotrova[1]*, Simin Li[1], Mikhail Tashkinov[2], Vadim V. Silberschmidt[1]

[1]*Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Leicestershire, UK *e.smotrova@lboro.ac.uk*

[2]*Faculty of Applied Mathematics and Mechanics, Perm National Research Polytechnic University, Perm, Russia*

HR-pQCT *Trabecular bone* *Mechanical competence*

Abstract Accurate measurement of bone mineral density (BMD) and morphometric parameters of trabecular bone is vital for diagnostics of low-bone-mass disorders (e.g., osteopenia and osteoporosis) and monitoring their progression [1]. Currently, dual-energy X-ray absorptiometry (DXA) is the only technique considered a "gold standard" for BMD measurement and recommended by the WHO for prediction of the primary osteoporotic fractures. However, due to its low resolution, DXA is cannot provide information on trabecular-bone microarchitecture, which plays important role in determining mechanical properties of this bone tissue [2]. In addition, areal BMD, measured with DXA, can to explain only 50–80% of variation in the whole-bone strength [3]. Thus, a combined use of high-resolution peripheral quantitative computed tomography (HR-pQCT) and numerical simulations with the finite-element analysis (FEA) was investigated to estimate mechanical properties of trabecular bone and risk of its fracture with higher precision.

HR-pQCT is a novel technique of bone visualization, which, thanks to its resolution of 82 μm, allows the depiction of individual trabeculae, ensuring the adequate assessment of trabecular-bone morphometric parameters. The results obtained from previous FEA simulations based on HR-pQCT data validated this approach for quantification of bone's mechanical parameters. However, loading conditions leading to failure of human trabecular bone (HTB) are currently unknown. The aim of this study is to determine the effect of different loading regimes and boundary conditions on HTB failure behavior. For this purpose, a 3D unit cell of trabecular lattice with bone marrow in its intertrabecular space, obtained from HR-pQCT scans of HTB was developed. The FE method was implemented for the reconstructed model loaded in tension, compression, and shear in both elastic and plastic deformation regimes to predict the onset of plasticity and failure in trabeculae.

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, **Analysis of cyclic properties of additive vs. conventionally produced material AlSi10Mg**

Vladimír Chmelko[1], Igor Berta[1], Matúš Margetin[1]

[1]Slovak University of Technology, Faculty of Mechanical Engineering, Institute of applied mechanics and mechatronics, Námestie slobody 17, 812 31 Bratislava, Slovak republic, vladimir.chmelko@stuba.sk

Additive manufacturing *AL alloys* *Cyclic properties*

Abstract. Additive metals are practically identical in strength to the properties of conventionally produced materials. The article experimentally analyzes fatigue properties in the tensile-pressure mode for two different directions of 3D printing of AlSi10Mg material. The resulting fatigue parameters of the Basuin curve are confronted with a conventionally produced alloy of the same composition. The microstructure analysis explains the different fatigue properties obtained by these two material production technologies.

Figure 1 *Microstructure of defect in additively manufactured AlSI10Mg*

, **Fatigue lifetime of a bicycle frame made additively from AlSi10Mg**

Róbert Ďurka[1], Marek Gašparík[2], Pavel Žlábek[3]

[1] VAKUUMTECHNIK s.r.o., Slovak republic,

[2]Slovak University of Technology, Faculty of Mechanical Engineering, Institute of applied mechanics and mechatronics, Námestie slobody 17, 812 31 Bratislava, Slovak republic
marek.gasparik@stuba.sk

[3]University of West Bohemia, RTI, Univerzitní 22, 306 14 Pilsen, Czech Republic

Additive manufacturing *Al alloys* *Bicycle frame*

Abstract. Additive manufactured metals are in the transition phase from research of technology of 3D printing and their properties towards use in industrial practice. The article analyzes the possibilities of producing bicycle frames using 3D printing. The stresses in the bicycle frame are analyzed for the measured load spectra. The operational fatigue life of a frame made by 3D printing and conventional technology are compared.

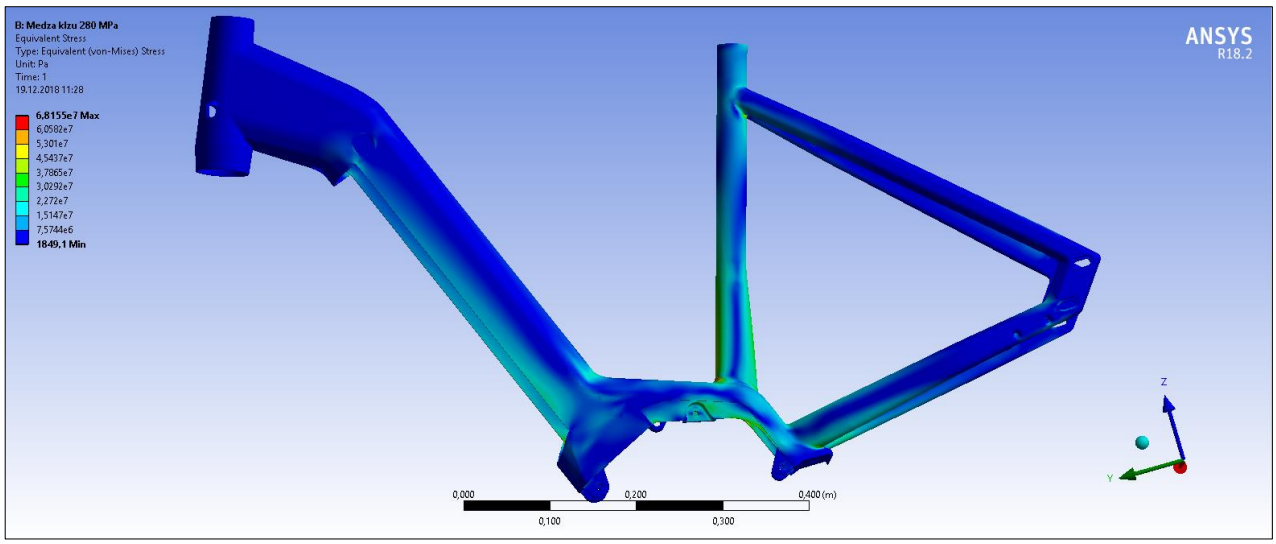

Figure 1 – *Stress-strain analysis of bicycle frame*

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Structural integrity analysis of a Kaplan turbine cover

Aleksandar Sedmak[1], Miodrag Arsić[2], Mirjana Opačić[3]

[1]*University of Belgrade, Faculty of Mechanical Engineering, Serbia*

[2]*Institute for Testing of Materials IMS, Belgrade, Serbia*

[3]*Innovation Center of the Faculty of Mechanical Engineering, Belgrade 35, Serbia*

Kaplan turbine cover *Structural integrity and life* *Ultrasound Testing*

Abstract Vertical Kaplan turbines are built in six hydro-power units 'Đerdap 1' (Kladovo, Serbia) with nominal power 176 MW. During recent revitalization and modernization of turbine aggregate A4 experimental investigation of the current state of turbine cover, made of structural steel St 3 (GOST standard), has been performed in order to analyse its structural integrity after 40 years of operation. In the scope of this investigation, the base metal and welded joints have been tested by non-destructive methods (NDT), as well as by testing of mechanical properties, including fracture mechanics parameters. In this paper results of magnetic particles and ultrasound testing of welded joints are presented, together with the chemical composition, tensile properties, impact toughness and fatigue crack threshold and growth rate for the base metal. Ultrasound testing (UT) indicated lack of penetration in weld metal and lamellar tearing in base metal. The latter one is in accordance with the reduced contraction of the base metal, as obtained by tensile testing, being significantly lower than the specified value. Also, fatigue crack threshold value is approximately two times smaller than expected for St 3 steel, whereas crack growth rate is significantly higher. These results indicate significant degradation of base material properties, requiring additional analysis to determine causes, including defects in welded joints. In addition, numerical analysis of the cover has been performed in different turbine operational modes to get all necessary stress distributions and enable structural integrity and life analysis. Despite significant degradation of the base metal and defects in weld joints, this analysis has shown that structural integrity of turbine cover is not jeopardized, not only because dynamic loading is just 5% higher than the static one, but also because defects in weld root (lack of penetration, Fig. 1) are much shorter than critical crack lengths, as evaluated by LEFM calculation.

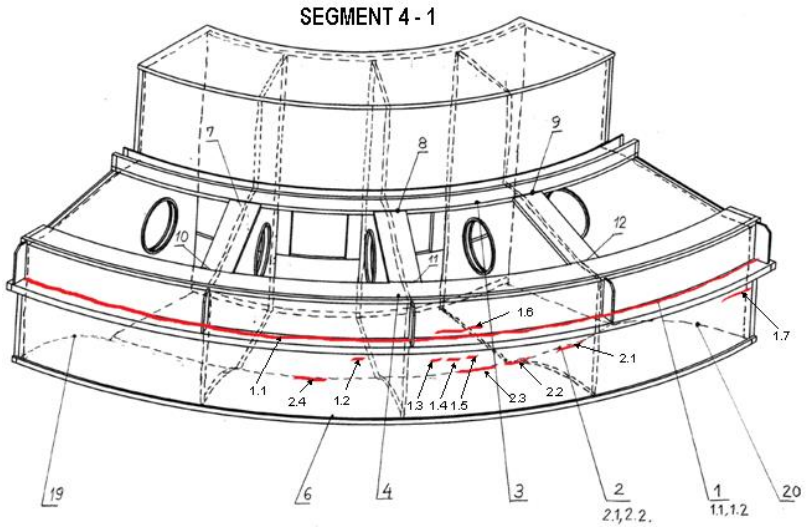

Figure 1 – *Location and indication of lack of penetrations as detected by UT*

Numerical simulation of fatigue crack growth in aircraft structure with a honeycomb mesh

M. Dinulović[1], A. Grbović[1], S. Sedmak[2], M. Aranđelović[2], T. Mijatović[2]

[1]*Faculty of Mechanical Engineering, University of Belgrade, Serbia*

[2]*Innovation Centre of Faculty of Mechanical Engineering, Belgrade, Serbia,*
simon.sedmak@yahoo.com

Extended finite element method *Fatigue* *Aircraft elements*

Abstract Work presented in this paper is one of the initial stages in the extensive research related to fatigue behaviour of structural elements which are commonly used in aerospace industry. The goal was to determine the number of fatigue cycles of one such structure, with a characteristic honeycomb-shaped geometry, in the presence of an initial crack. The locations of the crack were determined during the previous stage of the research, wherein a numerical model was subjected to three-point bending. Results indicated that there are two separate locations with highest stress values, and these locations were then adopted as the sites of crack initiation. For this reason, two extended finite element methods models were made, with slightly simplified geometry (only considering the part of the structure in the vicinity of the crack, as opposed to the whole, much larger model). In this case, aluminium was used as the material. Once the model is fully verified as representative, the next stage of research will commence, wherein aluminium is replaced with a newly developed composite material, which exhibits orthotropic behaviour and has more complex material properties, which vary with the direction.

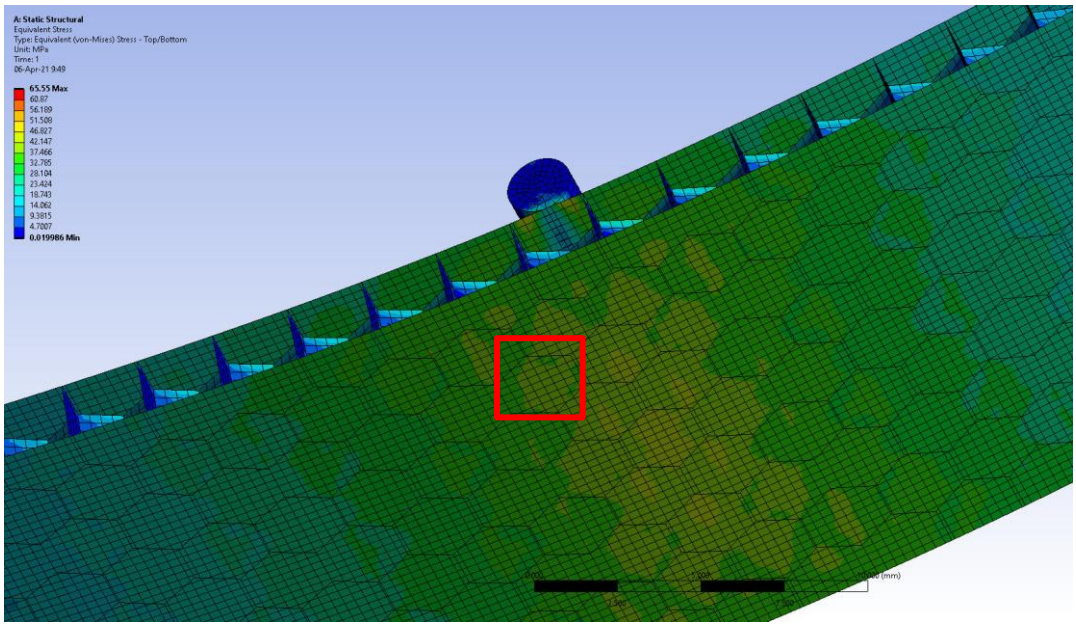

***Figure 1** – Model used for determining of highest stresses*

Analysis of fatigue behaviour of a bridge welded structure

Z. Burzić[1], A. Sedmak[2], S. Sedmak[3], S. Perković[1], I. Čamagić[4]

[1]Military Technical Institute, Belgrade, Serbia

[2]Faculty of Mechanical Engineering, University of Belgrade, Serbia, asedmak@mas.bg.ac.rs

[3]Innovation Centre of Faculty of Mechanical Engineering, Belgrade, Serbia,

[4]Faculty of Technical Sciences, K. Mitrovica, Serbia

Bridge welded structures *Fatigue crack growth* *Paris Law*

Abstract Results of extensive experiments involving the fatigue behaviour of welded structures which are a part of the "Gazela" bridge in Belgrade, Serbia, are presented in this paper. After non-destructive testing of these structures, crack-like defects were detected, and welded plates containing them were taken out for the purpose of destructive testing. This testing involved tensile tests, impact testing using an instrumented Charpy pendulum and fatigue tests, from which the S-N curves were obtained. Based on these results, fracture mechanics parameters were determined, including crack tip opening, critical J-integral, stress intensity factors and critical crack length. In addition, fatigue tests, which involved four point bending of standard Charpy specimens provided da/dN-ΔK curves, which were then used in order to determine Paris Law coefficient, C and m, Fig. 1. Obtained results are of great importance in order to better understand the behaviour of large-scale welded structures subjected to both static and dynamic (cyclic) loads, such as bridges.

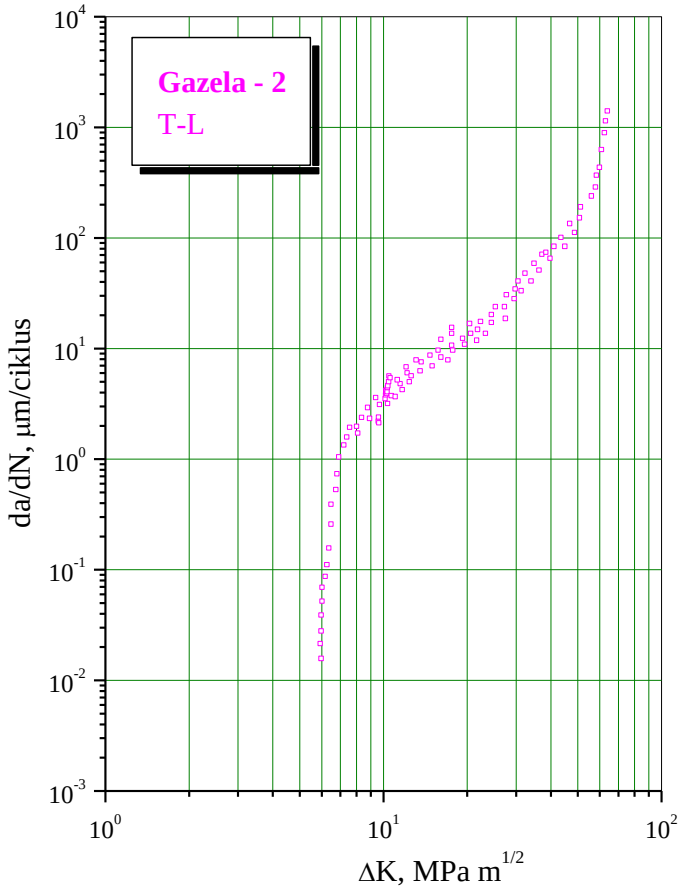

***Figure 1** – An example of the experimentally obtained results*

Crack identification in tungsten carbide using image processing techniques

Kafayat E Hazzan [1], Manuela Pacella [1]

[1] *Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Loughborough, Leicestershire, LE11 3TU, UK, M.Pacella@lboro.ac.uk*

Crack identification *Laser processing* *Tungsten carbide*

Abstract Laser processing of cutting tool materials particularly cemented carbides can induce many surface defects including porosity, balling and micro-cracks. Micro-cracks present in a microstructure can lead to chipping and early failure. The detection and identification of cracks can be used to predict tool performance. To develop a method for crack identification scanning electron microscopy (SEM) images were used. The manual review of SEM images is subjective and time consuming. This study presents a method to identify and quantify cracks from an SEM microstructure of tungsten carbide (WC) in MATLAB ®. Image processing algorithms were used to segment crack regions from other surface defects and the background; and subsequently to extract crack geometry and information. The results show successful segmentation of cracks from SEM images with an identification accuracy greater than 95 % across a range of different laser processing parameters.

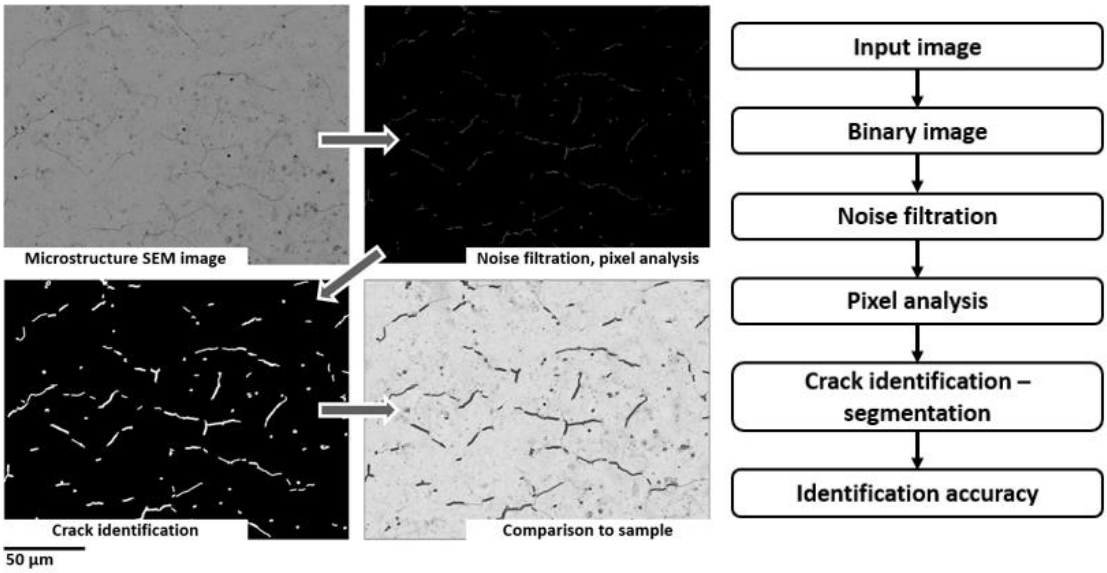

***Figure 1** – Outline of crack identification method in WC SEM.*

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Ultrasonically assisted turning of SiCp/Al composites

Jin Kim[1], Lorenzo Zani[1], A Abdul-Kadir[1], Marcelo L Ribeiro[2], Anish Roy[1],

Konstantinos P Baxevanakis[1], Lewis Jones[1], Vadim V Silberschmidt[1]

[1] *Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Loughborough, Leics. LE11 3TU, UK*

[2] *Aeronautical Engineering Department, São Carlos School of Engineering, University of São Paulo, Brazil.*

Ultrasonically assisted machining | *Aluminium Matrix Composites* | *Finite-element analysis*

Abstract Silicon carbide particle-reinforced aluminium (SiCp/Al) composites are poised to replace conventional alloys in aerospace and automotive industries thanks to their superior strength-to-weight ratio and high wear resistance. However, the processing efficiency of such a material is low due to abrasive SiC particles inducing high tool wear and surface defects as a result of particle-matrix and tool interaction during machining.

In this study, a SiCp/Al composite with a SiC particle size of <0.7 μm with a volume fraction of 17vol% was machined using both ultrasonically assisted turning (UAT) and conventional turning (CT) to compare and contrast the two machining processes. The results show an average force reduction in excess of 50% when machining using ultrasonic assistance. Thanks to rapid vibration in the machining direction the surface quality from UAT was improved considerably [1], with a resulting R_a being 28.4% lower when compared to that in CT. Tool wear was also qualitatively assessed after machining tests. UAT with formation of short chips demonstrated an appreciable reduction of built-up edge during machining since fewer particles accumulated at the tool tip. To complete the study, 3D finite-element models of both machining processes applied to aluminium-matrix composites were developed. These predictive numerical models accurately represent the cutting processes.

In conclusion, this study shows how ultrasonically assisted machining could play a key role in the manufacturing process of SiCp/Al, extending the tool life and enhancing the surface finish of machined parts.

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, Effectiveness of damage identification in composite plates using damage indices based on smoothing polynomials and curvelet transform: A comparative study

Andrzej Katunin[1], Sandris Ručevskis[2]

[1]*Department of Fundamentals of Machinery Design, Silesian University of Technology, Konarskiego 18A, 44-100 Gliwice, Poland, andrzej.katunin@polsl.pl*

[1] *Institute of Materials and Structures, Riga Technical University, Kipsalas iela 6A, Riga, LV-1048, Latvia, sandris.rucevskis@rtu.lv*

Damage identification *Damage indices* *Curvelet transform*

Abstract With continuously growing demands to the structural safety and reliability, effective damage identification methods in structures are crucial to react on the identified damage timely and perform necessary repairing or replacement actions. From the variety of available non-destructive testing techniques applied nowadays for this purpose, vibration-based damage identification is considered as effective and inexpensive approach widely used in mechanical and civil engineering applications. However, the research results in the last decades clearly indicate that detection and identification of small damage in structures requires additional processing of raw results acquired from a modal analysis. Usually, mode shapes or modal curvatures are taken into account during such a procedure due to their high sensitivity to structural damage. This is due to the ability of detection and localization of local decrease of stiffness indicating damage.

To-date, numerous approaches and algorithms have been developed for damage identification. These approaches can be grouped into two main categories: the approaches based on the damage index concept involving various processing techniques and the approaches based on direct application of various transforms. Within this study, we compare a performance of the approaches from both of these groups, namely, the damage indices based on smoothing polynomials and the curvelet transform. Both approaches are reference-free, which means that only a damaged structure is considered in the damage identification procedure and no reference data is necessary for a comparison purpose, which has significant practical meaning. The approach based on damage indices is selected due to its proven sensitivity to damage in previous studies, while the selection of the curvelet transform for processing of mode shapes was chosen due to its exceptional filtering capabilities and some other useful properties.

The studies were performed on experimental vibration data acquired for artificially damaged laminated composite structures. The advantages of the application of both approaches as well as their performance in terms of proper detection, localization, and identification of single and multiple damage sites were deeply analyzed and discussed. The results of this study show the superior filtering ability of both approaches, which makes it possible to identify small damage in composite structures using vibration data.

Quantitative Thermometry: A Revived Simplified Approach to Fatigue Strength Determination

Florian Schäfer[1], Jan Rosar[1], Michael Marx[1], Haoran Wu[2], Peter Starke[2]

[1]*Materials Science and Methods, Saarland University, Campus D2 3, 66123 Saarbruecken, Germany*

[2]*Materials Science & Materials Testing, University of Applied Sciences Kaiserslautern, Schoenstraße 11, 67659 Kaiserslautern, Germany*

Thermometry *Fatigue Strength* *Measurement Method*

Abstract It has long been known that plastic deformation and fatigue damage lead to a heat generation. In the past two decades, thermographic approaches have been improved and widely adapted to obtain an estimate for the fatigue strength from the change in temperature or the amount of heat generation. In this study, based on a 40-year-old, but never-established measurement technique using NTC thermistors, the temperature profile on a specimen was gathered and assessed based on state-of-the-art evaluation strategies, e.g. by using infrared camera technology. A direct comparison with thermographic measurement not only reveals the significantly higher resolution of this simple and inexpensive method. It also elucidated that in the transition from low to high heat generation, associated with a lower estimate for the fatigue strength, for some groups of materials the high resolution of the NTCs is necessary for a reliable determination.

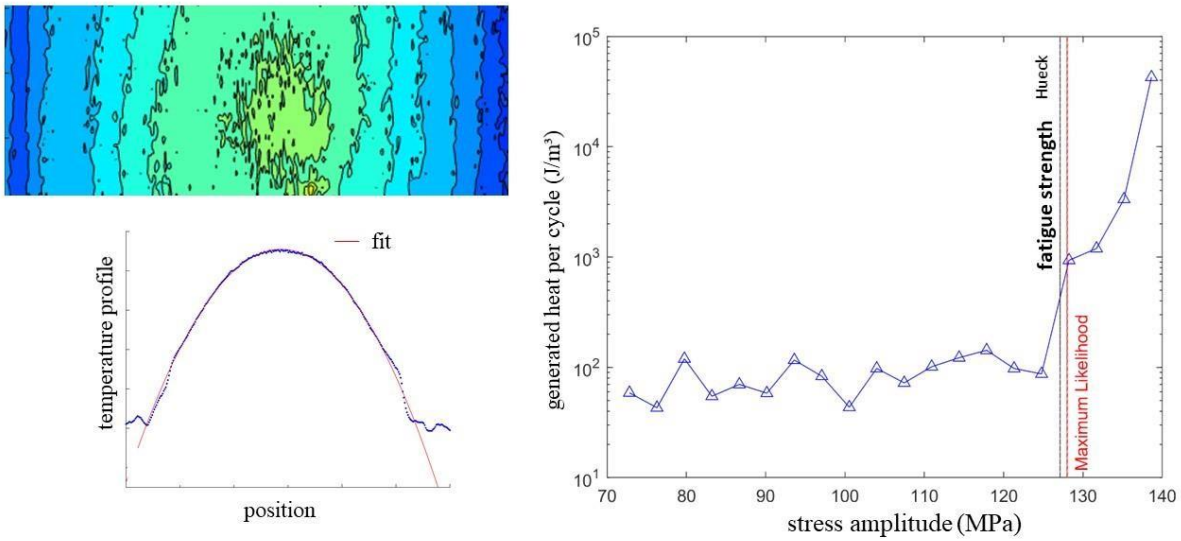

***Figure 1** – Graphical Abstract*

Eigenstrain Reconstruction from Contaminated Data using Inverse-EIM

Arun Agrawal[1]

[1]*Mechanical Engineering, Indian Institute of Technology, Kanpur, arunagrw@iitk.ac.in*

Inverse problem *Polynomial eigenstrains* *Matlab simulation*

Abstract. Eigenstrains are more localized compared to the elastic field induced by them and there is obvious relevance for inverse problem of eigenstrain reconstruction from the data, which enables convenient determination of the full elastic field. Elastic field data consists of observations at discrete locations through stresses using photo-elasticity; strains using digital image correlation or, is numerically simulated. Typically, data is contaminated with noise and errors and is not available in continuous form. Thus, the reconstruction of unknown eigenstrains is formulated as an ill-posed inverse problem, where the numerical solution is obtained through optimization procedure based on root-mean square error minimization.

This work uses extended form of equivalent inclusion method (EIM) for polynomial eigenstrains and focuses on the special feature stated as Eshelby's polynomial conservation conjecture. The analytical solutions show that prescribed eigenstrains of degree *m* induce elastic field with only half-series terms viz. having degree *m, m-2, ...,0* when m is even; and *m,m-2, ..., 1* when m is odd. Therefore, the conjecture implies that quadratic eigenstarins do not induce elastic field with linear terms, and vice-versa. A numerical example is shown for circular inclusion having radius ρ = 10m with elastic field measurements at 26 data points (Fig 1). Without the loss of generality, all computations use material parameters as κ_1 = 2.0; μ_1= 300 MPa. Through different selections of contaminated data types, the reconstruction solutions for the prescribed case of quadratic eigenstrains indicate that accompanying linear eigenstrain terms can cause undesired fluctuations in the presence of data noise. Thus, the reconstruction solution of the unknown eigenstrains is in agreement with the conjecture, based on inverse-EIM formulation.

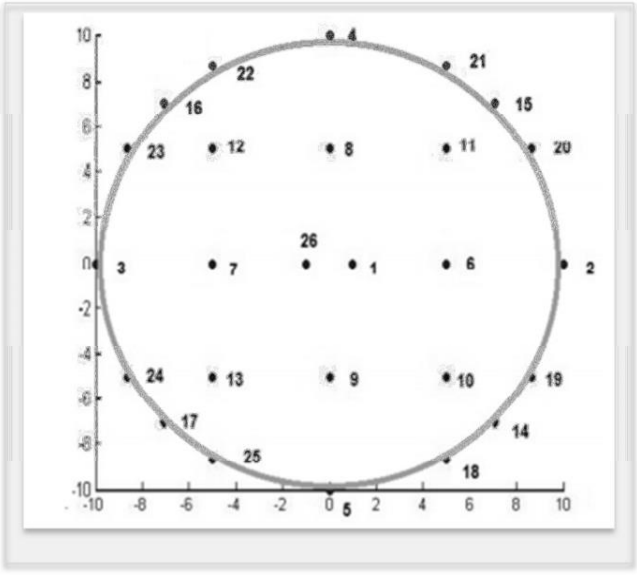

Figure 1 *– Configuration of Data Points*

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Fatigue Damage Assessment in a Welded Tubular Joint Under Random Loading

C. Ronchei[1], S. Vantadori[2], Andrea Carpinteri[2], Scorza Daniela[3], Andrea Zanichelli[2]

[1]Department of Civil Engineering, University of Calabria, via Pietro Bucci, 87036 Arcavacata di Rende (CS), Italy - email: camilla.ronchei@unical.it

[2]Department of Engineering & Architecture, University of Parma, Parco Area delle Scienze 181/A, 43124 Parma, Italy

[3]Department of Engineering, University of Naples Parthenope, Centro Direzionale Isola C4, 80143 Naples, Italy

fillet-welded joints *hot-spot approach* *multiaxial random fatigue*

Abstract As is well-known, crops are usually protected against harmful insects and herbs by using herbicides and fungicides. The most common machine used in pulverization process is the arm sprayer, which is a metallic bar equipped with spray nozzles. The bar is guided in the vertical movements by a structural component, called ‘‘H” component, consisting of fillet-welded tubular T-joints. Under service condition, the “H” component and its welded T-joints are subjected to forces, which are random in nature, and cracks are frequently observed in the stress concentration regions near the weld toe.

In order to define the strain state in the “H” component, firstly strain measurements were experimentally performed in some control points [1]. Then, the multiaxial random stress field in the “H” component was computed by means of a linear elastic finite element model, so that the numerical principal strain histories in the control points were equal to the experimentally registered ones.

The purpose of the present paper is to develop a novel procedure for fatigue damage assessment of fillet-welded joints under complex random loading. Such a procedure consists of two consecutive steps: (i) computation of the stress tensor at the verification point, according to the structural hot-spot stress approach; (ii) evaluation of damage (in the same verification point), by means of the multiaxial critical plane-based criterion by Carpinteri and co-workers for random loading, formulated in time-domain [2].

The novel procedure is applied to the T-joints of the “H” component in order to evaluate the region on the weld toe where cracks are expected to nucleate. The comparison between theoretical and experimental results related to crack nucleation position is quite satisfactory.

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Influence of the mesh size on plastic CTOD

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J. Sanchez-Mancera[1], D. Camas[1], P.A. Prates[2,3], F.V. Antunes[2]

[1] *University of Malaga, Department of Civil and Materials Engineering, Spain*

[2] *University of Coimbra, Centre for Mechanical Engineering, Materials and Processes (CEMMPRE), Department of Mechanical Engineering, Portugal*

[3] *University of Aveiro, Department of Mechanical Engineering, Centre for Mechanical Technology and Automation (TEMA), 3810-193 Aveiro, Portugal*

dcp@uma.es

Crack Tip Opening Displacement *Finite element method* *Fatigue crack growth*

Abstract The fatigue crack growth rate is experimentally correlated to the applied range of stress intensity factor, ΔK. However, the crack growth is taking place in an area where there are significant plastic deformations. At the same time, ΔK is an elastic parameter that cannot predict the influence of the load stress ratios and load history.

Elastic-Plastic Fracture Mechanics parameters such as the energy release rate, *G*, *J*-integral, or Crack Tip Opening Displacement (CTOD) have been used to represent the crack propagation when considering ductile materials. The CTOD is a parameter usually employed as a measurement of fracture toughness. Besides, it can be used as a crack driving force in fatigue predictions. This parameter can be decomposed into two different components: the elastic and the plastic one. The plastic component is responsible for the degradation of the material, while the elastic component is only affecting the atomic spacing.

In some recently published studies, the plastic CTOD range has been considered to study fatigue crack propagation instead of the range of stress intensity factor, which is an elastic parameter. The idea is to obtain a da/dN-ΔCTODp model, being ΔCTODp the range of plastic CTOD. For this purpose, it is necessary to obtain CTOD values with enough accuracy.

In this study, the influence of the mesh size on plastic CTOD results is analysed. For this purpose, a titanium CT specimen is modelled bi-dimensionally using the finite element method. Only one kind of element was employed to mesh the specimen. An element defined by four nodes with two degrees of freedom at each one. The mesh was divided into two different areas. The first one was defined around the crack growth region with a mesh size reduction, ranging from 4 to 64μm. The second one, where coarser elements were considered, is used in the rest of the model to not penalise the computational cost. Plane stress conditions were considered.

CTOD values were obtained in the first and the second node behind the crack front. It is concluded that the crack closure and the gradient of the linear behaviour increase with the increase of the element size. Although the CTOD at maximum load does not suffer significant variations for all the element sizes, the elastic CTOD decreases with the increasing of the element size while the plastic component increases.

Effect of primer and sealant in refill friction stir spot welded joints on strength and fatigue behaviour of aluminium alloys

Petr Homola[1], Roman Růžek[1], Anthony R. McAndrew[2], Jeroen De Backer[2]

[1] Czech Aerospace Research Centre, Beranových 130, 199 05 Prague 9 – Letňany, Czech Republic, homola@vzlu.cz

[2] TWI Ltd, Granta Park, Great Abington, Cambridge, CB21 6AL, UK

Friction stir welding *Primer* *Aluminium alloys*

Abstract The overall objective of the OASIS European project is to demonstrate the ability and cost-effectiveness of manufacturing aluminium aircraft structures using the latest developments in friction stir welding (FSW) and laser beam welding (LBW). Joining using rivets is more time consuming than using welding approaches enabling improved aerodynamics and light-weighting which subsequently will improve fuel efficiency and global competitiveness of the industry. The refill friction stir spot welding (RFSSW) is one of the promising FSW methods consisting in the joint creation by plunging and retracting the rotating tool into the overlapped sheets. Main advantage of this method is that the RFSSW process does not leave an exit hole after welding and is able to provide a larger weld area resulting in an improved weld strength.

This work aims to fulfil a knowledge gap related to use of aluminium semi-products in a final configuration state (including anodizing, primer and sealant application) for RFSSW process by means of the lap-shear and cross-tension mechanical test, fatigue performance, metallographic and fractographic analyses, and digital image correlation (DIC) technique. Sheet semi-products of thicknesses from 2 to 3 mm made of AA7050-T7451 and AA2024-T3 aluminium alloys in bare and/or anodized condition were used for the lap-joint specimens manufacturing and five various material joint combinations were analysed.

The effect on static strength for the joint configurations with primer and sealant was studied and compared with the bare material's RFSSW joints. From previous experiments, it is known that the sealant does not negatively affect the mechanical properties and it improves the lap-shear and fatigue properties in most situations. Fatigue tests showed that the primed configurations exhibited a higher scatter of the results and a different slope of fatigue curve with a higher fatigue limit value as compared with the bare material's joints exhibiting a higher ultimate static strength.

, **Acousto-Ultrasonic Investigation of corrosion in CORTEN steel by Deep Learning Neural Network approach**

Claudia Barile, Caterina Casavola, Giovanni Pappalettera, Vimalathithan Paramsamy Kannan

Dipartimento di Meccanica Matematica e Management, Politecnico di Bari, Via Orabano 4, 70125 – Bari, Italy

pk.vimalathithan@poliba.it

The integrity of the CORTEN steel exposed to corrosion agents is studied using Acousto-Ultrasonic approach. The Acousto-Ultrasonic approach was tested before and after exposing the CORTEN steel to the three different corrosion agents. The differences in the acoustic emission descriptors peak amplitude, energy, duration and counts before and after the corrosion exposure are compared to describe the integrity of the CORTEN steel. Furthermore, the waveforms recorded from the Acousto-Ultrasonic tests are analysed using Mel Spectrogram. The attenuation in the wave propagation due to the extent of corrosion in different CORTEN steel is studied using CWT/Mel scale. A Deep Learning Neural Network is constructed for analysing the waveforms recorded from the Acousto-Ultrasonic test. Deep learning is used to classify the characteristic acoustic emission waveforms propagated through the CORTEN steel exposed to three different corrosion agents. The Convolutional Neural Network (CNN) is built in MATLAB and is trained to classify the acoustic emission waveforms recorded from the Acousto-Ultrasonic test.

, 3D simulation models for developing digital twins of heritage structures: challenges and strategies

A. Shabani[1], M. Skamantzari[2], S. Tapinaki[2], A. Georgopoulos[2], V. Plevris[3,1] and M. Kioumarsi[1]

[1] *Department of Civil Engineering and Energy Technology, Oslo Metropolitan University, Pilestredet 35, 0166 Oslo, Norway (amirhose, mahdik)@oslomet.no*

[2] *Laboratory of Photogrammetry, School of Rural and Surveying Engineering, National Technical University of Athens, Greece (mskamantz, tapinaki, drag)@central.ntua.gr*

[3] *Department of Civil and Architectural Engineering, Qatar University, Doha, Qatar vplevris@qu.edu.qa*

3D Geometric Documentation *Cultural Heritage* *Digital Twins*

Abstract Structural vulnerability assessment of heritage structures is a pivotal part of a risk mitigation strategy for preserving these valuable assets for the nations. For this purpose, developing digital twins has gained much attraction lately to provide an accurate digital model for performing finite element (FE) analyses. Three-dimensional (3D) geometric documentation is the first step in developing the digital twins, and various equipment and methodologies have been developed to facilitate the procedure. Both aerial and terrestrial close-range photogrammetry can be combined with 3D laser scanning and geodetic methods for the accurate 3D geometric documentation. The data processing procedure in these cases mostly focuses on developing detailed, accurate 3D models that can be used for the FE modeling. The final 3D surface or volumes are produced mainly by combining the 3D point clouds obtained from the laser scanner and the photogrammetric methods. 3D FE models can be developed based on the geometries derived from the 3D models using FE software package. As an alternative, developed 3D volumes provided in the previous step can be directly imported to some FE software packages. In this study, the challenges and strategies of each step are investigated by providing examples of surveyed heritage structures.

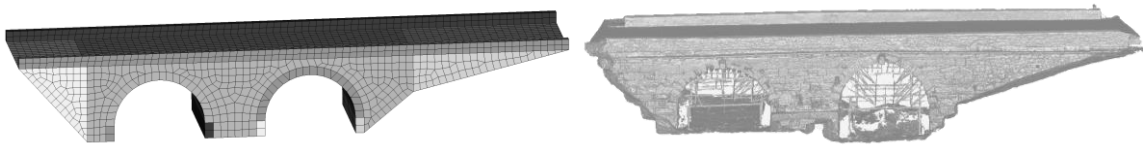

Figure 1 - *The 3D FE model (left) and the 3D model produced from the geometric documentation process (right).*

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NLFEA based design optimization of GFRP stirrups in partially confined concrete

Djenad Sonia[1*], Ait Taleb Souad[2], Si Salem Abdelmadjid[1] and Bouzidi M. Amin[1]

[1]*Laboratory of Construction Engineering and Architecture (LGCA), Faculty of Technology, University of Bejaia, 06000 Bejaia, Algeria ; * soniadjenad@gmail.com*

[2]*Civil Engineering Department, University Mouloud Mammeri of Tizi Ouzou, 15000, Algeria*

FRP Stirrups *NLFE-Analysis* *Confined concrete*

Abstract The present study aims to introduce a nonlinear finite element approach (NLFEA) carried out on precracked and repaired concrete members. The main objective is to assess the effect of design parameters of FRP composite stirrups based on various confinement rate. The constitutive materials were modeled according to numerical models embedded in ABAQUS code namely: Concrete Damaged Plasticity model to take into account the nonlinear behavior of compressive and strained concrete, coupled with damages theory to represent the cracks evolution and to be used for precracking. An orthotropic elastic model to predict FRP behavior with Tsai-Wu failure criteria is used. The proposed approach is validated by experimental models available in the literature. In conclusion, the predicted numerical results for various design of FRP stirrups and damage configurations highlight the promising of used FRP composites in the repair of concrete members in terms of mechanical performances enhancement.

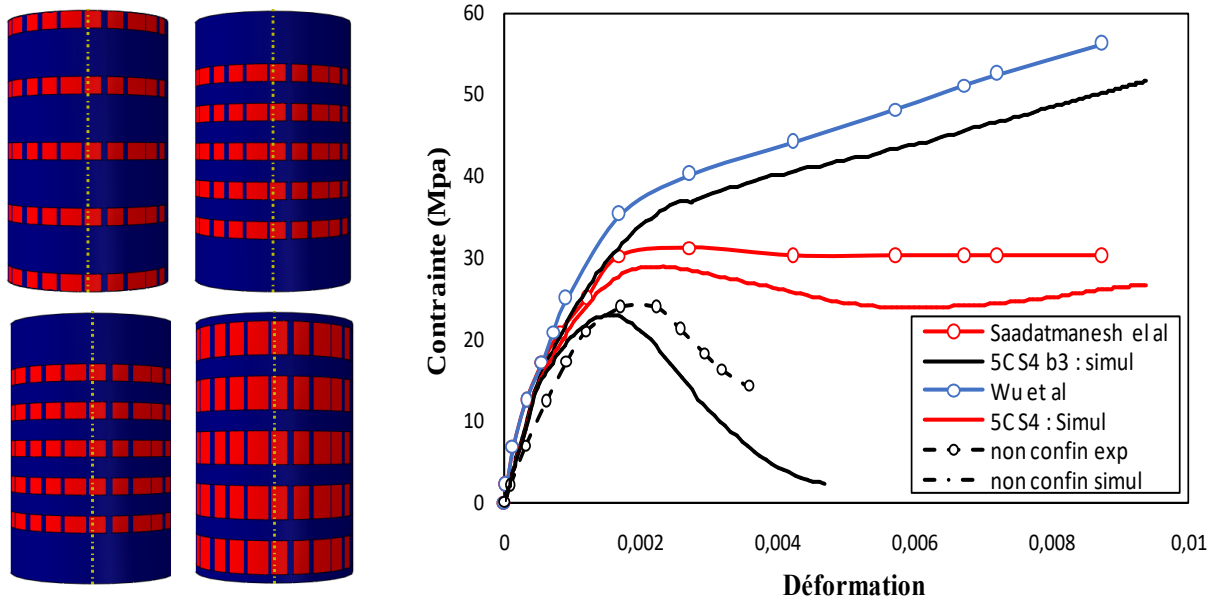

***Figure 1** – Main considered specimens and models validation*

Overloading effect on transient fatigue crack growth of TiAl6V4 parts produced by Laser Powder Bed Fusion

L. Borrego[1,2], J. Jesus[2], J.M. Ferreira[2], C. Capela [2,3], J.D. Costa [2]

[1] Coimbra Polytechnic – ISEC, Department of Mechanical Engineering,

Rua Pedro Nunes, 3030-199 Coimbra, Portugal; borrego@isec.pt

[2] Univ Coimbra, Centre for Mechanical Engineering, Materials and Processes (CEMMPRE), Department of Mechanical Engineering, P-3004 516 Coimbra, Portugal

[3] Mechanical Engineering Department, ESTG, Polytechnic Institute of Leiria, Portugal

KEYWORDS: Additive manufacturing, fatigue crack propagation, overloads, Titanium TiAl6V4 alloy.

ABSTRACT

Laser Powder Bed Fusion (LPBF) is one additive manufacturing (AM) technology increasingly used in the production of specific applications, like medical devices and aeronautical parts. Under cyclic loading, fatigue behaviour of SLM parts is mainly driven by local phenomenon, like: porosities, surface roughness, residual stresses and microstructure. For many of these applications, TiAl6V4 alloy is commonly used, because of its high strength, low weight and excellent biocompatibility.

This paper presents results of fatigue crack propagation of titanium alloy TiAl6V4 parts manufactured by laser powder bed fusion (LPBF), obtained using standard 6 mm thick compact specimens (CT). Both the propagation under constant amplitude loading and the transient behaviour after the application of overloads/underloads were studied. The effects of the mean stress and the transient retardation were analysed by using the crack closure parameter. Significant effect of the overload application was observed. Current study concluded that crack closure was the main parameter for mean stress effect and transient retardation, and allows uniform results in a single fatigue crack propagation curve. Contrary to significant overloading effect here observed, mainly justified by crack closure, underloading application did not produced detectable effect with the experimental apparatus used in the current work.

, Investigation of Crack Formation and Propagation in AA7475 using Multiple Potential Drop Measurement

Jürgen Bär, Mike Nahbein

Universität der Bundeswehr München, Institute of Materials Science,
D-85577 Neubiberg, Germany
juergen.baer@unibw.de

Fatigue *Crack detection* *Potential drop measurement*

Abstract The direct current potential drop method (DCPD) is a well known method for crack detection and crack length measurement in fatigue experiments. Recent Investigations have shown that with multiple potential drop measurements the location of crack initiation can be determined in round bars (Hartweg and Bär, 2019) and single edge notched specimens (Wiehler and Bär, 2020).

In this work a more detailled investigation of crack initiation and propagation is undertaken on single-edge notched specimens. The specimen were equipped with three potential probes – on the frontside (U_f), on the backside (U_b) and on the narrow side (U_n) of the specimen. During the fatigue tests all three potentials were measured simultaneously using amplifiers of the control electronics. The crack front was marked on the fracture surface by introducing overloads in defined intervals to allow a direct comparison between the meaured potential drop and the real crack location and crack front geometry.

In a first step relative Potentials P_i (i= f, b and n) were calculated by normalizing the actual potential on the potential of the crack-free specimen. To localize the crack initiation site and to eliminate temperature effects quotients of the potentials were formed by diding P_f and P_b by P_n, respectively. By comparing the runs of the potential quotients plotted over the cycle number, the time of crack initiation and the location of the crack initiation site can be determined. In addition, the run of the quotients gives information about the shape of the crack front of long fatigue cracks.

References

Hartweg, M.; Bär, J.; 2019. Analysis of the crack location in notched steel bars with multiple DC potential drop measurement, Procedia Structural Integrity 17, 254-261; DOI: 10.1016/j.prostr.2019.08.034.

Wiehler, L.; Bär, J.; 2020 Crack Detection and Localization with Multiple Potential Drop Measurement, Procedia Structural Integrity 28, 925-932; DOI: 10.1016/j.prostr.2020.11.065

CLT-concrete composite slab optimization

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Carlos Martínez-Criado[1], José-Ramón Aira[2]

1 Department of building structures and physics. ETS Arquitectura. Universidad Politécnica de Madrid. Avda. Juan de Herrera, 4, 28040 Madrid, Spain. Email: carlos.mcriado@upm.es

2 Department of architectural construction and technology. ETS Arquitectura. Universidad Politécnica de Madrid. Avda. Juan de Herrera, 4, 28040 Madrid, Spain. Email: joseramon.aira@upm.es

Successive Gamma Method *CLT-concrete composite floor* *Optimization*

The CLT-concrete slab solution contributes to notably improve several aspects where CLT shows some disadvantages related to its low stiffness or its low natural vibration frequency. This can affect the user's comfort or even the structural integrity against resonance phenomena. A concrete topping working along the CLT contributes positively to mitigate these weaknesses.

The current investigation work aims to analytically optimize the CLT-concrete composite floor under strength and stiffness criteria. Given the fact it is a complex and recently conceived constructive solution, there is still a lack of regulations when it comes to its calculation, which relegates the subject to a theoretical and investigation-related field. A new analytic method is proposed in this paper in order to obtain the effective bending stiffness based on the successive application of the gamma method (Successive Gamma Method or SGM) which could be used for the calculation of composite CLT-concrete sections of three, five or even more layers. In comparison with most extended methods within the scientific community, SGM provides a slightly higher bending stiffness and a similar answer when the span or the distance between supports changes.

The structural, economic and environmental answers of the optimized CLT-concrete composite floor have been studied through three different study cases in Spain. The solution has been compared with a simple reinforced concrete slab and a CLT slab too. It should be noted that the composite slab solution improves the mechanical properties and, besides, it is the deformation and not the strength which results more restrictive. From an economic point of view, the simple reinforce concrete slab is the cheapest, but from an environmental perspective the composite slab improvement is notable. When dimensioning for residential and administrative use, the slenderness (span/thickness) of the composite solution varies from 26 to 33 approximately.

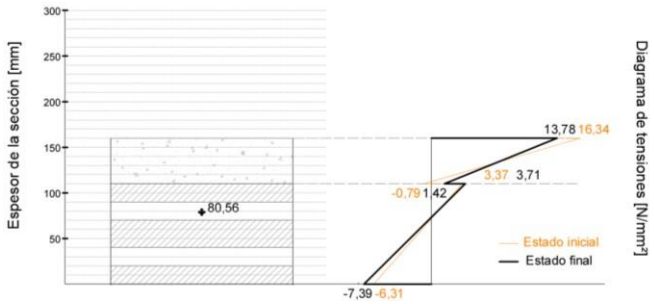

***Figure 1** – Stress diagram of a CLT-concrete composite floor*

Proof of concept for impact and flaw detection in airborne structures

Gabriel Vivas[1], Jon González[1], Josu Etxaniz[1], Gerardo Aranguren[1]

[1]Faculty of Engineering, University of the Basque Country, 48013 Bilbao, Spain; josu.etxaniz@ehu.es

Ultrasound test *SHM* *Composite*

Abstract All structures are subject to unwanted and uncontrolled bumps. For instance, when considering airborne vehicles, birds, hail, and meteors are usual sources of collision. Depending on the location and energy of the impacts, they can weaken the structure critically. On the other hand, ageing, scratching, corrosion, and manufacturing flaws also weaken structures. Furthermore, the subsequent damage could not be visible, as it usually happens in composite made structures. In addition, the cost of visual maintenance inspection, which is not negligible, sometimes could be just a waste of time and money.

Literature reports many laboratory researches on impact and/or flaw detection in metal and composite specimens. They include instrumentation such as general-purpose oscilloscopes, which usually are limited in size, weight, and number of channels to take measurements. The size of equipment and accessibility for the structure integrity testing are not major issues when dealing with big and heavy structures, as the civil ones. However, when the structures are lighter, such factors turn to be relevant. For instance, the integrity inspection on airborne vehicles requires reliable small lightweight electronic equipment with high technical capability.

This paper focuses on the detection of impacts and flaws of structures in airborne vehicles with the same instrumentation. The structures are made of materials as different as aluminum and composite (CFRP) are. They show completely different performance during the tests.

The paper provides a compact, lightweight, and powerful proof of concept for the implementation of an impact and flaw detection system. Two types of tests were performed, the ones to detect impacts, and those to detect flaws. Both are based on the propagation of ultrasound acoustic waves. The setup of the tests includes the structure under test, a set of transducers, an electronic monitoring system (SHMUS), and the software to control the monitoring tool. Some piezoelectric transducers attached to the structure under test transform the electric signals into acoustic waves and vice versa. Acoustic waves propagate along the material and the waves change with any new imperfection inside the structure due to damage.

The first type of tests are based on the Impact Detection System (IDS) included in SHMUS. Any impact on the structure under test generates an acoustic wave that IDS detects. The parameters of the waveform generated depend on the energy that the impact provides. The second type of tests, the flaw detection tests, are performed with SHMUS, which generates and acquires electric signals, and simplify them for further analysis and health diagnosis of the structure. Once an impact is detected, it is critical to know the degree of damage caused to the structure. To this end, SHMUS can perform an SHM test, the second type one.

The paper gives more details about the test methodology and discusses proof of concept testing results. The results show that the monitoring system SHMUS satisfactorily detects impacts and flaws as well as measures the damage as a decrease of the health of the structure under test. Furthermore, the decrease detected is proportional to the severity of the damage. Finally, the paper draws conclusions and points out future works.

, Effect of specimen configuration and notch root angle on fatigue behavior of novel dissimilar resistance spot welds of AA5754 to HSLA steel

Liting Shi[1,2,4], Jia Xue[2], Jidong Kang[2], Amberlee S. Haselhuhn[3], Blair E. Carlson[3]

[1] School of Materials Science and Engineering, Tianjin University, Tianjin, 300072, China

[2] CanmetMATERIALS, 183 Longwood Road South, Hamilton, Ontario, L8P 0A5, Canada

[3] General Motors Global R&D Center, 30470 Harley Earl Blvd, Warren, MI 48092, U.S.A.

[4] China Automotive Technology and Research Center Co. Ltd., 68 East Xianfeng Road, Tianjin, 300300, China

jidong.kang@canada.ca

shiliting@catarc.ac.cn

Fatigue life *Resistance spot welding* *Al-steel dissimilar welding*

Abstract Facing the stringent requirements for fuel economy and regulations for greenhouse gas emissions, structural lightweighting using multi-material solutions has become commonplace in the automotive industry. When joining dissimilar materials such as aluminum to steel by resistance spot welding (RSW), a thin layer of brittle intermetallic compound forms at the aluminum-steel interface and dominates mechanical behavior of the joint. In this contribution, RSW of 1.1 mm thick AA5754 to 2.0 mm thick high-strength low-alloy (HSLA) steel sheet was performed using multi-ring domed (MRD) electrodes and multiple solidification weld schedules to achieve acceptable static joint strength. Load-controlled fatigue tests were conducted, and the results show that the fatigue life is longer in the AA5754 to HSLA steel spot welds than that of the 1.1 mm thick AA5754 joined to itself (aluminum-aluminum). Structural stress analysis revealed that all fatigue life data points from both the lap-shear and coach-peel configurations fall onto a single master curve indicating that the weld nugget diameter is the controlling parameter for fatigue life. Finite element simulation considering material inhomogeneity in the weld further confirms that a large notch root angle at the weld nugget is beneficial to yield longer fatigue life as less maximum principal strain occurs in the aluminum sheet in the AA5754-HSLA steel spot welds compared to AA5754 joined to itself.

, Comparison between design guidelines in predicting FRP contribution to shear capacity of strengthened RC beams

Haya H. Mhanna[1], Rami A. Hawileh[2,*], Jamal A. Abdalla[3]

[1]*Department of Civil Engineering, American University of Sharjah, Sharjah, United Arab Emirates, hmhanna@aus.edu*

[2]*Department of Civil Engineering, American University of Sharjah, Sharjah, United Arab Emirates, rhaweeleh@aus.edu*

[3]*Department of Civil Engineering, American University of Sharjah, Sharjah, United Arab Emirates, jabdalla@aus.edu*

*Corresponding Author, E-mail: rhaweeleh@aus.edu

Fiber-reinforced polymers *FRP shear predictions* *retrofitting*

Abstract In the past few years, strengthening and retrofitting of reinforced concrete (RC) structures using externally bonded (EB) fiber-reinforced polymers (FRP) laminates has been deemed as a promising rehabilitation technique. Structural applications of FRP include flexural and shear strengthening of RC beams and confinement of columns. Many guidelines and standards were developed to predict the contribution of FRP to the strength of structural members. For shear strengthening applications, in particular, most of the design guidelines tend to underestimate the capacity of the strengthened members, whereas other models provide unsafe predictions. The accuracy of the models is dependent on many factors, such as but not limited to the wrapping scheme, amount of internal shear reinforcement, shear crack angle, concrete compressive strength, number of FRP layers, and FRP type. For this purpose, this paper focuses on comparing and evaluating the accuracy of the available FRP shear design guidelines. The design standards that are considered in this study are the American Concrete Institute (ACI440.2R-17), the Canadian Standards Association (CSA-S806.12 (R2017)), the technical report task group 5.1 (fib bulletin 90), and the Concrete Society in the UK (TR55). The accuracy of the design models was assessed against an experimental database collected from the literature. The database included RC beams externally strengthened in shear with different FRP types, configurations, and wrapping schemes. In addition, the database included strengthened beams with varying types of anchors. Results showed that most design codes provide reasonable predictions to the FRP shear strength in case of U-wraps. However, the guidelines are significantly conservative in case of complete wraps and anchored specimens.

Evaluation the effect of FRP anchor embedment depth on the flexural bond capacity of concrete prisms

Ghusoon S. Alshami[1], Rami A. Hawileh[2,*], Jamal A. Abdalla[3], and Haya H. Mhanna[4]

[1] *Graduate Student, Department of Civil Engineering, American University of Sharjah, P.O. Box 26666, Sharjah, United Arab Emirates, g00084800@aus.edu*

[2]*Department of Civil Engineering, American University of Sharjah, Sharjah, United Arab Emirates, rhaweeleh@aus.edu*

[3]*Department of Civil Engineering, American University of Sharjah, Sharjah, United Arab Emirates, jabdalla@aus.edu*

[4] *Department of Civil Engineering, American University of Sharjah, Sharjah, United Arab Emirates, hmhanna@aus.edu*

[*]*Corresponding author, email: rhaweeleh@aus.edu*

Flexural strengthening *CFRP* *FRP spike anchors*

Abstract The use of fiber-reinforced polymer (FRP) composites to strengthen and retrofit existing reinforced concrete (RC) structures has gained wide acceptance, owing to the superior properties of FRPs such as high strength-to-weight ratios and corrosion resistance. Externally bonded FRP (EB-FRP) laminates can be applied to enhance the flexural and shear capacities of RC beams and improve the ductility of RC columns. However, the premature debonding of FRP laminates from the concrete substrate is a major concern and usually results in a brittle member failure. To tackle this issue, many studies proved that adequate anchorage systems could improve the FRP-to-concrete bond, and therefore results in delaying FRP debonding and improves utilizing the tensile strength of the FRP laminates. One of the most commonly used anchorage systems is FRP spike anchors. Compared to other anchorage systems (for e.g. metallic anchors), FRP anchors have high compatibility with FRP laminates. In addition, FRP spike anchors are noncorrosive and have high tensile strengths. Although several studies addressed FRP spike anchors in flexural and shear strengthening of RC beams and slabs, the literature still lacks comprehensive information on the effect of all anchor parameters on the performance of such anchors. As a result, the aim of this study is to investigate the effect of anchor embedment depth on the behavior, strength, and effectiveness of the FRP spike anchorage system. Twelve concrete prisms were cast and strengthened with carbon FRP (CFRP) laminates and spike anchors. In addition, six prisms were cast to act as benchmark specimens, three were unstrengthened and three were strengthened with one layer of unanchored CFRP laminate. The anchor embedment depths considered were 50, 75, 100, and 125 mm. The prisms were tested in flexure under four-point bending tests and the results in terms of load-deflection responses, ultimate load, and strain in the FRP laminates were analyzed. Test results showed that installing CFRP spike anchors increased the capacity of the unanchored concrete prism by 80 - 120%. In addition, anchoring the laminates enhanced the capacity of the unanchored strengthened prisms by 11, 13, 15, and 33% for the 50, 75, 100, and 125-mm embedment depths, respectively. As a result, it was concluded that increasing the anchor embedment depths increased the ultimate load carrying capacity of the prisms.

Modelling the impact of climate change on a novel Irish Concrete Bridge

David R. Wallace[1], Paraic C. Ryan[2]

[1]ME Student, Dept. of Civil, Structural and Environmental Engineering, University College Cork, Cork, Ireland. Email: d.r.wallace@umail.ucc.ie

[2] Civil Engineering Lecturer, Dept. of Civil, Structural and Environmental Engineering, University College Cork, Cork, Ireland. Email: paraic.ryan@ucc.ie

Climate Change *Reinforcement Corrosion* *GGBS*

Abstract This paper assesses the impact of climate change on the novel repair of a reinforced concrete marine bridge on Ireland's south-east coast. Five unique durability solutions were applied to the seven crosshead beams on Ferrycarrig Bridge during its repair in 2007. Two of these solutions are examined in this research. The durability advantages of concrete containing Ground Granulated Blast Furnace Slag (GGBS) as a partial cement replacement material have been well established. However, the impact of climate change on such a solution has been subject to limited research. Changes to environmental policy mean that the use of GGBS in reinforced concrete (RC) structures is becoming increasingly popular. Thus, understanding its performance when subject to global warming is imperative. Chloride ingress and concrete crack modelling are completed to accurately determine how climate change will affect the service life of the crosshead beams in which the Ordinary Portland Cement (OPC) and GGBS concrete solutions are adopted. The results stemming from such modelling are used to determine the impact of reinforcement corrosion and concrete spalling on the crosshead beams' structural capacity and propose how GGBS may be used to its optimal potential in future RC infrastructure projects. Results obtained during this research indicate that without consideration for climate change, the GGBS concrete utilised is 4.75 times more resistant to severe cracking caused by chloride-induced reinforcement corrosion than the OPC concrete used. However, the durability of the GGBS concrete is affected by climate change more significantly than OPC, with a lifetime reduction of 15.8% associated with the worst-case climate change scenario considered. On the other hand, the associated reduction for OPC concrete is just 2.7%. Although GGBS concrete is more heavily impacted by climate change, its durability advantages over traditional OPC concrete make it a more attractive material for use in RC infrastructure applications.

	No Climate Change		**RCP4.5**		**RCP8.5**	
	Years	Decrease	Years	Decrease	Years	Decrease
OPC	40.44	-	39.35	2.7%	39.35	2.7%
GGBS	191.95	-	171.40	10.7%	161.54	15.8%
Relative Merit	4.75		4.36		4.11	

Figure 1 – *Time to severe cracking comparison*

Mechanical Characterization of PDMS with Different Mixing Ratios

Flaminio C. P. Sales[1], Ronaldo M. Ariati[1], Verônica T. Noronha[1], João E. Ribeiro[1,*]

[1]ESTiG, Instituto Politécnico de Bragança, 5300-052, Bragança; Portugal; jribeiro@ipb.pt;*

PDMS *Tensile Test* *Hardness Test*

Abstract: Polydimethylsiloxane (PDMS) is a transparent, biocompatible, flexible, simple processing, chemically and thermally stable polymer that has been attracting attention due to its wide range of applications in mechanical, civil and electronic engineering and biomedical field. In order to improve PDMS' properties, many studies have been made, investigating the effect of the mixing ratios of its components (base polymer and curing agent) on the mechanical properties, once they affect the number of interactions between the polymer chains of the material. With the aim to make a comparison of the mechanical response of pure PDMS (SYLGARD 184) with different ratios of the base elastomer and the curing agent, tensile and hardness tests were performed. The tested mixing ratios were 10:1, 10:2 and 10:3 (base: curing agent). Tensile tests were executed in a universal tester machine, set up with a velocity of 500 mm/min and pre-load of 1 N. An analogical portable durometer type Shore A was used to carry out the hardness test, according to ASTM D2240. The results for the tensile test are presented in Figure 1, showing that the increase of the amount of cure agent reduced the tensile strength. The hardness values obtained were 41.7±0.95, 43.2±1.03 and 37.2±1.14 Shore A for pure PDMS with ratios equal to 10:1, 10:2 and 10:3, respectively.

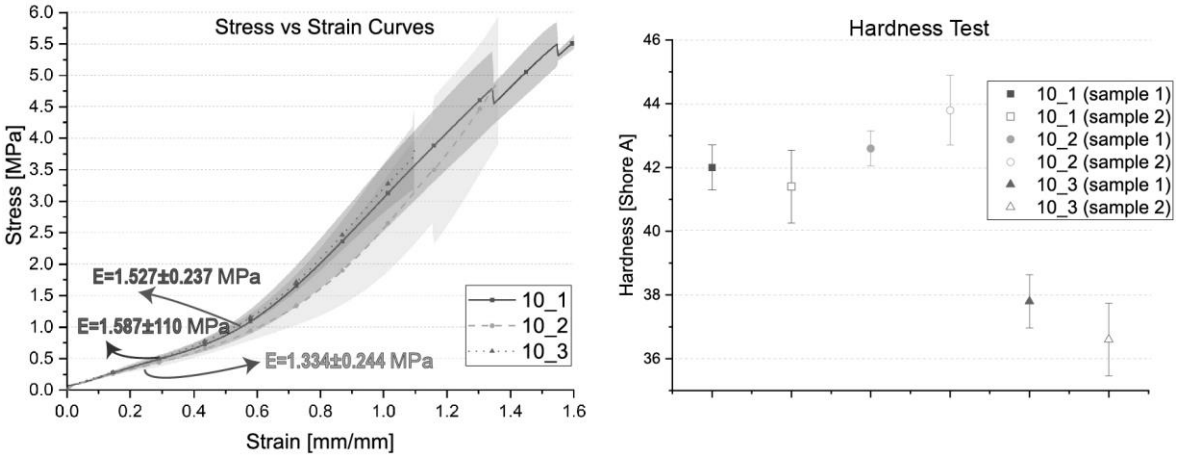

***Figure 1** – Engineering Stress versus Engineering Strain curves and hardness test results for pure PDMS with ratios 10:1, 10:2 and 10:3.*

, PU tensile tests: conventional and digital image correlation analysis.

Flaminio C. P. Sales[1,2], Ronaldo M. Ariati[1], Verônica T. Noronha[1], Romeu R. C. da Costa[2], João E. Ribeiro[1,*]

[1]ESTiG, Instituto Politécnico de Bragança, Portugal, [*]jribeiro@ipb.pt

[2]Dept. Eng. Mecânica, UTFPR, Cornélio Procópio, Brasil.

Polyurethane *Tensile Test* *Digital Image Correlation*

Abstract: Polyurethane (PU) is an extremely versatile polymer, used as coating, paint, foam, adhesive, and even in biomedical devices. It can be combined with additives such as Calcium Carbonate ($CaCO_3$), an inexpensive material, widely available in nature, or with fibers, as in glass fiber reinforced composites (FRC), explored in several sectors, such as aerospace and automobile industry. To determine the mechanical properties of these materials, the tensile test is the most used due to its great ease of application and method flexibility. However, conventional processes, such as the use of strain gauges or crosshead displacement data, may not provide detailed information about the strain field, or cannot be able to evaluate the Poisson's ratio and the true stresses for the entire curve. Thus, digital image correlation (DIC) methods are a promising alternative, consisting of strain field measurement without contact with the surface of the structure. In this context, this study carried out the tensile characterization of two main polyurethane samples: one petrochemical, distributed by Sika®, reinforced with type E glass fiber (Figure 1a); and the other, natural, manufactured by Kehl® from castor oils, and combined with $CaCO_3$ particles. During the tests, DIC was applied (figure 1c) to calculate the Poisson's ratio and, subsequently, Scanning Electron Microscopy (SEM) images were analyzed, revealing a higher number of bubbles on Sika's polymer, which contributes to the reduction of the maximum supported stresses, since these pores, with dimensions of up to 25 µm, were regions where the cracks started and headed the breakage. Poisson's ratios were all around 0,4 and the highest tensile strength values were obtained from E-glass reinforced samples (TS015), around 117.24 ± 13.20MPa. $CaCO_3$ particles also acted as reinforcements, increasing maximum stress from 20MPa to values between 29 and 37MPa.

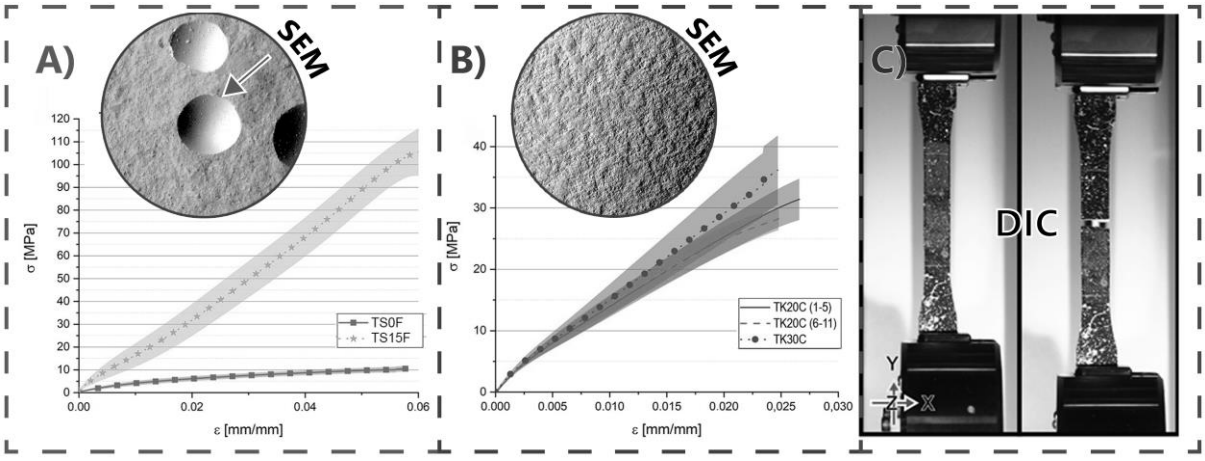

Figure 1: *Stress Strain curves for: a) Natural PU, pure (TS0F) and glass fiber reinforced (TS15F); b) Petrochemical PU, combined with 20 and 30%wt $CaCO_3$; c) DIC*

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Global and local fracture behavior in a brittle solid with a set of pre-existing small-scale cracks

Koji Uenishi[1,2], Kunihiro Nagasawa[2]

[1]Department of Advanced Energy, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8561 Japan

[2]Department of Aeronautics and Astronautics, The University of Tokyo, 7-3-1 Hongo, Bunkyo, Tokyo 113-8656 Japan, kunihiro@g.ecc.u-tokyo.ac.jp

Jumping fracture *Cluster of fractures* *Fracture dynamics*

Abstract In seismology, an earthquake source model usually assumes one single, relatively large fracture region in a brittle solid that may expand quasi-statically or dynamically and may radiate seismic waves. However, such a single large-scale fracture model causes most likely one sole seismic event, and may not be useful in clarifying the physical mechanisms of a cluster of earthquakes and earthquake swarms. For understanding these complicated seismic activities, not only global observations of large-scale material behavior but also more local tracing of smaller-scale fractures is needed. In this study, therefore, by using the technique of dynamic photoelasticity, the evolution of fractures and waves is experimentally traced in a two-dimensional linear elastic brittle specimen that has a set of pre-existing small-scale parallel fracture regions. The small-scale fracture regions or cracks, modeling a large-scale geological normal fault plane, are prepared by a digital laser cutter. Our experimental observations with a high-speed digital video camera, together with finite difference numerical simulations, indicate that the global fracture behavior significantly depends on the initial inclination angle and distribution pattern of the set of parallel cracks. In the case of pre-existing cracks that are more vertically inclined with respect to the quasi-static external load applied by a tensile testing machine, the main fracture develops dynamically and then the secondary fractures appear at spatiotemporally remote distances from that main fracture. The secondary fractures extend also dynamically, into the direction opposite to that of the main fracture. On the other hand, in the case of smaller inclination angles, the main fracture tends to evolve quasi-statically. Nevertheless, in both cases, it is found that fracture can jump without difficulties in a brittle solid having a number of small-scale cracks, which implies that such small-scale cracks may play an important part in the generation of a cluster of seismic events.

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The effect of confinement and material heterogeneities on the dynamics of a granular medium subjected to impact loading

Koji Uenishi[1], Dongyun Xi[1]

[1]*Department of Advanced Energy, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8561 Japan, ki.touyun20@ae.k.u-tokyo.ac.jp*

Stress transfer in granular media *Collapse of granular media* *Dynamic slope failure*

Abstract Understanding the fracture dynamics of granular media is of crucial importance not only in physics, mechanical and civil engineering but also in earth and planetary science where examples range from debris flows and earthquake-induced slope failures to sample-return spacecraft missions. Compared with the mechanics of continua that has been established well, however, the mechanical characteristics of granular particles, in particular, the dynamic ones, have not been thoroughly clarified yet. Therefore, in our previous preliminary study, dynamic stress transfer as well as wave and fracture development in granular media has been recorded using the experimental technique of dynamic photoelasticity in conjunction with high-speed cinematography. Penny-shaped particles have been prepared by a digital laser cutter and piled on a rigid horizontal plane to form a model slope with some inclination angle. The two-dimensional slope has been subjected to dynamic impact on its top free surface. From the experimentally recorded particle motion and transient stress evolution, two dissimilar failure patterns have been identified. One is the complete collapse of the slope or mass flow due to unidirectional force-chain-like stress transfer, and the other one is the toppling-type separation of the slope face caused by broadly expanding two-dimensional waves. Whichever occurs seems to be governed by the temporal profile of the energy given by the impact (Uenishi and Goji, *Proc. Strut. Integrity*, 2018). Here, in order to investigate the effect of confinement and material heterogeneities on granular dynamics, first, experimentally, rigid plates are additionally placed on some boundaries of the modelled slopes. It is found that stress transfer and dynamic motion in the confined granular medium is largely controlled by the additional rigid boundaries. Then, in order to numerically confirm the above experimental observations, the open source code ESyS-Particle is employed. In the discrete element simulations, heterogeneities like cavities and buried seismic barriers or stiffer materials are also included in the granular medium, and their effect is scrutinized. The numerical results compare well with the experimental ones if the parameters required for the numerics are carefully and properly selected.

, Prospects of Structural Damage Identification Using Modal Analysis and Anomaly Detection

Deniss Mironovs[1], Karlis Dzelzitis[1], Sandris Ručevskis[1]

[1]*Institute of Materials and Structures, Riga Technical University, Kalku street 1, Riga, Latvia, LV-1050*

Structural Health Monitoring *Operational Modal Analysis* *Anomaly Detection*

Abstract Structural health monitoring (SHM) has significant importance in providing reliability, safety, and economical sensibility for structures. High sensitivity and precision of SHM techniques can be quite demanding. Some SHM testing procedures require structures, for example, wind turbine blades or aircraft structures, to be taken out of operation, which increases costs and causes downtime. Other techniques include sophisticated signal processing and data analysis, which require skilled personnel. An alternative is to use a form of system identification technique called Operational Modal Analysis, during which an operator performs structural vibration measurements without disrupting normal operation of structure.

The aim of the current study is to develop a machine learning algorithm, which is able to identify damaged states of a structure, based on the assessment of its modal parameters. The assessment of the structural health is performed using machine learning technique called Anomaly Detection. The proposed method establish a description of normality using features representing undamaged conditions and then test for abnormality which indicates presence of damage in structure. Structure under test is one-meter-long laminated composite beam. The finite element model of the beam is developed using eight-node shear-deformable shell elements. Damage in the beam is introduced as delamination between the plies representing 5% of the total area of the beam. Numerical modal analysis is carried out to obtain modal frequencies and corresponding mode shapes for the first three bending modes of both the healthy and damaged beams. The results of the numerical experiments show possibilities of the proposed structural health monitoring method to identify damage in composite structures under varying modal parameters.

Effect of testing frequency on fatigue behavior of base materials AA2024, Ti-6Al-4V and Inconel 718

Ruslan Kuliiev[1], Stefan Riekehr[1], Volker Ventzke[1], Nikolai Kashaev[1]

[1] *Institute of Materials Mechanics, Department of Laser Processing and Structural Assessment, Helmholtz-Zentrum Hereon, Max-Planck-Str. 1, D-21502 Geesthacht, Germany*

Very High Cycle Fatigue (VHCF) *Testing Frequency* *Weibull Distribution*

Abstract Fatigue behavior of base materials AA2024, Ti-6Al-4V and Inconel 718 under uniaxial tensile load with a stress ratio of 0.1 was investigated. To analyze the effect of testing frequency on stress-number (SN) life, the fatigue tests were conducted at three different testing frequencies on servo-hydraulic (approximately 20Hz) as well as resonant (90Hz and 1000Hz) testing machines. By testing at approximately 1000Hz an emphasis was paid at the investigation of very high cycle fatigue behavior up to one billion loading cycles. To quantify the effect of the testing frequency on the fatigue behavior, at least six specimens were tested at the same load (300MPa for AA2024, 860MPa for Ti-6Al-4V and 650MPa for Inconel 718) in the high cycle fatigue regime and represented using the two-parameter Weibull distribution. The results show no noticeable difference in the fatigue behavior of the AA2024 tested at 20Hz and 90Hz loading frequencies, however, Ti-6Al-4V and Inconel 718 showed an increase in fatigue life at 90Hz compared to 20Hz. Longer fatigue lives were observed by testing at 1000Hz for all the materials. The effect of the testing frequency on the fatigue life is more pronounced in case of Ti-6Al-4V and Inconel 718. In AA2024 and Inconel 718 the fatigue crack was initiated in the surface region for all of the testing regimes, whereas sub-surface and internal crack initiation sites, so called ‘fish eye’, were obtained in case of Ti-6Al-4V specimens tested in the high cycle as well as very high cycle fatigue regimens. The ‘fish eye’ phenomenon confirmed the increase in the fatigue strength of the Ti-6Al-4V with an increase of the distance from the crack initiation site to the surface of the specimen. The results of the study contribute to a more complete knowledge of the fatigue behavior of the AA2024, Ti-6Al-4V and Inconel 718 materials as a function of the loading frequency.

Influence of the connector shape parameters in the structural behaviour of the adhesive-free timber floor panels

Gonzalo Moltini[1, 2], Vanesa Baño[1, 2]

[1]*Fundación Cesefor, Polígono Industrial Las Casas, Calle C, Parcela 4, 42005, Soria, Spain*

[2]*Instituto de Estructuras y Transporte, Fac. Ingeniería, Univ. de la República, Uruguay*

gonzalo.moltini@cesefor.com

Adhesive-free *Structural yield* *Timber-to-timber panels*

Abstract

Timber-to-timber panels (TTPs) are adhesive and steel-free structural components formed by carpentry joints of Scots pine to be used as floors. Figure 1 shows a schematic on the TTPs and a detail on the connectors. A numerical model simulating bending tests on TTPs, and considering timber as an orthotropic and bi-modulus material, was validated from experimental results of deflection and rolling shear strength. Since the serviceability and ultimate limit states of the TTPs was mainly defined by the rolling shear properties of the connectors, this paper aims to study the influence of different connector shape parameters in the structural behavior of the panels. For that, values of the connector height (h_c varying between 40 and 100 mm), width (b_1 varying between 40 and 100 mm) and the dove-tail angle (α varying between 45º and 75º) were introduced in the numerical models to obtain both failure load and stiffness for different span TTPs. For a same dove-tail angle results showed that TTP deflection was barely influenced by connector height in the slender connectors (b_1=40 mm); however, for wider connectors ($b_1 \geq 60$ mm), TTP deflection decreased up to 39% as height increased ($h_c \leq 100$ mm). For a same angle and height of the connector, the shear stress on the connector shows a decrease between 33% and 40% as width increases (b_1). The shear stress shows a higher dependence on b_1 that on h_c. The influence of the dove-tail angle shows that lower values of angle (α) are better at transmitting the stress from one layer to another. The tension perpendicular to grain in the connectors increases as the angle decreases.

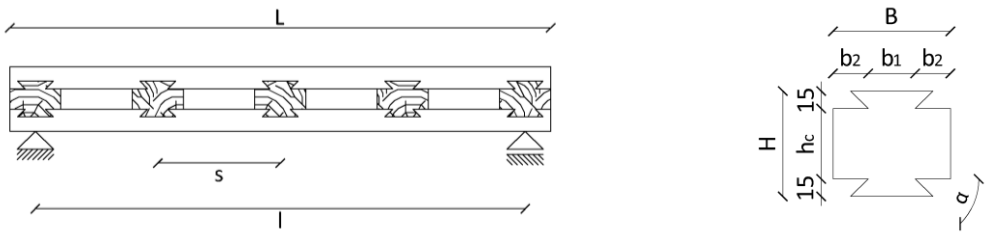

Fig 1. Parameters defining the TTPs

, Research and Prediction of the Stress-Strain State of Construction Facilities in the Undermined Territories

G. Gusev [1] and I. Shardakov [1]

[1] *Institute of Continuous Media Mechanics UB RAS, Russian Federation, Perm, 614013, Acad. Korolev st, 1 gusev.g@icmm.ru*

stress-strain state *undermined territories* *technical condition*

Abstract Deformations of the earth's surface in the territories of potash deposits occur for quite a long time. These times are calculated in decades. The processes of deformation of the earth's surface are caused by the shift of the soil mass layers that lie below the surface. Shifts in the layers of the soil mass are caused by the organization of mining workings. All this determines the pattern of the evolution of the stress-strain state of structures that are located in the undermined area. All this makes the task of studying the patterns of such behavior relevant. These tasks include predicting the evolution of the stress-strain state of structures, predicting the rates of deformation of the earth's surface, and predicting stress relaxation in the ground mass. The solution of these tasks determines the stages of design and construction of structures in the undermined territories. Also, the solution of these tasks determines the pattern of monitoring the technical condition of structures that are already in operation. This problem is very extensive, since there are a lot of types of structures. There are point objects and there are large arrays of structures. The processes of deformation behavior of such types of objects differ significantly, which complicates forecasting. There are great difficulties with the analysis of the stress-strain state of objects that are made of different structural materials and built using different technologies. It is worth focusing on the fact that modern regulatory documents in this field of knowledge are significantly outdated. They do not take into account the latest technologies of construction and production of mining workings. These regulatory documents are based on research that was carried out in the last century. The methods of predicting deformations used in these documents do not meet modern requirements. Thus, there is a huge list of specific tasks, united by a common direction. This direction is the safe construction and operation of various structures in the undermined territories.

Based on field studies, we assume that a uniaxial deformed state occurs in the surface layer of the soil mass in the plane of the soil layer. The thickness of the layer is comparable to the depth of the foundation structures. This condition is caused by mining operations in the underlying layers of the ground massif. We also assume that the deformations in the soil layer are uniform in the first approximation. The component of this state can be accurately recorded by geophysical measurement tools. This state can always be represented as a field of major deformations in the plane of the earth's surface. The structure rests on the described layer of the soil mass before the deformation process begins. We study the effect of soil mass deformation on the load-bearing elements of the structure. We determine the level of deformations in the ground layer, which corresponds to the critical state of the structure. Obviously, these questions are parametric in nature. They depend on: the type of structure and its height, the type of foundation structures, the type of materials, the type of construction technology, the technical condition of the structure, etc. The answers to these questions are formulated in the space of the described parameters. The answers are determined on the basis of numerical solutions of boundary value problems on the interaction of the structure with the ground mass. The simulation was carried out using the ANSYS software package. The simulation results contain information about the distribution of the parameters of the stress-strain state of the structure, depending on the deformation of the undermined area. The limiting parameters of the deformation state of both the foundation array and the structure itself are determined.

, Study of rock dilation effect on oil recovery during steam-assisted gravity drainage

A. Kostina[1], M. Zhelnin[2], O. Plekhov[2]

[1]*Institute of Continuous Media Mechanics UB RAS, 614013, Russia, Perm, Academika Koroleva st, 1, kostina@icmm.ru*

[2]*Institute of Continuous Media Mechanics UB RAS*

SAGD *Shear dilation* *Multiphysics problems*

Abstract Thermally-induced rock dilation is one of the key geomechanical effects accompanying steam-assisted gravity drainage (SAGD). Propagation of thermal front during steam injection leads to initiation of high compressive horizontal stresses with simultaneous reduction of vertical stresses which induces shear failure ahead of the steam front. On macroscale this effect is observed as displacement of the surface which can attain several centimeters. In addition, strong dilation can substantially enhance rock properties of the reservoir [1]. In this work we investigate effect of shear dilation on oil recovery rate on the base of the originally develop coupled thermo-hydro-mechanical model.

The governing equations of the model includes momentum, mass and energy balance laws which are supplemented by constitutive equations and state laws. It is assumed that pore space is occupied by three immiscible phases (steam, oil and water). Filtration of each phase is described by Darcy's law. Effect of pore fluid on stress-strain state of the reservoir is described within Biot theory. The reservoir is assumed to be isotropic and the strains are assumed to be small. Hook's law is applied to evaluate elastic strains. Plastic strains are estimated by associated flow rule with Drucker-Prager yield criterion. The soil behavior is assumed to be perfectly plastic. Steam condensation near the thermal front is determined by the additional heat source.

Numerical simulation is carried out in the finite-element software Comsol Multiphysics®. The following algorithm was proposed. Water saturation, steam saturation, pore pressure and displacement vector was chosen as primary field variables. Governing equations for three-phase flow was solved using pressure-saturation formulation with total velocity. To smooth the oscillations caused by the convective terms the artificial diffusion was added to each equation. The resulting equations were implemented to Comsol Multiphysics® by Weak Form PDE interface. Heat transfer and Solid mechanics modules were applied for energy balance and equillibrium equations.

Experimental data on temperature field distribution and oil recovery rate published in literature were used for the verification of the proposed model. Numerical simulation of reservoir's area containing one pair of SAGD-wells has shown that the model can successfully describe all stages of steam chamber development, surface heave induced by shear failure and increase in porosity and permeability values. Comparison with elastic solution has demonstrated that observed values of porosity could not be obtained without dilation.

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, Damage assessment of CFRP laminate plate subjected to close-range blast loading: hydrocode methodology validation and case study

A. Vescovini[1], L. Lomazzi[2], M. Giglio[2], A. Manes[2]

[1]Politecnico di Milano, Department of Mechanical Engineering, Via La Masa n.1, Milan, Italy, alessandro.vescovini@polimi.it

[2]Politecnico di Milano, Department of Mechanical Engineering, Via La Masa n.1, Milan, Italy

Blast loading *CFRP* *Damage*

Abstract Blast loading represents a critical damaging event in all structures. Although composite materials have been increasingly adopted in structural application, the effect of such dynamic loading event on composite structures is still to be evaluated in detail. This work defines a reliable numerical methodology to assess the damage occurring in carbon fiber reinforced polymer (CFRP) plate subjected to close-range blast loading. The numerical methodology is validated with a benchmark experiment found in literature and is employed to study in detail the damage mechanisms and eventual Fluid Structure Interaction (FSI) effects. The numerical analyses are carried out through a commercially available software package employing three methods, i.e., the fully coupled Eulerian-Lagrangian (CEL), the ConWep and the hybrid CEL-ConWep approaches, and the results from the three simulations are compared with experimental evidence from the original work. The results show that (i) CEL analyses require massive computational resources to carry out a simulation with satisfactory performances, (ii) the ConWep approach accurately reproduces experimental observations, even though such a method has strong limitations, and (iii) the hybrid approach seems to be the most promising solution in terms of efficiency and accuracy of the results.

Mechanical behavior of tropical Glued Laminated Timber (GLT) beams with fingers joints

Cédric Horphé Ndong Bidzo[1], Rostand Moutou Pitti[2], Claude Feldman Pambou Nziengui[2], Samuel Ikogou[3], Beat Kaiser[4]

[1] *Ecole Nationale des Eaux et Forêts, Libreville, Gabon*

ndonghorphe@gmail.com

[2]*Université Clermont Auvergne, Clermont-Ferrand, France*

rostand.moutou_pitti@uca.fr, claude_feldman.pambou_nziengui@uca.fr

Ecole Polytechnique de Masuku, Franceville, Gabon

ikogousamuel@yahoo.fr

[4]*Ecowood Sa, Zone Industrielle Acaé, Libreville, Gabon*

beat.kaiser@ecowood.ch

Tropicals woods *Phenol adhesives* *Glued Laminated Timber*

Abstract This paper presents an experimental investigation performed on Glued Laminated Timber (GLT) beams made by combining two tropical woods species. They have been chosen by considering their different density and by the fact that they are under-exploited. The species are *Dacryodes buettneri* (Ozigo) and *Pterocarpus osun* (Padouk) where Ozigo is considered as the reference species. To make the GLT beams (DUO and TRIO beams), the Phenol Resorcinol Formaldehyde (PRF), adhesive resistant to harsh tropical environments, is used for bonding. Then, a static bending tests were conducted on these two types of specimens (DUO and TRIO with or without fingers joints) to determine their mechanical parameters such as Module of Rupture (MOR) and Module of Elasticity (MOE). The aim of this study is to show the effect of the fingers joints on the bending strength of the GLT beams. The mechanical parameters of the combined beams are compared to those of the homogeneous beams made up specifically with Ozigo species. The results show, for the combined beams, that the position of lamella has an influence on the global mechanicals properties of GLT. We can see also that the bending strength of the combined beams, represents on average 85% of the strength bending of homogeneous beams consisting of the densest wood specie (Padouk). While the strength bending of Ozigo's solid wood represents on average 52% that of Padouk. The lamella with fingers joints usually lose 40 to 60% of strength bending compared to the massive lamella without fingers joints.

Ship Model Structural Health Monitoring using FBGS to obtain internal forces

M.González-Gallego[1 2], F. Terroba[1 3], J.L. Martinez[2], R.Atienza[3], M.Frövel[1]

[1] *National Institute of Aerospace Technology (INTA), 28048 El Pardo – Madrid, Spain, gonzalezgm@inta.es*
[2] *University of Castilla-La Mancha (UCLM), 13071 Ciudad Real, Spain*
[3] *University Alfonso X el Sabio (UAX), 28691 Villanueva de La Cañada, Spain*

Ship models *Fiber optics sensors* *Naval research*

Abstract: Reducing the carbon footprint by improving its efficiency is one of the main problems that faces the maritime transport and the naval industry nowadays. Great efforts are devoted to achieve this goal. One of the lines of action is focused in the ship hull optimization in order to reduce the lightship weight, mainly through the widespread use of composite materials. The problem, in that case, is the fact that most of the recent designs are not considered within the recommendations and design guidelines published by the classification societies that are currently used as reference during the design phase.

INTA, in collaboration with the UCLM department COMES (Mechanics of Continuous Media, Structural and Materials Engineering), has initiated a research line that intends to obtain the internal forces produced in the vessels by experimental tests on scaled ship models, and extrapolate the result to the actual vessels. For this purpose, it will be manufactured a scaled model with a stiffness equivalent to the one of the actual ship, and it will be monitored using FBGSs. The model will be calibrated to able matching the internal forces with the strain results provided by the FBGSs in different status. The model will be exposed to different test conditions (wave type, wave height, course... etc.) and the internal forces values obtained can be extrapolated to support the data of pressure distribution calculated by CFDs means.

In parallel, it is performed a composite material characterization and FBGS sensors analysis to carry out the main research. The focus is on tracking the influence of transverse loads on the sensor readings.

The experimental tests performed in the model basin (at El Pardo Towing Tank and El Pardo Dynamic Ship Laboratory) will be matched with the data from FEM and CFD calculation, in order to perform and complete analysis of the fluid and structure interaction.

, An approach for assessment of concrete deterioration by surface waves

Alexey Tatarinov[1], Aleksandrs Sisojevs[2], Gennady Shahmenko[2], Viktors Kurtenoks[2]

[1]Institute of Electronics and Computer Science, 14 Dzerbnes Str., Riga, Latvia, aleksejs.tatarinovs@edi.lv

[2]Riga Technical University, Latvia

Concrete degradation *Ultrasonic surface waves* *Pattern recognition*

Abstract The aging of concrete and reinforced concrete infrastructure facilities is a global problem. External and internal factors such as water ingress, freeze and thaw cycles, chemical attack, alkali-aggregate reactions and forces lead to concrete degradation and loss of the structural integrity of concrete objects. The harmful influence of these factors frequently is initiated at the concrete surface and it is important to know how deep the deterioration process is expanded into the depth of the concrete bulk. Although ultrasonic testing is the most popular non-destructive assessment tool for concrete quality, no ultrasonic instrument is known that can represent the quality of concrete by the depth of the surface layer. The purpose of the study was to demonstrate the feasibility of an approach based on the analysis of propagated signals of surface ultrasound waves at several frequencies in the lower kilohertz range using pattern recognition methods. Two variable factors-of-interest (FOI) were physically modelled: the material degradation degree of the conditionally weak surface layer and the thickness of the weak layer on the strong concrete underlay. A series of specimens was made according to the experimental design in order to build a mathematical model for FOI evaluation. Ultrasonic signals were acquired in the surface transmission at 3 frequencies in the range from 50 to 200 kHz by stepped scanning of the specimens' surface. Obtained 2D spatiotemporal waveform matrices, where coordinates were propagation distance and ultrasonic time, served as the material for processing. The approach based on the methods of pattern recognition included steps of transformation the signals by discrete Fourier transform signals, creation of statistical criteria and decision rules and comparison of statistical tests to the decision rules. The decision rules were formed as mathematical approximation surfaces with FOI as the coordinates. In statistical verification tests, comparison of new specimens with the given values of FOI gave an adequate definition of both the thickness of the weak layer and the degree of its deterioration.

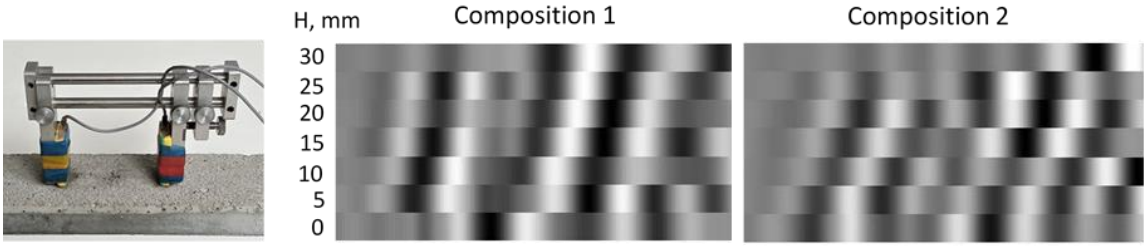

Figure 1 – *Ultrasonic testing of specimens from the side of weak concrete and ultrasonic signals at 50 kHz presented in brightness mode for two conditions of weak layer (Composition 1 and Composition 2) and different thicknesses of weak layer H.*

Fracture Mechanics Based Approach for Fatigue Assessment of Ultra-High Strength Steels

I. Varfolomeev[1], T. Straub[1], M. Luke[1], A. Kleemann[2]

[1]Fraunhofer Institute for Mechanics of Materials IWM
Wöhlerstr. 11, 79108 Freiburg, Germany igor.varfolomeev@iwm.fraunhofer.de

[2]Institute of Materials Research and Testing at the Bauhaus-University Weimar
Coudraystr. 9, 99423 Weimar, Germany

ultra-high strength steels *fracture mechanics testing* *fatigue assessment*

Abstract This paper focuses on fatigue life assessment of ultra-high strength steels (UHSS) considering the stages of crack initiation from microstructural defects and micro crack propagation until fracture. In view of high stress levels achieved in components made of UHSS and small crack sizes tolerable in such materials, particular attention is given to the experimental determination of the fracture toughness and fatigue crack growth threshold representative of micro cracks. For this purpose, a series of tests are performed on small specimens containing sharp microscopic notches produced by means of the focused ion beam technique. The material parameters K_{Ic} and ΔK_{th} determined in those tests are compared to respective results derived in tests on deeply cracked standard specimens. Finally, several series of fatigue tests performed on microscopic and macroscopic specimens with different geometry and loading conditions are evaluated using the fracture mechanics approach.

, Cyclic deformation behaviour of AlSi10Mg aluminium alloy fabricated by laser powder-bed fusion

R.F. Fernandes[1], J. Jesus[1], R. Branco[1], L.P. Borrego[2,1], J.A. Martins Ferreira[1]

[1]*University of Coimbra, CEMMPRE, Department of Mechanical Engineering, Rua Luís Reis Santos, Coimbra, 3030-788 Coimbra, Portugal*

[2]*Department of Mechanical Engineering, Coimbra Polytechnic – ISEC, Rua Pedro Nunes, Quinta da Nora, 3030-199 Coimbra, Portugal*

Keyword 1 *Low-cycle fatigue* *AlSi10Mg*

Abstract Selective laser melting is a state-of-the-art additive manufacturing process for producing complex metal components. Nevertheless, a critical issue is the evaluation of mechanical properties under cyclic loading. This work aims to study, in a systematic manner, the low-cycle fatigue behaviour of AlSi10Mg aluminium alloy manufactured by SLM. Tests are conducted under fully reversed strain-controlled conditions, with strain amplitudes ranging from 0.3% to 1.5% for three final conditions, more specifically as-built, T6 heat treated, and stress relieved. After testing, fracture surfaces were examined by scanning electron microscopy to identify the main fatigue damage mechanisms. In a second stage, stress-controlled fatigue tests are conducted in notched samples under constant-amplitude and variable-amplitude loading. Fatigue lifetime is determined based on the cumulative strain energy density concept combined with a linear damage accumulation law. Microstructure is analysed by optical microscopy, transmission electron microscopy and X-ray diffraction, and the fracture surfaces for both strain-controlled and stress-controlled fatigued samples are examined by scanning electron microscopy and transmission electron microscopy to identify the main failure micro-mechanisms.

Mechanical, electrical and piezoresistive properties of hydraulic lime paste reinforced with modified carbon nanotubes

Angeliki Eirini DIMOU[1], Zoi S. METAXA[2], Stavros K. KOURKOULIS[3], Ioannis KARATASIOS[4] and Nikolaos D. ALEXOPOULOS[1]

[1] University of the Aegean, School of Engineering, Department of Financial Engineering, 821 32 Chios, Greece, c.charalampidou@fme.aegean.gr

[2] International Hellenic University, School of Science and Technology, Department of Chemistry, Hephaestus Laboratory, St. Luke 654 04, Kavala, Greece

[3] National Technical University of Athens, Department of Mechanics, Laboratory of Testing and Materials, 9 Heroes Polytechniou Str., 15780 Athens, Greece

[4] NCSR ''Demokritos'', Institute of Nanoscience and Nanotechnology, Laboratory of Ceramics and Composite Materials, Aghia Paraskevi 153 41, Attica, Greece

Carbon nanotubes *Hydraulic Lime* *Piezoresistivity*

Abstract The aim of the present work is to study a binary paste matrix for the restoration of Cultural Heritage Monuments with incorporated carbon nanotubes. More specifically, a mixture of natural hydraulic lime (NHL5) and metakaolin (MK) is examined. The NHL5 content is 80 wt % and the content of MK is 20 wt %, while the water to binder ratio is 0.55. The incorporation of two different types of Multi-Wall Carbon Nanotubes (MWCNTs) is examined, namely sulfonated MWCNTs and carboxylated MWCNTs. Those nanomaterials are added at a concentration of 0.10 wt % of the binder and 0.15 wt % of the binder respectively. In order to evaluate the performance of these pastes, mechanical tests (compressive) were performed, as well as electrical resistance measurements. Finally, the piezoresistive properties of the composite materials were evaluated under progressive loading. The mechanical results indicate that the compressive strength is practically not affected when MWCNTs are added, while the electrical resistance drops significantly. Also, the composite materials possess piezoresitive properties.

Acknowledgment: *This research has been co‐financed by the European Regional Development Fund of the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH‐CREATE‐INNOVATE (project code: T1EDK-03069, MIS 5031866).*

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Numerical modeling of a masonry arch structure

Khalil Naciri[1], Issam Aalil[1], Ali Chaaba[1], Muzahim Al-Mukhtar[2]

[1]Dept. of Civil Engineering, National Higher School of Engineering (ENSAM), Moulay Ismail University, Marjane II, BP 15290 Al Mansour, Meknès, Morocco. E-mail: khalil.nac@gmail.com

[2]Univ. Orleans, Univ. Tours, INSA-CVL, LaMé-EA7494, 8 rue Léonard de Vinci, F-45072,Orleans, France

Masonry arch modeling *Concrete damaged plasticity* *Surface-based cohesive behavior*

Abstract The use of masonry as a building material has been widely practiced throughout history for the construction of buildings, towers, mosques, retaining walls, arches, domes and other structures. Most of these buildings require interventions to preserve this heritage for future generations. To implement these restoration techniques, adequate information on the structural behavior and capacity of these structures must be determined by conducting experimental tests on a large number of specimens, which may be challenging at large scales. Therefore, several valuable modeling approaches have been proposed as an alternative to experimental testing. However, most of them are based on user-defined subroutines that are not available for practical use.

In this work, a simple masonry modeling technique was proposed. Stone and mortar were modeled using concrete damaged plasticity model. Surface-based cohesive behavior was adopted to model the stone-mortar interface. These constitutive laws are already implemented in the ABAQUS environment with no need for any specific subroutines. This strategy has been previously validated by the authors in the case of masonry under shear loading, and will be used in this work to simulate the experimental behavior of a masonry arch under compressive load. The comparison with the experimental test shows good agreement in terms of the total load supported by the arch and the observed failure mode. The technique can therefore be adopted in the engineering practice to derive adequate insights into the structural behavior of masonry arches.

Impact of mechano-sorptive loading on crack propagation of notched beams of White-fir and Okume

Martian ASSEKO ELLA[1], Samuel IKOGOU[2], Giacomo GOLI[3], Rostand MOUTOU PITTI[1,4], Joseph GRIL[1,5], Eric FOURNELY[1], Gaël GODI[1]

rostand.moutou_pitti@uca.fr

[1]*Clermont Auvergne INP, Université Clermont Auvergne, CNRS, Institut Pascal, 63000 Clermont Ferrand, France, rostand.moutou_pitti@uca.fr*

[2]*USTM, Ecole Polytechnique de Masuku, BP 901 Franceville, Gabon*

[3]*University of Florence, DAGRI-Department of Agriculture, Food, Environment and Forestry, 50145 Firenze, Italia*

[4]*CENAREST, IRT, BP 14070, Libreville, Gabon*

[5]*Université Clermont Auvergne, INRA, PIAF, F-63000 Clermont Ferrand, France*

Crack propagation *Mechano-sorptive creep* *Viscoelastic creep*

Abstract: The paper presents the experimental results of the crack process induced by viscoelastic effect and mechanical loadings. The notched specimens are White-fir and Okume with dimensions equal to 160x12x60mm and notch length of 20mm. These specimens were tested in 3-point bending for 5 days under an initial stress of 80% of the rupture stress. At the end of these 5 days we applied a second stress corresponding to 100% of the rupture stress. These tests were carried out under a sorption cycle of 45-75% relative humidity and at a constant temperature of 20°C. Monitoring of the crack propagation was performed by using an USB microscope. The results show that the crack propagation is accentuated by the drying effects on the one hand and by the effects of the applied stress on the other hand. The results show that crack propagation is influenced by viscoelastic effects, and by mechano-sorptive effects as shown in Figure 1. It can be seen that the crack propagation is more important when mechano-sorptive effects occur, especially during the drying.

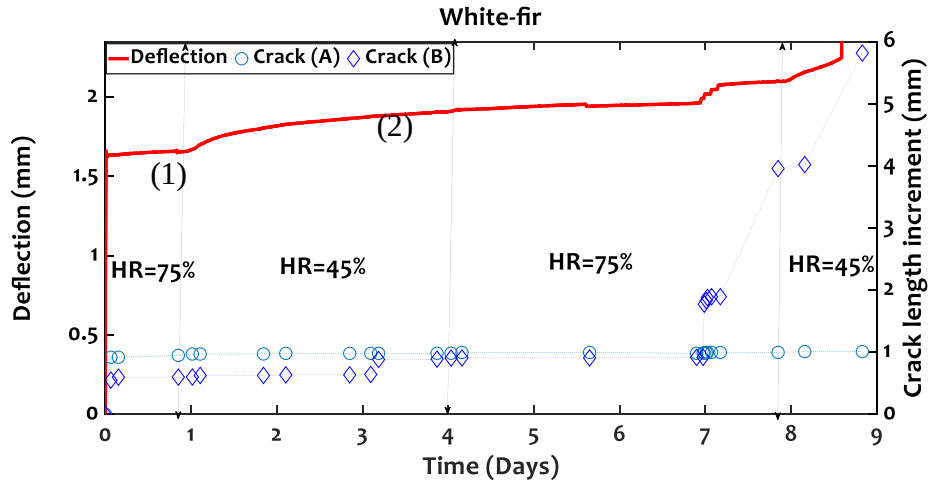

***Figure 1** – Effect of crack on the viscoelastic and mechanical creep of White-fir*

Optimization of the graphene reinforcement in cement-based materials

Anastopoulos G Stylianos[1], Givannaki Th Faidra[2], Zoe S Metaxa[3] , Paraskevas. Papanikos[4] , Alexopoulos D Nikolaos[5]

[1]Department of Financial and Management Engineering, University of the Aegean, 41 Kountouriotou Str., 82100, Chios, Greece,
fmer18001@fme.aegean.gr
[2]BETA CAE Systems SA,
Kato Scholari, Thessaloniki GR-57500 Epanomi, Greece,
p.givannaki@beta-cae.com
[3]Department of Petroleum, Natural Gas and Mechanical Engineering, Eastern Macedonia and Thrace Institute of Technology,
St. Luke, 65404, Kavala, Greece,
zmetaxa@chem.ihu.gr,
[4]Department of Financial and Management Engineering, University of the Aegean , Konstantinoupoleos 1, Ermoupoli, 84100, Syros, Greece,
ppap@syros.aegean.gr
[5]Department of Financial and Management Engineering, University of the Aegean , Kountouriotou Str., 82100, Chios, Greece,
nalexop@aegean.gr

optimization Nanocomposites *Multi-step method*

Abstract During the last decades composites had been successfully strengthened at the scale of micrometer using different types of reinforcements, e.g. carbon or even glass fibers. During the last years, the production of multiwall carbon nanotubes and of graphene, enabled the reinforcement of the cement-based materials at the nano-scale. The produced nanocomposites have increased mechanical properties than the non-reinforced materials and especially on the "effective" properties such as modulus of elasticity and Poisson ratio. In several cases and for compatibility issues, it is of imperative importance to "tailor" a nano-reinforced composite with specific material properties, such as the modulus of elasticity and Poisson ratio. To this end, a methodology to identify the "optimum" material synthesis needs to be effectively addressed.

The present article presents an optimization method to quantify the appropriate volume fraction of graphene nanostructures to design a cement-based nanocomposite with a target value of the effective Modulus. The effective Modulus of elasticity is assumed as volume fraction dependent. The iopt algorithm is used for the optimization iterations applied to the homogenization properties calculated by ANSA pre-prossesor. The effective modulus of elasticity is evaluated applying the multi-step method for an initial volume fraction. Thereinafter, according to the objective f(x) value a high number of re-calculation cycles are following. The objective function is the difference between the calculated value and the target value of the effective modulus of elasticity. At every cycle a new volume fraction is set and a new objective is recalculated. The points x which satisfies the constraints (inequality) lower and upper bounds (gL and gU) are considered as feasible. Convergence is achieved when either the objective value is less than 1e-04 or 1000 iterations have been completed. This method is applicable at any kind of composite material or alloys. The results of this research are compared with the volume fraction of a realistic material.

, **Direct evaluation of Mode I cohesive law of eucalyptus bonded joints**

Almudena Majano-Majano[1], Antonio José Lara-Bocanegra[1], José Xavier[2], Fábio Pereira[3], José Morais[3]

[1]*Department of Building Structures and Physics, ETS Architecture, Universidad Politécnica de Madrid, Avda Juan de Herrera 4, 28040 Madrid, Spain; almudena.majano@upm.es*

[2]*UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, NOVA University Lisbon, 2829-516 Caparica, Portugal.*

[3]*CITAB, School of Science and Technology, University of Trás-os-Montes e Alto Douro, 5001-801 Vila Real, Portugal*

Strain energy release rate *Double cantilever beam* *Digital image correlation*

Abstract *Eucalyptus globulus* L. is a hardwood species with high mechanical properties and great potential for engineered timber products. In the development of glued laminated products using high density wood species such as eucalyptus, bonded joints (e.g. finger-joints) could be a weak point and therefore require special analysis. Numerical cohesive zone models in the framework of fracture mechanics can be applied to accurately simulate the brittle failure behaviour of such bonded joints. These models require assuming a cohesive law that relates cohesive forces and displacements ahead of the crack tip to predict the crack growth along a fracture process zone. In the present research, the fracture cohesive laws in mode I loading of *Eucalyptus globulus* L. bonded joints using one-component polyurethane adhesive (1C-PUR) are directly identified by coupling Double Cantilever Beam tests (DCB) with full-field displacements at the crack tip (*COD*) measured by Digital Image Correlation (DIC). The Compliance-Based Beam Method (CBBM) is applied as data reduction scheme to evaluate the strain energy release rate (*G*) from the Resistance-curves of the specimens considering an equivalent crack length. Cohesive laws are determined by fitting a logistic function to the experimental data curve (*G-COD*). High fracture properties values of eucalyptus bonded joints resulted, which are in the range of those obtained for eucalyptus solid wood in previous research by the authors.

Figure 1 – *DCB set-up coupled with DIC*

Estimation of the fatigue strength of ultra-high strength steels

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Patrick Yadegari[1], Dr.-Ing. H. Thomas Beier[2], Prof. Dr.-Ing. Michael Vormwald[2], Dipl.-Ing. Andreas Kleemann[3]

[1] Technical University of Darmstadt, Department of Civil and Environmental Engineering Sciences, Materials Mechanics Group, Franziska-Braun-Straße 3, 64287 Darmstadt, Germany. yadegari@wm.tu-darmstadt.de

[2]Technical University of Darmstadt, Department of Civil and Environmental Engineering Sciences, Materials Mechanics Group, Darmstadt, Germany

[3]Institute of Materials Research and Testing at the Bauhaus-University Weimar, Germany

ultra-high strength steels *fatigue strength* *local strain approach*

Abstract Ultra-high strength steels are being used in an increasing number of applications in mechanical engineering, which is due to some of the advantages of these materials. In the automotive industry, for example, sustainability can be increased by using ultra-high strength steels in car body construction to maintain the same strength while reducing vehicle weight and thus consumption and emissions. Likewise, in the manufacture of bearings and transmissions, ultra-high strength or case-hardened steels are mostly used.

For the dimensioning of components made of low- and medium-strength steels, there are established estimation methods for material parameters as well as transfer functions to transmit these parameters to components. However, this level of knowledge is still insufficient for ultrahigh strength steels and has not yet been specified in guidelines. This often leads to over-dimensioning when using these materials and thus to a waste of resources or to a high dimensioning risk in lightweight construction. The aim of a recently completed research project was to develop a validated method for calculating the fatigue strength of components made of ultrahigh strength steels up to a tensile strength of 2400 MPa. Especially the estimating of cyclic material behaviour for the local strain approach is to be extended to include the coverage of ultra-high strength materials.

In the present publication, various ultra-high strength steels are examined in more detail. The results of tensile and fatigue tests as well as the determination of cyclic material characteristics are presented. In addition, the estimation of the cyclic material behaviour based on a minimal amount of input data (only tensile strength) is presented. These studies serve to determine input values for the local strain approach, which will be extended to include suitable parameters for ultra-high strength steels.

This publication is part of the research project “Ultra-high strength steels” which was funded by the German Federal Ministry for Economic Affairs and Energy (IGF-Nr. 19667 BG).

Microstructure and mechanical properties of laser beam-welded AA2198 using Al-Si filler wire under post-weld heat treatment

T.N. Examilioti[1,2,3], V. Ventzke[3], N. Kashaev[3], B. Klusemann[2,3], N.D. Alexopoulos[1]

[1]School of Engineering, Department of Financial Engineering, University of the Aegean, Chios, Greece

[2]Institute of Product and Process Innovation, Leuphana University of Lüneburg, Lüneburg, Germany

[3]Institute of Materials Mechanics, Helmholtz-Zentrum Hereon, Geesthacht, Germany

Al-Cu-Li alloys *Laser beam-welding* *Mechanical properties*

Abstract The last decade's trend of aluminum alloy producers is to manufacture new aluminum alloys that are even lighter, have increased mechanical properties as well as to have the ability to be welded in order to compete the composite materials in aeronautical applications. Third generation aluminum-copper-lithium (Al-Cu-Li) alloys are highly promising materials, which provide improved mechanical properties and damage tolerance behavior when compared to the already commercially available Al alloys. These alloys have been established as structural materials for aerospace applications mainly because of the reduced density and therefore increased specific strength. Additionally, further reduction of manufacturing costs and structural weight can be achieved with the introduction of alternate joining processes such as advanced welding methods in order to replace the conventional rivets where necessary.

In the present study, the Al-Cu-Li alloy AA2198 in T3 heat treatment condition with nominal thickness of 5.0 mm was laser beam-welded (LBWed) with and without filler material. Al-Si alloy AA4047 was used as a filler material. The effect of post-weld heat treatment (PWHT) on tensile mechanical behavior of butt joints was investigated under different ageing conditions. Tensile specimens were machined according to ASTM E8 standard from both autogenous and non-autogenous welds. The received microstructure of the joints was investigated by optical microscopy (OM), scanning-electron microscopy (SEM) equipped with electron backscatter diffraction (EBSD) as well as micro-hardness measurements.

Preliminary results for autogenous and non-autogenous welded joints show a decrease in yield stress and ultimate tensile strength in the as-welded condition of approximately 45 % and 37 %, respectively, when compared with AA2198-T3 base material. The use of filler wire increased the amount of Si and Cu in the fusion zone and as a result the micro-hardness was decreased by approximately 27 % when compared with autogenous joints. By applying PWHT, an increase of yield stress up to peak-ageing condition for both autogenous and non-autogenous joints was observed. To this end, both LBWed joints fractured in between the equiaxed and the fusion zone during tensile testing.

Strain measurements by FBG-based sensors embedded in various materials manufactured by different technological processes

Matveenko V.P. [1], Kosheleva N.A.[1], Serovaev G.S. [1]

[1]*Institute of Continuous Media Mechanics of the Ural Branch of Russian Academy of Science, 1 Akademika Koroleva str., 614013, Perm, Russia,* nataly.kosheleva@gmail.com

Fiber Bragg grating *Strain measurements* *Process-induced strains*

Abstract Fiber-optic sensors (FOSs) have a number of advantages that determine the suitability and prospects of their use for strain measurement: they are not sensitive to electromagnetic effects, can operate in a wide temperature range, there is a possibility of placing multiple fiber Bragg gratings (FBGs) on the one optical fiber and simultaneously recording readings from all sensors. One of the main advantages of FOSs is the ability to embed them, due to their small size, into the structure of the controlled object at the manufacturing stage using various technologies. Examples of such technologies are various options for the manufacture of polymer materials, which are accompanied by the processes of polymerization and crystallization, additive technologies and other technologies that allow embedding an optical fiber into the material. Thus, FOSs allow to assess the state of the product not only during its operation, but also to monitor the technological process of manufacturing and detect in advance possible deviations of the mechanical state from the norm. Due to these advantages, FOSs can be effectively used to monitor the mechanical state of various infrastructure and transport facilities.

This study presents an analysis of experimental results on recording the spectrum of a reflected optical signal and measuring strain with fiber-optic sensors based on Bragg gratings embedded in various materials. Polymer materials such as epoxy resin, injection molding plastic, thermoplastics used in 3D printing, as well as an important structural material, cement, are considered as materials into which the optical fiber was embedded. The evolution of the reflected spectra of the FBG sensors and the measured strain during the technological processes of materials fabrication and during loading of finished samples in different directions is shown.

In the course of this experimental study, the operability of fiber-optic sensors based on Bragg gratings was demonstrated, as well as the features associated with embedding process in various materials, which must be taken into account to preserve the integrity of the sensor.

, On the exploitation of multiple 3D full-field pulsed ESPI measurements in damage location assessment

Dr. Alessandro Zanarini[1]

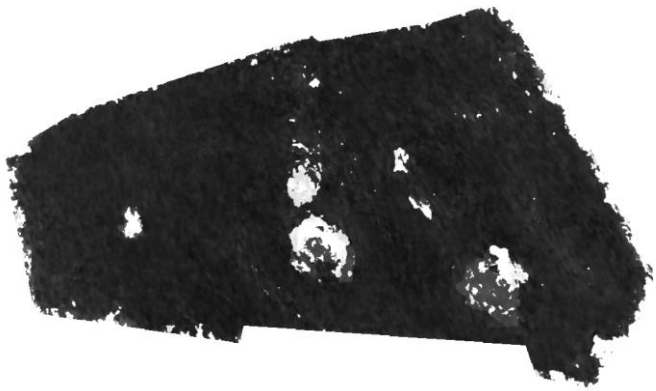
[1]DIN-Dept. Industrial Engineering, Bologna University, Viale Risorgimento 2, I-40136 Bologna, Italy. e-mail: a.zanarini@unibo.it

multiple data processing *3D full-field dynamic data* *damage location*

Abstract The structural dynamics of a manufactured part or system is often used as a key player in the discrimination of a sound behaviour or of a defected component, which must not go into service. Many NDT approaches exploit different loading systems to enhance the recognition of defects in components. Among the NDT techniques, Shearography, with its opto-mechanical shearing of electronic speckle pattern interferometry fields, mainly uses the vacuum technology to give a distributed, but static, loading on the scanned surface. Instead, it was already demonstrated that broad frequency excitation can enhance the defects recognition, as the higher structural dynamics may reveal local anisotropies that are not excited by static loading only, but need tonal signature in the testing deformation source.

In this work the attention is drawn onto the concurrent exploitation of multiple 3D full-field data, obtained by pulsed ESPI displacement measurements with sound pressures and shaker mono-tonal excitations at different frequencies. The usage of multiple data allows to gather the information about different defects that are oddly revealed at single frequency lines. The 3D nature of the datasets plays a relevant role, as the inhomogeneities are more easily detected from the in-plane displacements. Before summing all the available information, the single datasets can be enhanced by thresholding and functionally grading the 3D displacements. The application of the proposed method on a FGRP honeycomb panel, defected on purpose by proper manufacturing, was able to reveal all the know discontinuities, as in Fig. 1 by the bright clustered areas, by means of the processed 3D full-field dynamic maps.

Figure 1: *Preliminary results of the 3D full-field dynamic displacement data processing, revealing defects and shaker locations*



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On the defect tolerance by fatigue spectral methods based on full-field dynamic testing

Dr. Alessandro Zanarini[1]

[1]*DIN-Dept. Industrial Engineering, Bologna University, Viale Risorgimento 2, I-40136 Bologna, Italy. e-mail: a.zanarini@unibo.it*

defect tolerance *full-field dynamic testing* *fatigue spectral methods*

Abstract In real life production of dynamically loaded components, we might accept the risk of defects only if we can assess their position by NDT techniques, their effect by proper cumulative damage theory, the dynamic signature of the excitation and the structural dynamics of our structures in service. This work addresses the latter topic by means of experimental full field optical techniques, which can provide accurate surface displacement distribution in a broad frequency band directly from real components, while recording the excitation, thus, with advanced numerical derivations, coming to an experiment-based full-field strain FRF characterisation, here applied on an aluminium plate. The knowledge of the material constitutive parameters is used to obtain the Von Mises equivalent stress FRFs. The signature of the excitation permits the evaluation of the Von Mises stress PSDs, which can be used in a spectral fatigue method (here the one from Dirlik), coming to a frequency-to-failure distribution as in Fig. 1 below. The same distribution can be scaled to a risk index and compared to the defect locations from NDT, in order to build a defect tolerance map and discriminate the product acceptance for dynamically loaded components. The smart exploitation of full-field optical techniques play a relevant role in measuring, with high spatial resolution, the manufactured components in their effective broad structural dynamics and give defect tolerance experiment-based maps, without the need of a highly tuned FE model.

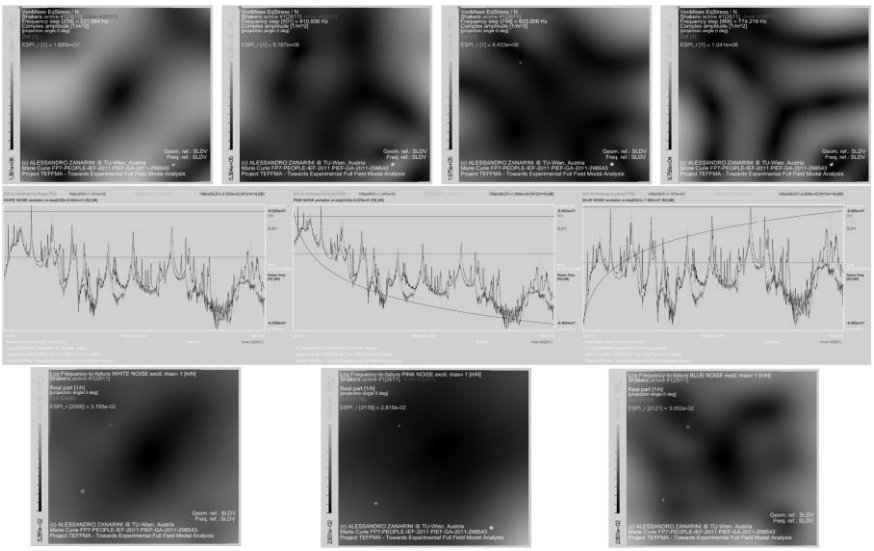

Figure 1: *From examples of VonMises equivalent stress distributions to risk maps, depending on excitation signature (white, pink and blue noise)*

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Structural Integrity of Polymeric Components Produced by Additive Manufacturing

Rui F. Martins[1], Ricardo Branco[2], Filippo Berto[3], Nuno Santos[1], Sebastião Bandeira[1]

[1]UNIDEMI, Department of Mechanical and Industrial Engineering, Nova School of Science and Technology, Universidade NOVA de Lisboa, Campus de Caparica, 2829-516 Caparica – Portugal, rfspm@fct.unl.pt

[2]Department of Mechanical Engineering, CEMMPRE, University of Coimbra, 3030-788 Coimbra, Portugal, ricardo.branco@dem.uc.pt

[3]Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology, Trondheim 7491, Norway, filippo.berto@ntnu.no

Polymers *Additive Manufacturing* *Structural Integrity*

Abstract

Additive Manufacturing (AM) is defined as a process of joining materials to make objects from 3D model data, usually layer-upon-layer, as opposed to subtractive manufacturing methodologies, such as traditional machining. In fact, since its invention, the impact of AM continues to grow in both commercial and scholarly activities, by processing several types of polymers, and more recently, metals. Therefore, this technology is shifting from prototyping to a dominant production industry.

Moreover, polymers, either in their natural or synthetic form, thermoplastic or thermosetting, can be considered cheap materials, characterised by low density and a vast diversity of mechanical resistance, ductility, toughness, or viscoelasticity, to mention a few. Its use has been rising tremendously since the 1930s, substituting steel, glasses, and introducing an extensive list of new synthetic polymers in final products.

In the work herein presented, the structural integrity of polymeric components made of Nylon-6 and PLA produced by additive manufacturing (FDM) was addressed. The two PLA components under study were selected from the production line of a brewing company, and they were redesigned, analysed using the Finite Element Method, 3D printed, and installed under real service.

The results obtained indicated that, even though the durability of the 3D printed parts were lower than the original ones, savings of about 7 000 € a year could be achieved for the two components understudy that were produced by additive manufacturing. Moreover, the widespread use of additive manufacturing to other specific components of the company could result in significant savings.

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Failure Analysis of a Ball Mill located in a Cement's Production Line

Alexandre Fragoso[1], Rui F. Martins[1], António Soares[2]

[1]UNIDEMI, Department of Mechanical and Industrial Engineering, Nova School of Science and Technology, Universidade NOVA de Lisboa, Campus de Caparica, 2829-516 Caparica – Portugal, am.fragoso@campus.fct.unl.pt; rfspm@fct.unl.pt

[2]Cimpor – Cimentos de Portugal S.A., Praceta Teófilo Braga, Araújo Rato, 2600-540 Alhandra – Portugal

Failure Analysis *Ball Mill* *Cement Production*

Abstract

The main objective of the work herein presented is to analyse an existing failure in a ball mill of a cement's line production. This equipment has the function of grinding the mixture of clinker and selected additions, resulting in cement. The ball mill understudy has a length of 16.2 metres between supports, and the formation of cracks was noticed approximately midspan near a maintenance manhole. The failure is recurrent and responsible for the reduction of the period between overhauls.

The cracks were detected using dye penetrant liquids and were eliminated by a rewelding procedure; hence, it was impossible to access the fracture surface. Nevertheless, numerical simulations were carried out using the Finite Element Method, and displacements and stresses induced in the structure were calculated. The maximum stress values were registered in the region where failure had occurred, in through holes used to bolt the ball mill's cladding plates.

Redesign of the ball mill was carried out to ensure high endurance for the equipment. Therefore, internal and/or external reinforcement rings were inserted in the structure, and maximum stresses calculated were reduced by 32%, increasing approximately five times the fatigue life predicted for the ball mill.

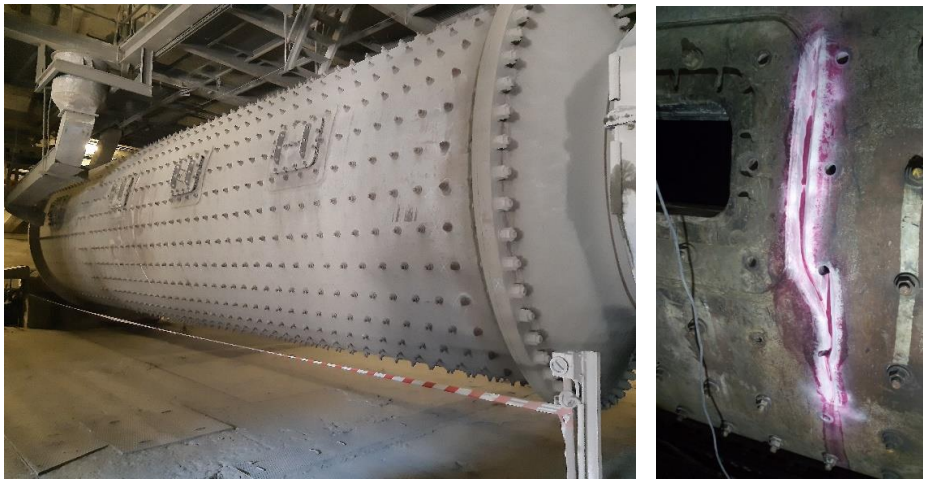

Figure 1 - *Overall view of the ball mill under analysis and its analysis.*

Failure Analysis and Prevention of a Cyclone located in a Cement Production Line

Alexandre Fragoso[1], Rui F. Martins[1], António Soares[2]

[1]*UNIDEMI, Department of Mechanical and Industrial Engineering, Nova School of Science and Technology, Campus de Caparica, 2829-516 Caparica – Portugal,*
am.fragoso@campus.fct.unl.pt; rfspm@fct.unl.pt

[2]*Cimpor – Cimentos de Portugal S.A., Praceta Teófilo Braga, Araújo Rato, 2600-540 Alhandra – Portugal*

Failure Analysis *Cyclone* *Cement Production*

Abstract

The equipment under analysis is a double cyclone, which makes up the fourth stage (of five) of a preheating tower, with a total height of 11 metres.

The preheating tower's importance is justified by the increased efficiency of the kiln system, by using the hot exhaust gases from the kiln to preheat and partially decompose the raw material. In this way, it is possible to shorten the kiln's length, reduce the heat dissipation into the atmosphere and the respective heat consumption.

The working principle of cyclones is the tangential injection of the dust-laden gas into the conical chamber, creating a vortex that concentrates the densest particles close to the wall (centrifugal force). Consecutively, the relatively clean gas moves to the upper cyclone level, and the heated mixture precipitates, crossing a one-way valve to the lower cyclone level.

Cyclones are exposed to temperatures that can reach 900°C. For this reason, their metallic structure is coated with an insulating material and a refractory material, to prevent the metal from undergoing corrosion, expansion, and deformation, either by chemical attack or due to extreme temperature conditions.

The cyclone roof was initially designed to couple bricks cut to size, which, together with an insulating layer on top and a concrete layer on the bottom, constituted the coating. As time passed, some cyclone roof covering sections underwent some changes, such as brick elimination, introduction of concrete slabs anchored to the ceiling, and brick support elimination.

However, it was identified that, with relative frequency, the ceiling refractory material (in this case, concrete) cracked, giving rise to chemical attack, exposure to temperature, and consequent fall.

The cyclone tower understudy has been in operation since 1984. Over the years of operation, it has undergone several stops for repairs, which led to changes in the equipment. Despite the repairs and improvements that have been carried out, all of these may have contributed, in some way, to the observed failure.

The first step was to model the equipment according to the manufacturing drawings. In addition, remodelling was also carried out to help understand the equipment's structural behaviour when subjected to different service conditions.

The various finite element analyses carried out allowed us to conclude that the exterior framework is the main responsible for supporting the weight of the roof. On the other hand, it was concluded that the interior framework is not necessary if the bricks are not used. It was also possible to conclude that concrete is essential for the equipment, both at the structural and insulating levels, so its good layout can considerably increase the service life of the equipment.

Therefore, the solution found will be to reinforce the outer framework and its connection to the roof of the cyclone, increasing the points of contact between them, and proceeding with the dismantling of the inner framework where concrete is chosen to be applied.

Nevertheless, further testing will be done in the future by redoing the inner framework for brick support and applying a new brick layout, which is simpler in maintenance, since it can be repaired only in specific areas where the bricks get damaged. This testing aims to confirm the better heat and wear resistance of a brick layout.

An appreciation of the effect of rainwater infiltration on the roof, which may evaporate inside the concrete, causing it to crack, should also be considered.

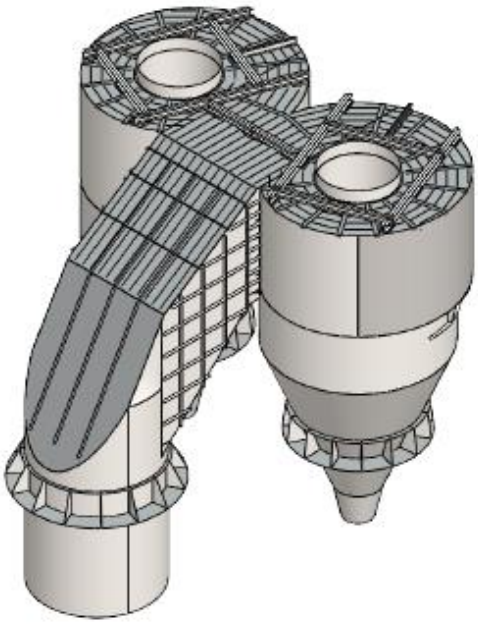

Figure 1 - *Isometric view of the cyclone under analysis.*

Cyclic compression behavior of multilayered polymeric nanostructured foams: FEM simulation and experimental testing

Ignacio Gutiérrez Montero[1], Raffaella Sesana[2], Sebastián D'hers[1], Fabrizio Scarpa[3]

[1]*CMC, Instituto Tecnológico de Buenos Aires, Av. E. Madero 399, Buenos Aires, Argentina.*

[2]*DIMEAS, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy*

[3]*Bristol Composites Institute, University of Bristol, BS8 1TR Bristol, U.K.*

raffaella.sesana@polito.it

Composite foams *FEM* *Fatigue*

Abstract Open cell polymer foams are used in several engineering fields due to their flame resistance, lightweight properties, dissipation, energy absorption and acoustical insulation. Polymeric foam nanocomposites can be obtained either by mixing the chemical components and the nanoreinforcements before foaming and polymerization, or by dip coating several nano ink layers coatings with nanoparticles. The mechanical properties can then be controlled through the engineering of nanostructured multiple coating layers. The mechanical response of these complex porous materials at macroscopic scale under cyclic and fatigue behaviour is often described by using hyperelastic models as the Ogden one. However, the effect of the foam architecture, its material properties and the layered nano ink cannot be addressed in detail by using a simple homogenized hyperelastic material approach. In this work we simulate the coated open cell foam material by using a Representative Volume Element of Finite Elements FE-RVE model at the microscale with periodic boundary conditions. The RVE is initiated from data related to the microscopic foam configuration and density, and then uses a tessellation to create a random representation of the inner foam structure. The FE representation is created from the RVE solid model and the overall response is validated and calibrated from experimental data related to the quasi-static and fatigue behavior of the nanostructured foams. Finally, the microscale numerical model is used to understand the inner deformation mechanisms present during the compression of the nanocomposite foams, their cell buckling and energy dissipation.

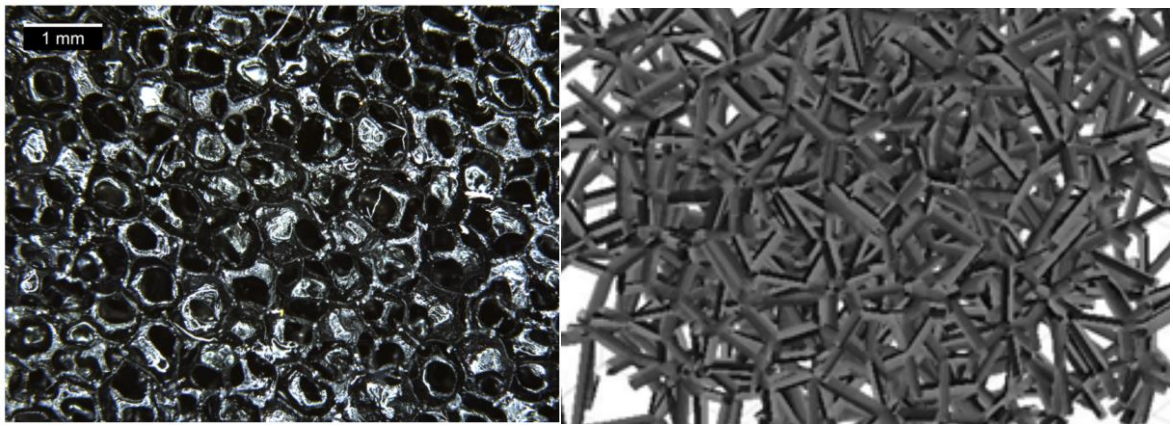

Figure 1 - *Actual coated foam – FE-RVE solid model*

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Fatigue peculiarity of metals treated by laser shock impact

Prokhorov A.[1], Vshivkov A.[1], Plekhov A.[1], Kashaev N. [2], Zherebtsov S. [3]

[1]*Institute of Continuous Media Mechanics UB RAS, 1, Korolev St., Perm 614013, Russia*

[2]*Institute of Materials Research, Helmholtz-Zentrum Geesthacht, Max-Planck-Str. 1, 21502 Geesthacht, Germany*

[3]*Laboratory of Bulk Nanostructured Materials, Belgorod National Research University,*

Belgorod 308015, Russia

prokhorov.a@icmm.ru

Fatigue *Heat dissipation* *Laser shock peening*

Currently, an increase in the fatigue life of parts made of metallic materials is possible in two different ways: by searching for new materials or by changing the structural state of existing ones. Particularly promising from the point of view of increasing the fatigue life is a change in the state of the surface and the creation of compressive residual stresses. At present, the domestic industry uses methods that create compressive residual stresses to a depth of 0.2 mm (shot blasting), which is significantly inferior to foreign methods and creates significant problems associated with the high sensitivity of critical parts to mechanical damage and, as a result, the need for more frequent replacement. Using the laser shock peening method, it is possible to create residual compressive stresses in the sub-surface layer of the material up to a depth of 1 mm, which significantly exceeds the results obtained by classical methods.

This work is devoted to study of the effect of surface compressive stresses obtained by the laser shock peening method on the physical and mechanical characteristics of metals. Armco-iron was chosen as the material for the study. Samples of the material were subjected to laser shock peening and tested in the high-cycle fatigue regime and quasi-static tension. The samples were subjected to rapid tests for fatigue life and ultimate strength. To compare the obtained characteristics, tests were carried out on initial state samples and samples treated by LSP. After mechanical testing, structural studies were carried out.

The results of the studiy have shown that on this material, subject to laser impact hardening, the energy dissipation changes significantly when a cyclic load is applied, in comparison with the material in the initial state. The number of cycles before sample failure also changed significantly. Structural studies also show significant differences in the indices of dislocation density in the near-surface zone, which may explain the anomalous energy dissipation.

The reported study was funded by program for the creation and development of a world-class scientific center "Supersonic" for 2020-2025 with financial support from the Ministry of Education and Science of Russia (agreement dated November 16, 2020 No. 075-15-2020-925)

, Method of Coaxial Accelerometers Correlation for Quality Assessment of Structural Joints

D. Serdjuks[1], V. Kurtenoks[2], A. Tatarinov[3], V. Mironovs[4], V. Lapkovskis[5], K. Buka-Vaivade[2], A. Macevičs[2], K. Topcijs[2], M. Vilnitis[4]

[1]*Institute of Structural Engineering and Reconstruction, Riga Technical University, Kipsalas st. 6A/6B, LV-1048, Riga, Latvia, dmitrijs.serdjuks@rtu.lv*

[2]*Institute of Structural Engineering and Reconstruction, Riga Technical University, Riga, Latvia karina.buka.vaivade@gmail.com*

[3]*Institute of Electronics and Computer Science, Riga, Latvia*

[4]*Institute of Construction Technology, Riga Technical University, Riga, Latvia*

[5]*Scientific Laboratory of Powder Materials, Riga Technical University, Riga, Latvia*

Nondestructive examination *Dynamic response* *Joints*

Abstract Assessment of the stiffness of joints is important for the joints' design, monitoring the condition of building structures and prognosis of the lifetime and safety of buildings or its elements. Typically, such assessment is done by a non-destructive way using either shock or vibration analysis with a network of accelerometers as sensors. To improve the quality of diagnostics of structural joints and to make it more specific, a method and measurement system realizing the principle of correlation of normalized coaxial accelerations measured in 3D space were proposed. The method is based on the mathematical analysis of vibrations of structural joints in 3 spatial directions using 3D accelerometers, located at different parts of a joint and orientated coaxially. The correlation method was verified in a laboratory experiment using rigid, semi-rigid and hinge joints of steel and timber beams. Two stands with timber and steel beams joined at right angles by steel screws were fabricated and tested by static loading to confirm the actual state of the joints. Steel and timber beams with hot-rolled HEA 100 profiles and 150X50 mm solid sections made of S355 and C16 strength classes were used for the steel and timber stands, correspondingly. Decrease of the joint's stiffness in the case of probable damages was modelled by the loosening of the steel screws in the timber beams and changing the values of friction forces in joining bolt in the steel stands. Both stands were subjected to a vibration load provided by electrodynamics actuators fixed on one of the joint elements. This element was excited by a chirp signal in a frequency sweep range from 30 to 50 Hz, where the most prominent resonances of the stands were found. Acceleration responses were recorded by 3D accelerators placed on the loaded and connected beams, whereas the joint was located between the beams. Peak values of the cross-correlation function between the responses from the correspondingly orientated pairs of coaxial accelerometers were determined. It was shown that the difference between the peak values of the correlation functions obtained for the rigid, semi-rigid and hinge joints enabled specification of the joints' stiffness.

Acknowledgments *This research was supported by Latvian Council of Science funded project "Method of correlation of coaxial accelerations in 6-D space for quality assessment of structural joints (COACCEL)" (Nr. lzp-2020/1-0240).*

, Non-model vibration analysis methods for health monitoring of structural joints

V. Lapkovskis[1], V. Kurtenoks[2], K. Buka-Vaivade[2], D. Serdjuks[2], V. Mironovs[3], A. Tatarinov[4], A. Podkoritovs[2]

[1] *Scientific Laboratory of Powder Materials, Riga Technical University, Kipsalas st. 6B, LV-1048, Riga, Latvia,* Vjaceslavs.lapkovskis@rtu.lv

[2]*Institute of Structural Engineering and Reconstruction, Riga Technical University, Riga, Latvia* karina.buka.vaivade@gmail.com

[3]*Institute of Construction Technology, Riga Technical University, Riga, Latvia*

[4]*Institute of Electronics and Computer Science, Riga, Latvia*

Nondestructive examination *Structural Health Monitoring* *Joints*

Abstract Structural health of the joints play an important role in behaviour of the building structures. Structural Health Monitoring methods enable to investigate and carry under the control behaviour of structural joints during the whole service life of the buildings. Choice of Structural Health Monitoring methods depends on the material of the joined structural members, it loading case, joints structure and it stiffness. Since the beginning of the 21st century, many Structural Health Monitoring methods have been developed to investigate structural behaviour by means of vibration analysis. Vibration analysis methods make it possible to determine possible damages of structures or structural joints due to changes in frequency response, modal shape, its attenuation, etc. Methods based on vibration analysis are classified into two categories - methods based on the use of ready-made mathematical models and methods that do not employ models for vibration analysis. Current paper discusses various vibration analysis methods for assessing a structural health of joints. Particular attention is paid to non-model based methods, as this avoids the need for complex mathematical representations of models for specific investigation objects. In the context of the development of vibration analysis methods for building structures, the authors propose the concept of a 6-dimensional coaxial approach to the study of joints based on an acceleration analysis in 6-dimensional space.

Acknowledgments *This research was supported by Latvian Council of Science funded project "Method of correlation of coaxial accelerations in 6-D space for quality assessment of structural joints (COACCEL)" (Nr. lzp-2020/1-0240).*

Behaviour of timber-concrete composite with defects in adhesive connection

K. Buka-Vaivade[1], D. Serdjuks[2]

[1]*Institute of Structural Engineering and Reconstruction, Riga Technical University, Kipsalas st. 6A/6B, LV-1048, Riga, Latvia, karina.buka-vaivade@rtu.lv*

[2]*Institute of Structural Engineering and Reconstruction, Riga Technical University*

Adhesive connection *Rigid connection* *Wood-concrete composite*

Abstract Rigid timber to concrete connection is the most effective solution for timber-concrete composite members subjected to the flexure which provides full composite action and better structural behaviour. One of the most used technologies to produce glued connection of the timber-concrete composite is "dry" method, which includes gluing together of timber and precast concrete slab. This technique has high risk of forming a poor-quality rigid connection in timber-concrete composite, and there are difficulties in controlling the quality of the glued connection. The effect of the non-glued areas in connection between composite layers on the shear stresses and energy absorption were investigated by finite element method and laboratorian experiment. Three timber-concrete composite panels in combination with carbon fibre reinforced plastic composite tapes in the tension zone with the span 1.8 m were statically loaded till the failure by the scheme of three-point bending. Mid-span displacements were measured in the bending test. One specimen was produced by dry method, by gluing together cross-laminated timber panel and prefabricated concrete panel. Timber-concrete qualitative connection of the other two specimens was provided by the granite chips, which were glued on the surface of the cross-laminated timber by epoxy, and then wet concrete was placed. Dimensions of the crushed granite pieces changes within the limits from 16 to 25 mm. The investigated panel with different amount and sizes of non-glued areas in the timber to concrete connection was numerically modelled. Obtained results shown, that the increase of shear stresses is influenced not so much by a total amount of non-glued areas, but by the size of the individual defective areas. Moreover, large non-glued areas significantly reduce the energy absorption of elements subjected to the flexure, which was observed experimentally for defective panel produced by the classical dry method with almost 4 times larger mid-span displacements than for panel with full composite action provided by the proposed production technology of the timber to concrete rigid connection. So, the proposed technology based on the use of granite chips, provides a high-quality connection between timber and concrete layers, with insignificant ration between possible defect and total connection surface area, which is equal to the area of one granite chips edge.

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, Energy balance and acoustic emission in titanium Grade 2 under fatigue

A. Vshivkov, A. Iziumova, V. Mubassarova, A. Prokhorov, I. Panteleev, O. Plekhov

ICMM UB RAS, Academika Koroleva st, 1, Perm, 614013, Russia, vshivkov.a@icmm.ru

Fatigue *Dissipated and stored energy* *Acoustic emission*

Abstract Acoustic emission method is one of the widely used and well-proven non-destructive testing methods. The energy of the acoustic emission signal correlates with the change in the material state during crack propagation. A similar correlation probably exists for the dissipated (also accumulated) energy. Moreover, according to the thermodynamic theory of strength, the measure of damage is internal energy stored in material due to deformation. Thus, the establishment of a connection between signals of different nature (acoustic and thermal) will allow one a deeper look at the processes occurring in the material under fatigue loading.

The features of energy balance and acoustic emission accompanying the fatigue crack propagation in titanium Grade 2 using the Charpy V-notch specimens are discussed in the presented work. The quantitative measurements of the heat dissipation rate were carried out by an original heat flux sensor. The stored energy was determined as a difference between plastic work and heat dissipation. Waveforms and parameters of acoustic emission signals (maximum amplitude, energy) were recorded during the fatigue test.

As a result, two characteristic stages of heat dissipation were identified during fatigue crack growth. At the first stage, dissipation is constant; its value depends on the loading amplitude. The second stage is characterized by unstable crack growth and avalanche-like increase in heat dissipation. It was shown that stored energy rate is smoother than heat dissipation rate and it slows down when approaching the moment of damage. Cluster analysis of the acoustic emission signal allows us to identify two most probable clusters. One of them is present throughout the test, the second appears later. The dependence between cumulative energy of both clusters and the crack length is obtained. The correlation between the acoustic emission energy and heat dissipation was found to be a harbinger of the approaching transition from stable to unstable crack growth.

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Characteristics of old irons and steels, a statistical analysis

Stéphane Sire[1]

[1]*University of Brest, UMR CNRS 6027 IRDL, 29200, Brest, stephane.sire@univ-brest.fr*

Irons & steels *Statistical analysis* *Static loading*

Abstract Since the middle of the 19th century, the materials used in the construction of metallic bridges have followed the evolution of the production process and metallurgy. The composition and the mechanical characteristics of these irons and steels have thus evolved. Therefore, their knowledge is essential for a better maintenance of these structures. This global statistical study based on a literature review and integrating recent data shows the evolution of these properties for a more appropriate consideration in the calculations of old metallic structures.

Effects of long-term loading on Moabi timber beams in the tropical environment of Gabon: spatial variability of mechanical parameters in 3-point bending and axial compression tests

Valérie Nsouami [1], Nicaise Manfoumbi Boussougou [2], Emilio Bastidas-Arteaga [3], Rostand Moutou Pitti [4,5]

[1] *Ecole Normale Supérieure L'Enseignement Technique (ENSET), LaReVa Bois, BP 3989 Libreville, Gabon; nsouamijeanj@gmail.com*

[2] *Ecole Polytechnique de Masuku, Université des Sciences et Techniques de Masuku, BP 901 Franceville, Gabon; nicaise.manfoumbi@gmail.com*

[3] *Laboratoire des Sciences de l'Ingénieur pour l'Environnement (LaSIE UMR CNRS 7356), La Rochelle Université, 17042 La Rochelle, France; ebastida@univ-lr.fr*

[4] *Clermont Auvergne INP, CNRS, Institut Pascal, Université Clermont Auvergne, BP 10448, 63000 Clermont-Ferrand, France; rostand.moutou_pitti@uca.fr*

[8] *CENAREST, IRT, BP 14070 Libreville, Gabon*

Moabi (Baillonella toxisperma) *Spatial variability* *Long-term-loading*

Abstract This work is devoted to 3-point bending and longitudinal compression tests performed on tropical specimens of Moabi (*Baillonella toxisperma*) origin from Gabon. The beams are formerly subjected to long-term loading in three media (air-conditioned, unsheltered and sheltered outdoor) in a tropical environment. The beams were sawn into nine 340 mm long sections and subdivided into three sections in the vertical direction (top section, middle section and bottom section). From each section, two specimens were extracted for the bending test, two for the tensile test and four for the compression test. In the present study, 216 compression specimens with a cross-section of 20 x 20 mm^2 and a length of 120 mm, and 324 bending specimens with a cross-section of 15 x 15 mm^2 and a length of 300 mm were used. The tests for the determination of the local modulus of elasticity and failure strength in bending and compression were carried out according with NF EN 408. The results obtained show a strong influence of time and exposure environments on the mechanical parameters (bending and compression strength, modulus of elasticity). There is also a strong variability of these mechanical parameters along the length of the beams with a clear correlation between the sampling areas and the level of exposure; this confirms quite well the level of complexity of the wood material.

, **Innovative processing for ceramic ball manufacturing: analytical estimation, experimental testing and numerical simulation**

Raffaella Sesana[1], Irene Pessolano Filos[1], Sebastiano Rizzo[2], Rocco Lupoi[3]

[1]DIMEAS, Politecnico di Torino, Italy, raffaella.sesana@polito.it

[1]DIMEAS, Politecnico di Torino, Italy

[2]Director of Quality & Central Laboratory, Tsubaki Nakashima, Italy

[3]Trinity College Dublin, The University of Dublin, Department of Mechanical, Manufacturing & Biomedical Engineering, Parsons Building, Dublin 2, Ireland

Pin on disc test *Wear simulation* *Hybrid bearings*

Abstract Technological progress in hybrid bearings has led to the development of the manufacturing process of ball bearing. It is traditionally performed by using grinding wheels that operate by abrasion. In this frame, the bearing manufacturing industry is demanding improvements in materials, geometry, and process parameters calibration. In the case of ceramic balls for hybrid bearings, grinding wheels are generally made of cast iron and the grinding process is obtained by means of the contribution of diamond paste, with abrasive diamond particles.
In this paper the result of the innovative research on abrasive coatings applied to metallic grinding wheels. This innovation can lead to obtain time and material saving, to more controllable processes and maybe to a more environmental friendly process.

This work aimed at studying the evolution of griding processes performed by means of diamond coated grinding wheels on Si_3N_4 balls for hybrid bearings. Experimental pin on disk test were performed on two samples of specimens obtained by means of two different diamond coating processes, being the Si_3N_4 ball the pin and the coated sample the disk. The wear tests were simulated by means of ANSYS FEM software [Fig.1], to compute the wear depth of a Silicon Nitride Si_3N_4 ball. Simulation solutions resulted to be consistent with experimental measurements and analytical estimations. These preliminary results demonstrate the feasibility of using numerical simulation to predict wear evolution in innovative Si_3N_4 ball processing.

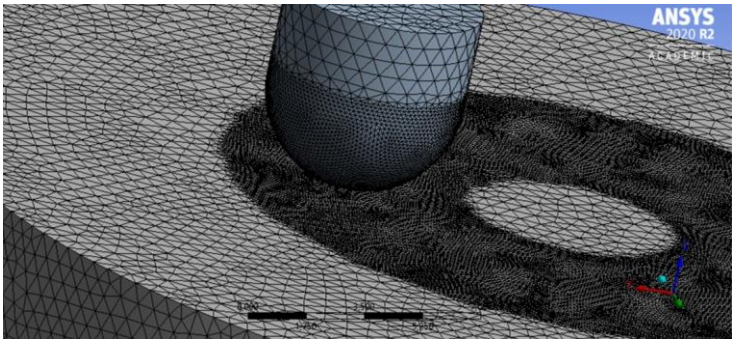

Figure 1 - *caption for the Figure*

, Experimental study on the mechanism of wheel-rail steels crack initiation and wear growth under rolling contact fatigue

Junpeng Li[1], Yu Zhou[1], Zheng Wang[1] , Zhechao Lu[1] , Zhongning Cheng[1] , Shiye Wang[1]

[1] The Key Laboratory of Road and Traffic Engineering of the Ministry of Education, Tongji University, 201804, No. 4800, Cao'an Road, Shanghai, China; ljpjunpengli@163.com

Rail *Twin-roller fatigue test* *Crack initiation*

Abstract Rolling contact fatigue (RCF), like head checks (HCs), have been common rail defects in Chinese heavy-haul railway. At present, the prediction of HC initiation life is mainly based on the Miner rule, which assumes a simple linear accumulation of damage, and is commonly used in fatigue damage accumulation. Actually, the wheel–rail contact on the rail by passing vehicles is a variable amplitude load with a random loading sequence and interacting by adjacent wheels, which should be treated as a nonlinear fatigue damage process. Therefore. in this paper, the nonlinear fatigue damage accumulation model was applied in the fatigue damage process by combining the damage curve method considering the load sequence, and the fatigue damage method considering the interaction of the adjacent loads. However, due to the complexity of HC initiation mechanism, the theoretical prediction is also difficult to verify the correlation between crack initiation and wear growth, therefore, the prediction of crack initiation life and wear need to be supplemented and verified by experiments. Based on this, a twin-roller fatigue test rig was used to reproduce the process of the coexistence of fatigue crack initiation and wear growth in the specimens from rail samples. Based on the test rig situation, a nonlinear prediction method for the coexistence of HC initiation and wear growth in the rail was presented. The results were compared with those from the linear fatigue accumulation model. At the same time, the microcrack initiation characteristics of the test specimens were observed by SEM, and the accuracy of the theoretical prediction results was verified.

Current research results indicate that:

1. The modified fatigue damage accumulation model shows nonlinear characteristics in the form of the stress ratio, the exponent on the loading cycle ratio, and the damage accumulation process between each of the variable amplitude load phases controlled by rail wear and profile evolution. The HC initiation life from the linear and nonlinear models was close to the upper range value and the median of the test respectively.

2. SEM observation shows that the pearlite is extruded and deformed under rolling contact load on the contact surface of the sample, and micro-pores are formed after dislocation slippage. In the micro-pores, due to stress concentration, micro-cracks are initiated. Many micro-cracks have a tendency to be connected with each other, and finally join into sheets to form surface crack initiation. There are many states such as micro-pores and micro-cracks on the contact surface at the same time. Under different rolling times, the proportion of each state is different, and the contact surface is always in a dynamic equilibrium process.

3. The crack initiated at the sub-surface of the roller contact surface in the test, which was 0.034 mm average deep to the contact surface. The predicted crack initiated at the sub-surface of the roller contact surface by nonlinear model, which was 0.031mm deep to the contact surface. The predicted crack initiation depth is basically consistent with the test results. The relative error between the two was about 9%.

Assessment of potential alkali-silica reactivity of aggregates for concrete

João Custódio[1], Dória Costa[2], António Santos Silva[2], António Bettencourt Ribeiro[2]

[1] *LNEC – Laboratório Nacional de Engenharia Civil, Av. do Brasil, 101, 1700-066 Lisboa, Portugal, jcustodio@lnec.pt*

[2] *LNEC – Laboratório Nacional de Engenharia Civil, Av. do Brasil, 101, 1700-066 Lisboa, Portugal*

Concrete degradation *Alkali-Silica Reaction* *Prevention*

Abstract Deterioration of concrete structures by Alkali-Silica Reaction (ASR) has increased dramatically in recent years in Portugal. ASR has important economic implications, since it is normally observed in very large structures (*e.g.* dams, bridges) and the work necessary to remediate the problem involves large areas of reconstruction and complex and expensive repairing techniques and materials. In addition, ASR diminishes the affected structure service life, may involve the interruption of its function and, ultimately, can lead to its decommissioning and demolishing. In Portugal, ASR has been detected in more than thirty bridges and dams. Due to the rhythm at which ASR is being identified in existing structures and the large number of structures under or planned for construction in Portugal, which may also develop ASR, it is predicted that concrete structures deterioration due to ASR will continue to increase in the near future. Presently, in Europe, only two standards deal with ASR, namely EN 206 and EN 12620, and they just state that actions shall be taken to prevent ASR in new structures using procedures of established suitability. Due to the complexity and multiplicity of factors involved in ASR together with the variability of the materials used, no such established procedures exist, and each country has to rely on national specifications. Because of that, in Portugal, LNEC Specification E415 was created in 1993 and LNEC Specification E 461 was created in 2004, revised in 2007. However, due to the scientific developments occurred since then, new revised versions were prepared and will soon be published. Although, LNEC Specifications provide guidance on the identification of potentially alkali-silica reactive aggregates, *i.e.* aggregates that contain forms of silica that can be potentially reactive with alkalis, there are still some knowledge gaps on how to reliably assess the potential reactivity of some minerals present in granites and similar rocks, which are the type of aggregate most used in large structures in Portugal. Therefore, to contribute to the current ongoing discussion on the role of the main components of these rocks on ASR development, this paper presents the methodology that was applied in the evaluation of concrete granitic aggregates used in recently built Portuguese hydroelectric projects as well as in a dam constructed several decades ago, and in which the deleterious development of ASR was detected 15 years after construction.

,Oil transmission pipelines with corrosion defects reinforced by two types of sleeves: comparison efficiency of sleeves

Jan Kec[1], Ivo Černý[1], Adam Poloch[1], Barbora Kyselá[1], Miloslav Poupa[1], Přemysl Kuchař[2]

[1]SVÚM a.s., Strength Department, Tovární 2053, 250 88 Čelákovice, Czech Republic, kec@svum.cz

[2]MERO ČR, a.s., Veltruská 748, 278 01 Kralupy nad Vltavou, Czech Republic

Structural integrity *Failure analysis* *Strain gauge measurement*

Abstract Two segments of transition oil pipeline DN500 and DN700, operating since 1980, were subjected to full-scale pressure testing. In 2000, corrosion defects were found on both pipelines - the two corrosion defects on the outside wall of DN500 pipeline, and the one corrosion defect on the inside wall of DN700 pipeline. Both pipes were sleeve reinforced to increase the safety and reliability of the lines. The DN500 pipeline used the Cold Lock sleeve - the steel sleeve with a composite filling. On the other hand, the DN700 pipeline used the Clock Spring composite sleeve. In 2020, after two decades of operation with sleeve repairs, both pipelines were dug out, removed from operation and used for full-scale pressure testing to determine the residual strength sleeves repairs and to compare the efficiency of the sleeves. The full-scale test included three stages of loading. The first step was continual loading up to the yield strength of pipelines. The second step was the fatigue pressure test at 4-6.3 MPa with a total of 10,000 cycles. The third step was the burst pressure test. The stress-strain behavior was measured with help of strain gauges placed on the pipeline surface and on the surface of sleeves. From strain gauge measurement, it was found that both sleeves still have a remarkable residual strength even after two decades of operation. However, the Cold lock sleeve has a higher efficiency compared to the Clock Spring sleeve, as it showed lower strains during loading. The test method, procedure and results will be fully discussed in the proposed paper.

, Static and fatigue properties of maraging steel X3NiCoMoTi18-9- 5

Miloslav Kepka[1], Ivana Zetkova[1], Miroslav Zetek[1], Ludmila Kucerova[1]

[1]University of West Bohemia, Faculty of Mechanical Engineering, Regional Technological Institute, Univerzitni 22, 306 14 Pilsen, zetkova@rti.zcu.cz

Maraging steel *Fatigue life* *SN curve*

Abstract The paper deals with static and fatigue properties of additively manufactured samples of maraging steel X3NiCoMoTi18-9- 5 and their comparison with convectional steel. Experiments were performed by normal and increased temperature about 450°C. Two types of heat treatment were chosen – standard process of solution annealing and high isostatic pressure. High-cycle fatigue tests were performed on sets of test specimens with both heat treatments, and the fatigue limit and slope of the SN curve was evaluated. The results of static and fatigue tests were used to verify the service strength of the real component.

Figure 1 – *Components for static and fatigue tests*

, The influence of high temperature on dynamic response of concrete beams reinforced with GFRP rods

Beata Zima

Department of Structural Mechanics, Faculty of Civil and Environmental Engineering, Gdańsk University of Technology, Gdańsk, Poland, email: beata.zima@pg.edu.pl

concrete *composite* *dynamics*

Abstract The article presents the results of the experimental investigation of the influence of the high temperature on concrete structures reinforced with composite rods. Within the study the concrete specimens were subjected to varying temperature and next, the nondestructive and destructive tests were conducted. The nondestructive tests based on free vibration induced by impact force. The changes in the natural frequencies allowed to assess the level of degradation caused by temperature, which next was verified during destructive bending tests. The presented study allowed for assessment of the composite rods, which in general susceptible to high temperatures. It was proved that nondestructive tests allow for detection the damages caused even by relatively low temperatures (<100ºC).

, **Effect of elliptical defect orientation on the durability of specimens subjected to cyclic bending**

Zbigniew Marciniak[1], Ricardo Branco[2], Rui F. Martins[3] , Dariusz Rozumek[1], Wojciech Macek[4]

[1]Opole University of Technology, Department of Mechanics and Machine Design, ul. Mikolajczyka 5, 45-271 Opole, Poland z.marciniak@po.edu.pl

[2]CEMMPRE, Department of Mechanical Engineering, University of Coimbra, Rua Luís Reis Santos, Pinhal de Marrocos, 3030-788 Coimbra, Portugal

[3]UNIDEMI, Department of Mechanical and Industrial Engineering, Nova School of Science and Technology, Universidade NOVA de Lisboa, Campus de Caparica, 2829-516 Caparica – Portugal

[4]Opole University of Technology, ul. Proszkowska 76, 45-758 Opole - Poland

Fatigue of material *Non-local methods* *Defects*

Abstract The work presents the effect of elliptical defects orientation on the durability of specimens made of C45 steel. Three kinds of specimens with elliptical defects in the form of a one-sided notch oriented at different angles 45, 60, and 90 degrees were subjected to cyclic bending (R=-1). The stress state analysis was performed using local and non-local methods to determine an equivalent amplitude of stress then the results were compared with those obtained for smooth specimens. Figure 1 shows the fatigue life diagram for stress calculated with the non-local volumetric method for the specimens with the defects and smooth specimens. As can be seen, levels of stress are similar despite the different values of the bending moment amplitudes.

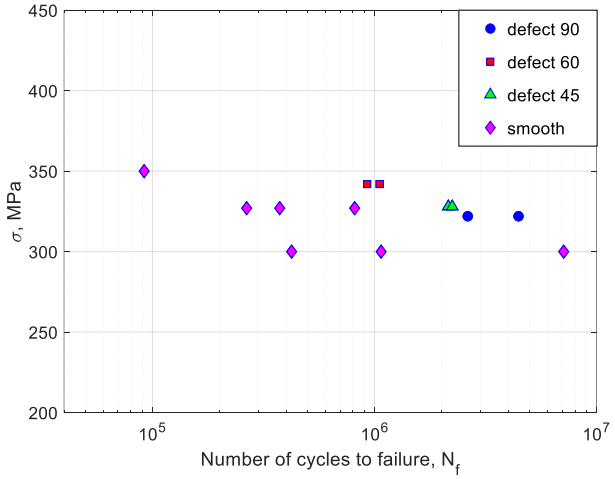

Figure 1 - *Fatigue life diagram for stresses calculated with the non-local volumetric method*

, Thermal and Electrical characterization of Si_3N_4 blanks through Active Thermography Techniques: experimental tests and numerical simulation

Raffaella Sesana[1], Irene Pessolano Filos[1], Andrea Uva[2]

[1]*DIMEAS, Politecnico di Torino, Italy, irene.pessolano@polito.it, raffaella.sesana@polito.it*

[1]*DIMEAS, Politecnico di Torino, Italy*

[2]*Central Laboratory Manager Global Function, Tsubaki Nakashima, Italy*

Thermal and Electrical conductivity *Active thermography* *Hybrid bearings*

Abstract Technological progress in the gas turbine, machine tool spindles, electric motors, and generators has led to the development of hybrid bearing, which features ceramic rolling elements. In this frame, the bearing manufacturing industry is demanding improvements in materials, geometry, and process parameters calibration. In the case of ceramic balls for hybrid bearings, the physical, thermal, and electrical properties of raw materials are important parameters to guarantee a high-performance product.

Three samples of specimens were obtained with three different Si_3N_4 powders and manufactured according to 3 different processes. This work aimed at characterizing the thermal and electrical properties of different Si_3N_4 blanks for ceramic ball production. Second aim of the research is to correlate the physical properties obtained with the different techniques and to non-destructive thermography measurements.

The physical properties of the samples were investigated by means of different experimental techniques. Active thermography non-destructive technique was performed on three disks with different crystal structures of Si_3N_4 samples [Fig.1]. Moreover, the thermal and electrical response was numerically simulated through COMSOL software, to investigate their correlation. Simulation solutions resulted to be consistent with experimental measurements. The electrical response was experimentally measured with appropriate equipment. These preliminary results demonstrate the feasibility of using numerical simulation and non-destructive methods to predict physical properties of Si_3N_4 ball in the hybrid production process.

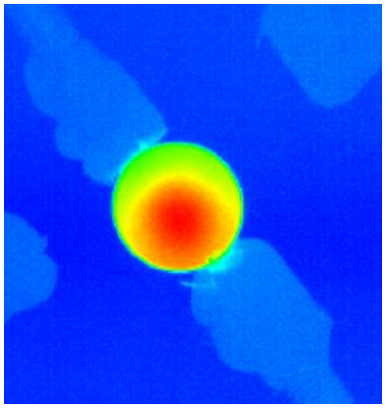

Figure 1 – *Active thermography on Si_3N_4 blanks*

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Security determination in timber structures

Miguel Tortoriello[1], Luis Lima [2], Ana Clara Cobas[3]

[1]*UNNOBA-LEMEJ. Pergamino, Argentina.* miguel.tortoriello@nexo.unnoba.edu.ar

[2]*UNNOBA-LEMEJ. La Plata, Argentina.* luislima@unnoba.edu.ar

[3]*UNNOBA-LEMEJ. Junín, Argentina.* cobasanaclara@yahoo.com.ar

Structural security *Failure mechanism* *Willow timber*

Abstract

To calculate structural security it is necessary to determine its failure mechanism.

In elasto-plastic materials like timber, structural ultimate load arrives when in an n-degree hyperstatic structure the (n+1) plastic hinge is produced

Consequently, to calculate structural ultimate loads, the modelling of the basic failure mechanism of timber elements is necessary.

In this paper, we propose basic ultimate load models of willow timber elements experimentally determined. They are models of compression, tension and flexural failure mechanisms in elements with a rectangular cross section.

Numerical results will be included.

, Notched Connection Design in Timber-Concrete Composite Floors

Lei Zhang[1], Jianhui Zhou[2], Ying Hei Chui[3]

[1]Department of Civil and Environmental Engineering, University of Alberta, Edmonton, AB Canada T6G 1H9. Email: lzhang9@ualberta.ca

[2] School of Engineering, University of Northern British Columbia

[3] Department of Civil and Environmental Engineering, University of Alberta

Timber-concrete composite *Notched Connection* *Parametric study*

Abstract Timber-concrete composite floors combine the material merits of timber and concrete by connecting bottom timber elements with a top concrete layer. Notched connections made by cutting grooves on timber and then filling them with concrete are considered as one of the most structural efficient and cost-effective connecting solutions in timber-concrete composite floors. The guidelines for notched connection design to achieve the overall best structural performance of the composite floors are scarce. This study investigated the effects of different notched connection designs on the bending stiffness and strength of the timber-concrete composite floors through analytical, numerical, and experimental methods. The composite beam models and finite element models built in this study were verified by the results from bending tests on timber-concrete composite floors. Parametric studies were carried out on the bending stiffness and ultimate strength of the composite floors with varying notched connection number, location, depth, as well as the relative thickness of concrete and timber. It is found that the depth of notches is the most important factor for the floor bending stiffness and load-carrying capacity while the locations of notches only have a major influence when the number of connections is small. This study provides an important reference for the optimal design of timber-concrete composite floors connected with notches and the continued evolvement of design guidelines for notched connections.

, **On the transmission of non-Gaussian random loading through linear structures**

Arvid Trapp, Fabian Hollweck, Peter Wolfsteiner

Munich University of Applied Sciences,
Dachauer Str. 98b, 80335 München, Germany,
atrapp@hm.edu

non-Gaussian loading *higher-order statistics* *linear systems theory*

Abstract The kurtosis finds popular application for characterizing the non-Gaussianity of random loading. Hereby it is often overseen that the kurtosis has a spectral density, which provides substantial information regarding the specific nature of the non-Gaussianity and the affected frequencies. This becomes crucial when estimating the degree of non-Gaussianity that transfers into structural responses and consequently affects fatigue damage. The rare use of higher-order spectra, which provide this frequency-domain decomposition of the kurtosis, seem to be related to their complexity. These multi-dimensional spectra compromise redundancies (symmetries) and considerable computational effort. Therefore and to provide simple access, this contribution discusses challenges of higher-order spectra and their capability for visualization. From this consideration we propose a representation of the structural transfer behavior for an input-trispectrum (the spectral density related to the loading's kurtosis). This provides the basis for calculating response output-trispectra and to define a descriptor for the transmissibility of the kurtosis. Popular kurtosis control algorithms are employed to discuss what has become known as the Papoulis rule – the tendency of non-Gaussian loading to cause Gaussian responses. Results are demonstrated showing that for typical mechanical structures with pronounced resonances the nature of the non-Gaussianity is crucial for the transmission of the kurtosis and the resulting fatigue damage. These results support experimental data that has been published in recent years, which has shown that a loadings kurtosis cannot directly be related to fatigue life of mechanical structures.

SLM process parameters effects on the fatigue strength of AMed Inconel 718

G. Macoretta[1], B. D. Monelli[1]

[1]*Department of Civil and Industrial Engineering, University of Pisa, Largo Lucio Lazzarino 2, Pisa, giuseppe.macoretta@phd.unipi.it*

SLM process parameters *Fatigue assessment* *Inconel 718*

Abstract Selective Laser Melting (SLM) emerged as a technology suitable for the industrial production of structural components featuring complex geometries. In the field of elevated temperature applications, the possibilities offered by the SLM can be successfully used to produced complex geometries as internal cooling channels or lattice structures, as long as the process doesn't jeopardize the mechanical properties, in particular the fatigue strength.

The SLM process parameters play a fundamental role in determining the mechanical performances of the component but are also the key parameter for increasing the productivity of the process and thus the industrial spread of the technology.

In the present work, it is presented an experimental assessment of the effects produced by different sets of productivity-oriented SLM process parameters on the Wöehler curves of cylindrical plain specimens. The adopted process parameters were defined on the basis of a previously developed thermal analytical model aimed to predict the melt pool dimensions and shape.

HCF tests were carried out at room temperature in an axial load configuration with a stress ratio of 0.05 and a loading frequency of about 150 Hz, by using a resonant testing machine. Test frequency was monitored to detect the occurrence of crack nucleation and monitor the propagation phase.

In order to understand the causes of the fatigue behavior, metallographic analyses were carried out to investigate the microstructural properties or the presence of internal defects, i.e. porosity and hot tearing cracks, produced by each set of process parameters. The surface quality was also investigated in detail through optical microscope analyses. Fractographic analyses were used to identify the nucleation and crack propagation region, as well as the presence of the defects in proximity to the fracture onset.

The experimental data, along with an analytical model of the thermal field produced by a single scan line, allowed to define a preliminary feasible region for the SLM process on Inconel 718, in terms of scan velocity, laser power, layer thickness, and scan strategy.

, Estimation of maximum temperature attained during concrete cure for internal sulfate reaction prevention in structures

João Custódio[1], Manuel Vieira[2], António Bettencourt Ribeiro [2], António Mesquita[3], Rodrigo Santos[3]

[1] LNEC – Laboratório Nacional de Engenharia Civil, Av. do Brasil, 101, 1700-066 Lisboa, Portugal, jcustodio@lnec.pt

[2] LNEC – Laboratório Nacional de Engenharia Civil, Av. do Brasil, 101, 1700-066 Lisboa, Portugal

[3] CIMPOR, Avenida José Malhoa, n.º 22 - Pisos 6 a 11, 1099-020 Lisboa, Portugal

Concrete degradation *Internal sulfate reaction* *Temperature*

Abstract Nowadays, the internal sulfate reaction, ISR (term hereinafter used to designate the phenomenon heat-induced internal sulphate attack, which is also referred in the literature as delayed ettringite formation, DEF) still constitutes one of the main causes of concrete degradation in massive concrete elements or structures. In most practical situations, there is no effective way of stopping ISR. Therefore, ISR prevention is of upmost importance to prevent costly rehabilitation procedures or even the need to decommission/replace the affected structure. The most effective way to prevent the deleterious development of ISR is to control the maximum temperature attained during concrete cure. The control of temperature can be made (i) with an adequate mix design, and (ii) by controlling temperature during concrete production, concrete transport, concrete pouring and after the concrete has been placed and compacted. The tools currently available to practitioners, for predicting the maximum temperature attained in a concrete element, require the previous knowledge of the heat of hydration of the cement to be used in the structure. Several methods can be used to determine the cement heat of hydration, although the most common has been the Lagavant method, *i.e.* by means of semi-adiabatic calorimetry, the isothermal conduction calorimetry method is now becoming a widely used method. Since the two test methods produce different values, it is important to establish a correlation between the results obtained with both of them and to determine their influence on the temperature estimate made with the currently available calculation tools. This paper aims at addressing these concerns by presenting the heat of hydration determinations made with the two methods to several cement types normally used in concrete structures, the correlation obtained between the two methods, the temperature estimates made with them, and their comparison with the actual temperatures recorded in a structure.

, Behavior of R/C Beams Strengthened in Flexure using Externally Bonded Aluminum Alloy Plates

Jamal A. Abdalla[1,*], Rami A. Hawileh[2] and Hayder A. Rasheed[3]

[1]*Department of Civil Engineering, American University of Sharjah, Sharjah, United Arab Emirates, jabdalla@aus.edu*

[2]*Department of Civil Engineering, American University of Sharjah, Sharjah, United Arab Emirates, rhaweeleh@aus.edu*

[3]*Department of Civil Engineering, Kansas State University, Manhattan, KS, USA hayder@k-state.edu*

*Corresponding Author, E-mail: *jabdalla*@aus.edu

Experimental/Retrofitting *Large Structures* *Aluminum Alloy Flexure*

Abstract The utilization of carbon, glass, aramid and basalt fiber reinforced polymers (FRP) in shear and flexural strengthening of reinforced concrete beams have been well established and proved its effectiveness. As externally bonded strengthening materials, FRP composites have many advantages and some disadvantages. The main disadvantage of FRP composites are that they brittle materials. Aluminum Alloy (AA) plates are ductile materials which is a desirable characteristics for reinforced concrete (R/C) beams. This study investigated the structural integrity of R/C beams strengthened in flexure using externally bonded AA plates. Four beams were cast and three of them were strengthened in flexure using AA plates. The AA plate covered 90% of the beams' span and two of the beams were anchored at the end of the AA plates using one layer and two layers of carbon fiber reinforced polymers (CFRP). The control beam was not strengthened and was therefore used as bench mark for measuring the performance the strengthened beams with and without anchorages. The beams were tested until failure under four-point bending. Load-deflection curves and load-strain curves were plotted and the ductility indices of the tested beams were calculated. It was observed that the strengthened beams showed increase in strength of up to 27.2% of that of the control beam. However, the ductility of the strengthened beams with anchorages decreased slightly. The use of anchorages influenced the types of failure modes of the tested beams.

, Strengthening of RC Columns using NSM-CFRP Strips and CFRP-Fabric Wraps

Jamal A. Abdalla[1,*], Raed Abokwiek[2], Rami A. Hawileh[3]

[1]*Department of Civil Engineering, American University of Sharjah, Sharjah, United Arab Emirates, jabdalla@aus.edu*

[2]*Department of Civil Engineering, American University of Sharjah, Sharjah, United Arab Emirates, b00021265@aus.edu*

[3]*Department of Civil Engineering, American University of Sharjah, Sharjah, United Arab Emirates, rhaweeleh@aus.edu*

*Corresponding Author, E-mail: jabdalla@aus.edu

NSM-CFRP; CFRP Wraps *Retrofitting* *Column Capacity Predictions*

Abstract A comprehensive experimental investigation was carried out on reinforced concrete (R/C) columns strengthened with Near Surface Mounted (NSM) Carbon Fiber Reinforced Polymer (CFRP) strips with CFRP fabric wraps as confinement. The number of NSM-CFRP strips and the number of CFRP-Fabric wraps were varied. The R/C columns were subjected to concentric and eccentric loads with different eccentricities that resulted in uniaxial bending. Significant improvements in strength and ductility were observed in the strengthened columns compared to that of the control one. In this investigation four empirical models, based on the experimental results, were developed to predict the un-strengthened and the NSM-CFRP strengthened R/C columns using different parameters. The capacities of the columns predicted by the developed empirical models were validated using the obtained experimental results. It is observed that the developed empirical models have exponential decay and a near-perfect fit to the experimental results, with R^2 averaging more than 99% and an average mean absolute percent error (MAPE) of 6.6%. It is concluded that the developed models can be used as useful tools for predicting capacity of columns with NSM-CFRP strips and CFRP wraps under axial and uniaxial bending.

, Active thermography for the investigation of corrosion in steel surfaces

M. M. Dugand[1], F. Curà[2], R. Sesana[2], S. Lazzaro[2]

[1]CRF - Materials Engineering Methods & Tools, E/E & Multifunctional Materials - Opto-Electronic & Glazing, C.so Settembrini 40, 10235 Turin – Italy

[2] Dimeas Politecnico di Torino, corso Duca degli Abruzzi 24, 10129 Torino, Italy

raffaella.sesana@polito.it

NDT *Active thermography* *Corrosion*

Abstract The present work aims at developing an experimental methodology for the analysis of corrosion phenomena of steel surfaces by means of Active Thermography (AT), in reflexion configuration (RC).

The peculiarity of this AT approach consists in exciting by means of a laser source the sound surface of the specimens and acquiring the thermal signal on the same surface, instead of the corroded one: the thermal signal is then composed by the reflection of the thermal wave reflected by the corroded surface. This procedure aims at investigating internal corroded surfaces like in vessels, piping, carters etc. Thermal tests were performed in Step Heating and Lock-In conditions, by varying excitation parameters (power, time, number of pulse, ….) to improve the experimental set up. Surface thermal profiles were acquired by an IR thermocamera and means of salt spray testing; at set time intervals the specimens were investigated by means of AT. Each duration corresponded to a surface damage entity and to a variation in the thermal response. Thermal responses of corroded specimens were related to the corresponding corrosion level, referring to a reference specimen without corrosion. The entity of corrosion was also verified by a metallographic optical microscope to measure the thickness variation of the specimens.

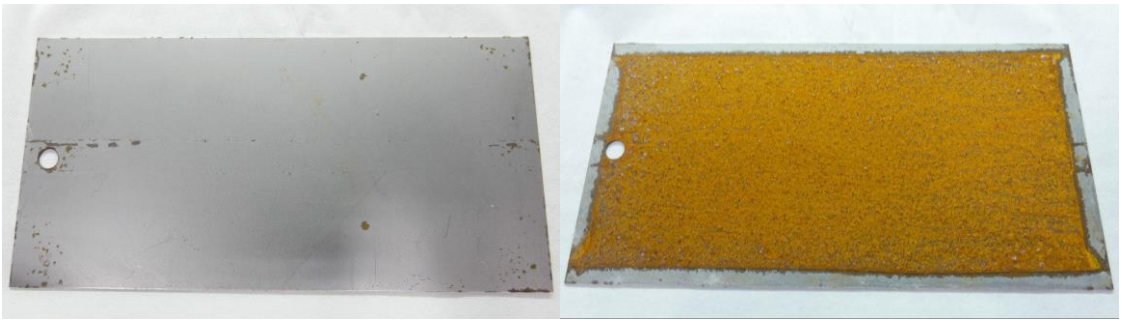

Figure 1 – *front (clean) and rear (corroded) specimen surfaces*

, Lock-in thermography for residual stresses investigation in steel welded joints

Francesca Curà[1], Raffaella Sesana[1], Luca Corsaro[1], Irene Pessolano[1], Luca Santoro[1],

[1]*Politecnico di Torino, raffaella.sesana@polito.it*

Lock-In IRT *HAZ* *Residual Stresses*

Abstract

A non-destructive method for the residual stresses evaluation in welded joints is here proposed. Conventional residual stress determination techniques are based on the destruction of the original material stress state that causes a relaxation, hence is not possible to use those methods on working components.

The proposed method provides for an active lock-in infrared thermography analysis by means of a FLIR thermal camera and an exciting laser head for the evaluation of the thermal diffusivity.

In general, it is possible to relate the thermal diffusivity to the diffusion length, which is the ability of a thermal wave with a known wavelength to penetrate inside the sample, using the phase contrast trend as a function of the distance from the laser spot. Through the variation in diffusivity is possible to investigate the level of anisotropy in the Heat Affected Zone (HAZ). On the basis of these considerations, tests were run by varying thermal source parameters, as laser power level and number of impulses in the time unit.

The post-processing of the experimental data needs to face high noise to signal ratio and phase mapping extraction algorithm, therefore Single Value Decomposition (SVD)-denoising and lock-in amplifier techniques were implemented in a Matlab script.

Thus, the diffusivity is expected to be dependent on the local characteristics in the joint and varying through the different directions

Preliminary experimental results obtained on custom made welded joint samples are presented and discussed.

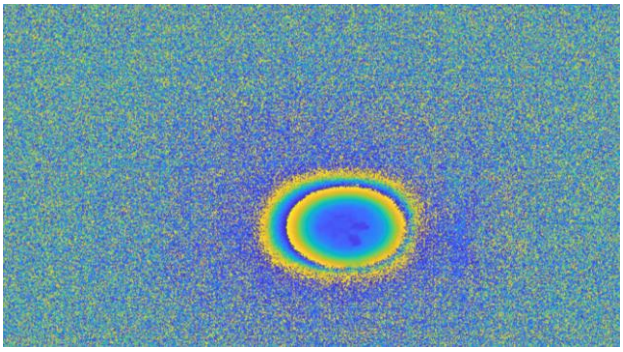

Figure 1 – *Phase mapping of the temperature in proximity of the laser spot*

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Crack Closure Analysis Using Digital Image Correlation

Behzad V. Farahani, Frederico Direito, Pedro J. Sousa, Pedro M. G. P. Moreira

INEGI – Institute of Science and Innovation in Mechanical and Industrial Engineering, Campus of FEUP, R. Dr. Roberto Frias 400, 4200-465 Porto, Portugal.

bfarahani@inegi.up.pt

Crack Closure *Fracture Mechanics* *DIC*

Abstract The crack closure phenomenon plays a significant role in both fracture and fatigue mechanics, explaining the mechanical behaviour of specimens when subjected to fatigue loading, and the effect of several parameters, such as the stress ratio or the crack length. This work aims to study the plasticity-induced crack closure phenomenon. Therefore, cracked Middle Tension (MT) specimens, made of an aluminium alloy (AA6082) were considered. The 2D Digital Image Correlation (DIC) is used to measure the displacement field on the crack flanks upon loading and unloading procedures. The effective Stress Intensity Factor (SIF) is calculated through the obtained deformation field over a region around the crack tip. According to Elber's methodology, the direct measurement of the crack flanks' opening, immediately behind the crack tip, using virtual displacement gages (spreading over the initial notch) is a viable methodology. Therefore, this study follows Elber's method to analyse the crack closure through the data obtained by the DIC.

The main contribution of the present work is the description of the phenomenon of plasticity-induced crack closure, associated with the development of residual plastically deformed material on the flanks of an advancing fatigue crack.

, A Study on the Passive Safety Solution on Transit Buses According to Regulation No. 66 of UN/ECE

Behzad V. Farahani[1], Nuno V. Ramos[1], Pedro M. G. P. Moreira[1], Rafael Cunha[2], André Costa[2], Ricardo Maia[2], Rui. M. Rodrigues[2]

[1]*INEGI – Institute of Science and Innovation in Mechanical and Industrial Engineering, Campus of FEUP, R. Dr. Roberto Frias 400, 4200-465 Porto, Portugal*

bfarahani@inegi.up.pt

[2]*CaetanaBus – Av. Vasco da Gama, 1410, 4431-901 Vila Nova de Gaia, Portugal*

Transit Bus *R66 Standard Regulation* *FEM*

Abstract This study focuses on the structural behaviour of passenger buses in accordance with Regulation No. 66.02 of UN/ECE. It aimed at establishment of passive safety solutions of the bus if subjected to the rollover test. Despise this regulation only applies to Vehicles M3 Class II/III, it aims to provide solutions applied on Vehicle 3 Class I, city busses.

The rollover test is a lateral tilting test in which the complete vehicle is standing on the tilting platform, with blocked suspension and is tilted slowly, from a height of 800 mm from the ground level, to its unstable equilibrium position. This regulation applies to a single-deck rigid vehicle and a residual space must be considered in the bus's interior space. Hence, no part of the vehicle, which is outside the residual space at the beginning of the test, shall intrude into the residual space during the test. A segment of the whole bus structure, including the superstructure and chassis, has been considered as the case study. According to real geometrical characteristics of the bus segment, numerical analyses have been performed through Finite Element Method (FEM) formulations. It aims at the structural safety assessment whether it possesses the sufficient strength to ensure that the residual space during and after the rollover test on complete vehicle remains unharmed.

The rollover test has been numerically simulated. As a result, the force-displacement curve was characterised and the internal energy released by the segment during loading has been obtained and compared to the value recommended by R66 regulation. Besides, the contour of the deformed structure was also determined. The outcome of this work contributed to assess the structural integrity of the bus and propose the passive safety solutions if necessary.

Compression fatigue behaviour of extrusion-based 3D printed PLA

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R.A. Cláudio[1,3], R.A Baptista[1,3], J. Dupont[2], M. Leite[3], L. Reis[3]

[1]*CDP2T, Instituto Politécnico de Setúbal, Portugal, ricardo.claudio@estsetubal.ips.pt*

[2]*Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal*

[3]*IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal*

Compression Fatigue *PLA* *3D Printing*

Abstract The incredible advance of 3D Printing in the last years make this process available not only for prototyping, but also for the production of functional parts. One of such applications is for tooling, for production support, rising the concept of direct rapid tooling with most of the cases with considerable reduction of lead-times and development costs. In aeronautical production, where the production quantities are usually low, are necessary many tools for production support, like dies, which in general are unique and complex. For these cases, 3D printing is a good alternative against traditional subtractive process like CNC milling. The tools produced by additive manufacturing, even with polymeric materials like PLA, are durable enough for demanding applications like aluminum sheet metal forming. One these widely used processes is hydroforming or rubber die forming, in which the die is mainly subjected to compressive fatigue loads. In this work, several tensile, compression and compression fatigue tests were performed on specimens manufactured through fused filament fabrication (FFF) to study the effects on mechanical behavior of some printing parameters. In a first stage, several static tensile and compressive tests were performed to characterize stress strain curves under tension and compression. For compression static and fatigue tests, cylindrical specimens were tested according to ASTM D7791 and ASTM D695. Design of experiments was conducted to identify and quantify the effects of the printing parameters on the fatigue behavior of these specimens. A discussion with a detailed analysis with the influence of each parameter is provided. At the end, specimens with the best combinations of parameters where fully characterized to obtain the Ramberg-Osgood and Coffin Manson parameters.

, Fatigue Behavior of PLA Material and the Effects of Mean Stress and Notch: Experiments and Modeling

Mohammed Algarni[1]

[1] *Mechanical Engineering Department, Faculty of Engineering, P.O. Box 344, Rabigh 21911, King Abdulaziz University, Saudi Arabia*

malgarni1@kau.edu.sa

Additive manufacturing *Fused deposition modeling* *Fatigue life* *PLA* *Mean stress* *Notch*

Abstract

Additive manufacturing (AM) is a 3D printing technology that creates complex engineering parts by printing layer by layer. AM is a disruptive technology that is rapidly growing, owing to its effective features: high accuracy, fast production, and low cost. Parts made of polylactic acid (PLA) biodegradable material fused deposition modeling are being increasingly produced in the industry because of their high strength and environment-friendliness. Three-dimensionally printed parts are prone to different loading types (static, dynamic, and time-dependent loading) during in-service operations. They react differently to loadings based on their manufacturing process parameters and geometry. This research aims to study the effect of mean stress and notch on the uniaxial fatigue behavior of PLA parts. Load-controlled fatigue tests were performed with fatigue load ratios of R = -1, 0.1, and 0.3 on three rectangular-shaped specimens with large, medium, and sharp notches. The study was conducted with 180 fatigue tests and mainly focused on the high cycle fatigue regime. The experimental results showed that the effect of mean stresses and notches were significant on the PLA fatigue life. The Kohout and Vechet model, along with the stress triaxiality factor, was used to study the notch effect on fatigue life. Moreover, the Walker model was applied to investigate the effect of mean stress on PLA fatigue life. The models of life prediction were in good agreement with the experimental results.

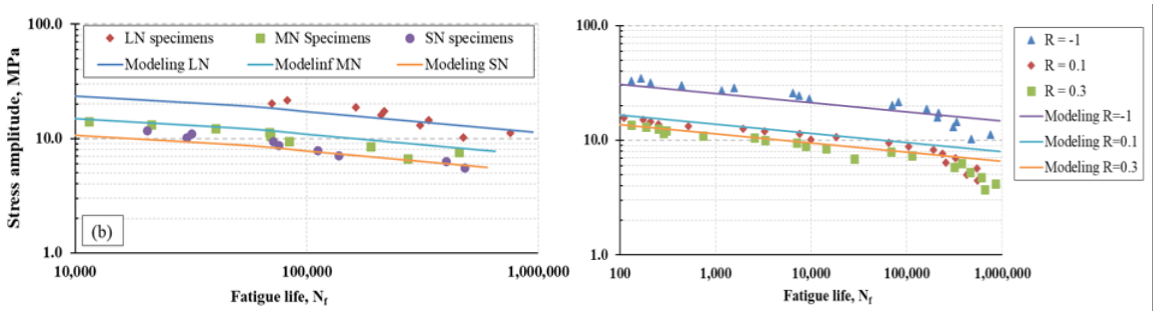

Figure 1 - *KV fatigue life model (with zero mean stress) perfectly predicted fatigue life with the stress triaxiality factor (left). Effect of mean stress accurately predicted by the Walker fatigue life model for LN specimens (right).*

, Dynamic delamination resistance of electrically modified composites

Sahand P. Shamchi[1,2], Marcelo F.S.F. de Moura[2], Zhongjie Zhao[3], Xiaosu Yi[3,4], Pedro M.G.P. Moreira[1]

[1]INEGI, Institute of Science and Innovation in Mechanical and Industrial Engineering, Rua Dr. Roberto Frias, 400, 4200-465 Porto, Portugal

[2]Faculdade de Engenharia da Universidade do Porto, Departamento de Engenharia Mecânica, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal

[3]AVIC Composites Co., Ltd, 66 Shuanghe Road, Shunyi District, Beijing 101300, PR China

[4]Faculty of Science and Engineering, University of Nottingham Ningbo China (UNNC), 199 Taikang East Road, Ningbo 315100, PR China

[*]E-mail: pmoreira@inegi.up.pt

Impact behavior *Delamination* *Conductive polymer composites*

Abstract This work investigates the delamination toughness of carbon fiber-reinforced epoxy composite laminates with enhanced electrical conductivity. The laminates were electrically modified by Functionalized Interlayer Technology (FIT) to offer a potential Lighting Striker Protection (LSP) solution applicable in modern aircrafts. To examine the influence of loading rate, the specimens were subjected to both quasi-static and high velocity impact loadings. The impact tests were carried out using a developed dynamic three-point bend apparatus by modifying the Hopkinson bar technique. The rate sensitivity of the electrically modified carbon/epoxy composites under out-of-plane loading is discussed.

Ironing process influence in the mechanical properties of seams in PLA specimens produced with multiple extrusion modules

Manuel Sardinha[1], Nuno Frutuoso[3], Marco Leite[2], Relógio Ribeiro[2], and Luís Reis[2,*]

[1]*ADIST, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049–001 Lisboa, Portugal.*

[2] *IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049 – 001 Lisboa, Portugal. * luis.g.reis@tecnico.ulisboa.pt*

[3] *FabInventors, Av. Rovisco Pais, 1049–001 Lisboa, Portugal.*

AM Polymers *PLA seams* *Ironing Process*

Abstract In this work, the effect that a thermal process, termed ironing, has on the mechanical properties of PLA samples produced through material extrusion with multiple extrusion modules is evaluated. The manufacture of parts with multiple collaborative extrusion heads emerges as a potential solution to overcome the limitations of speed, cost, and scale of the conventional extrusion processes. The existence of multiple extrusion modules will impose the existence of intersection areas in parts, treated as seams or joints. Previous research has shown that the seams act in a part by creating a localized fragility, due to a lack of material continuity, diminishing its mechanical strength. To promote remelting of the polymer near this discontinuity, ironing is applied in the surroundings of the seam location, in each layer. Since the understanding of the ironing process is still far from reaching its potential, different samples with different extrusion strategies were applied. Among the tested parameters are the seam dimension, the ironing application area, the amount of extruded material during its application, and the correlation between deposition direction of the ironing paths and deposition paths, i. e., orthogonal or parallel to each other. Achieved results allow concluding about the influence of the ironing process on seams behavior.

Experimental and theoretical study of a laser beam-welded Al-Li AA2198 alloy under different artificial ageing conditions

A. Germanou[1], T. N. Examilioti[1, 2, 3], P. Papanikos[4], N. Kashaev[3], B. Klusemann[2,3], N. D. Alexopoulos[1]

[1]School of Engineering, Department of Financial Engineering, University of the Aegean, Chios, Greece

[2]Institute of Product and Process Innovation, Leuphana University of Lüneburg, Lüneburg, Germany

[3]Institute of Materials Mechanics, Helmholtz-Zentrum Hereon, Geesthacht, Germany

[4]University of the Aegean, Department of Product and Systems Design Engineering, 841 00 Syros, Greece

Al-Cu-Li alloy *Laser beam-welding* *Finite element method*

Abstract Third generation Al-Cu-Li alloys are highly promising materials with improved mechanical properties and damage tolerance behavior compared to other commercially available 2xxx series Al alloys. The aluminum alloy AA2198 is a relatively new alloy and is developed for fuselage skin applications in aircrafts. The use of high strength Al-Cu-Li alloys can lead to 20 % in structural weight savings compared to conventional Al-Cu-Mg alloys, e.g. AA2024. The improved mechanical properties are quite often associated with the lithium concentration that enables the formation of additional strengthening precipitates.

In the present work, Al-Cu-Li AA2198-T3 alloy sheets were laser beam-welded with Al-Si wire as filler material. Micro-flat tensile (MFT) specimens were extracted from all regions of interest within the welded joint to address the local changes in the mechanical properties. The theoretical investigation involves the development of a finite element (FE) model that takes into account the geometry of the welded joint cross-section, as well as the local mechanical properties of the different zones of the weld. This model will be used to estimate the macroscopical tensile mechanical properties of the laser beam-welded joints under different artificial ageing conditions.

Higher silicon content in the fusion zone (FZ), due to the filler material, affects the local tensile mechanical properties. As result a decrease of the tensile strength with a simultaneous increase in elongation to fracture was observed in the FZ of the weld. In the FZ of the weld, MFT specimens showed a decrease in yield stress of approximately 26 % and an increase in elongation to fracture of about 2.8 % from the radiation exposure side to the weld root side. MFT specimens from the FZ present approximately 43 % to 56 % lower yield stress when compared to the base material. The theoretical analysis show that the FE-predictions based on MFT experiments fit well with the experimental load – displacement results obtained using standard tensile specimens.

Identification of material properties of green laminate composite plates using bio-inspired optimisation algorithms

A. F. F. Rodrigues[1], J. V. Araújo dos Santos[2], H. Lopes[3]

[1]*Instituto Superior Tecnico, Universidade de Lisboa, Lisboa, Portugal*

[2]*IDMEC, Instituto Superior Tecnico, Universidade de Lisboa, Lisboa, Portugal*

[3]*DEM-ISEP, Instituto Politecnico do Porto, Porto, Portugal*

Composite Materials *Elastic constants* *Nature-inspired optimisation*

Abstract This work proposes a non-destructive method for the identification of material properties of composite materials. The proposed optimization problems have for design variables the material elastic constants and make use of nature-inspired metaheuristic optimization algorithms. The objective functions relate experimental natural frequencies with computationally obtained ones. The nature-inspired metaheuristic optimization algorithms used are the: (1) Genetic algorithm, (2) Particle Swarm Optimization algorithm, (3) Grey Wolf Optimization algorithm, (4) Firefly algorithm, and (5) Cuckoo Search algorithm. The study is focused on laminated composite materials, whether they are synthetic fiber reinforced, such as glass fibers reinforced composites, or natural fibers reinforced like wooden fibers reinforced composites and plywood. However, a specimen of aluminum is also analyzed to establish a baseline and test the proposed method. The proposed method allows the identification of the elastic constants within an acceptable range compared to other methods, provided that enough natural frequencies are accurately measured. This method presents several advantages in comparison to other methods: (1) it does not require an initial guess of the elastic constants, (2) it does not need the gradient of the objective functions, and (3) it allows the identification of a large range of elastic constants of different materials due to its good adaptability and versatility.

Numerical Simulation of Deformation Behavior of Additively Manufactured Polymer Lattice Structures with a Porosity Gradient

Mikhail Tashkinov[1], Natalia Elenskaya[1]

[1] *Perm National Research Polytechnic University, Komsomolsky Ave., 29, Perm, Russia, m.tashkinov@pstu.ru*

Lattice structures *Porosity gradient* *3D printing*

Abstract Active development of the additive technologies (3D printing) opens up new possibilities in developing and creating structures with optimal properties. A natural solution to the need for efficient, lightweight, yet durable materials has been found in periodic and non-periodic lattice structures. These new material systems have great potential in a wide range of applications, from modern engineering structures to biomedical products. One of the concepts of creating functional materials is the design of structurally heterogeneous materials with a gradient of properties. In recent years, the use of porous 3D-printed functional-gradient materials has increased significantly. In such materials, the structure of the material varies as a function of volume. Such mechanical gradients play a crucial role in stress distribution. An important aspect of gradient structures is the smoothing of stress gradients to avoid stress concentrations caused by abrupt geometric changes. A separate challenge is the combination of multiple unit cell types, since the automatic transition from one unit cell type to another is not always straightforward.

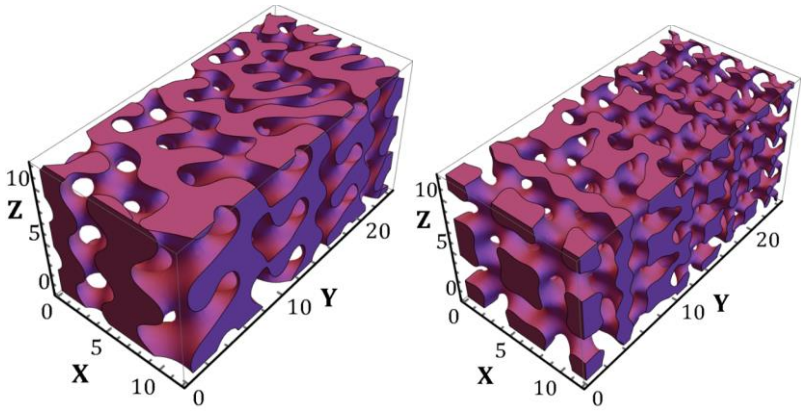

***Figure 1** – Lattice structures with porosity gradient*

This work is devoted to modeling of the specifics of mechanical behavior of polymer 3D lattice structures with a gradient of porosity and scaling factors. Geometric models of 3D heterogeneous lattice structures have been obtained using Triply Periodic Minimal Surfaces (TPMS) with variety of parameters. Numerical analysis was performed using finite elements method.

The authors gratefully acknowledge financial support from the Government of the Russian Federation under the mega-grant program, contract no. 075-15-2021-578 of May 31, 2021, hosted by Perm National Research Polytechnic University.

On the use of finite differences for vibration-based damage localization in laminated composite plates

T. Oliveira[1], J. V. Araujo dos Santos[2], H. Lopes[3]

[1]*Instituto Superior Tecnico, Universidade de Lisboa, Lisboa, Portugal*

[2]*IDMEC, Instituto Superior Tecnico, Universidade de Lisboa, Lisboa, Portugal*

[3]*DEM-ISEP, Instituto Politecnico do Porto, Porto, Portugal*

Laminated composites *Modal analysis* *Damage localization*

Abstract Laminated composite materials are a staple of modern material development, with extremely strong fibers being combined with resins to form versatile and efficient engineering structures. However, the advancements in material development must be accompanied by equally advanced methods for damage detection, as these materials develop inherently unique failure modes. This thesis aims to further the study of the use of modal shapes and their spatial derivatives to damage localization in laminated composite rectangular plates. ANSYS® Parametric Design Language (APDL) is used to perform Finite Element simulations of plates with several damage scenarios and damage mechanics models. MATLAB® is used to post-process these simulations results, namely by calculating the derivatives using the Finite Difference Method, applying three different Damage Detection Methods, including one that is being proposed here. To mimic experimental conditions and testing the resilience of the derivatives orders, different noise levels are introduced in the results of the Finite Element simulations. A Quality Index is employed to quantitatively evaluate the solutions, mainly regarding the response to the introduced noise. The results show that the different Damage Detection Methods tested have comparable results in terms of quality. These results also show that the damage detectability is higher when the damaged areas coincide with high displacement/curvature areas of the mode shapes and that higher noise levels have a more noticeable negative impact when employing higher-order derivatives.

VHCF under biaxial loading of a mold tool steel

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Pedro R. da Costa[1], Luís Reis[1,2,*], and Manuel Freitas[2,3]

[1] *Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049–001 Lisboa, Portugal.*

[2] *IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais, 1049 – 001 Lisboa, Portugal. * luis.g.reis@tecnico.ulisboa.pt*

[3] *Atlântica, Instituto Universitário, Fabrica da Pólvora, Barcarena, 2730-036 Barcarena, Portugal*

VHCF *Biaxial loading* *Mold steel*

Abstract Ultrasonic fatigue methodology was raised from the need for an energy and time reliable method to reach and study between 10E07 and 10E09 cycles, what is established as the Very High Cycle Fatigue (VHCF) regime. The main purpose is to study the fatigue life behavior of a material in the regime between 10E07 and 10E09 cycles. In this study an ultrasonic fatigue testing machine was used in order carry out biaxial fatigue tests at a frequency of 20 kHz. The objective is to reach a reliable multiaxial fatigue testing method, by modifying only the specimen, with the ability to choose the shear-axial stress ratio. The improved design of the testing method was focused in innovative design specimen by conducting both numerical and experimental analysis. Thermographic imaging, laser displacement measurements, and the application of rosette strain gauges to the main stress region of the specimen were carried out in order to validate the new design concept and compared with the ones obtained by finite element. A series of fatigue tests were carried out in tension/torsion fatigue, either at ultrasonic frequencies or in servo-hydraulic machines and the results are compared and discussed in order to understand the feasibility of multiaxial fatigue tests at ultrasonic frequencies.

Effect of WC-Co Grade on Heading Die Performance in Cold Forging

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M. Burak Toparli[1,2], İlhan Burak Özhan[1]

[1]Nedu Bağlantı Elemanları San. ve Tic. A.Ş., AOSB, Çiğli, İzmir, Turkey,
burak.toparli@norm-fasteners.com.tr

[2]Norm Cıvata San. ve Tic. A.Ş., AOSB, Çiğli, İzmir, Turkey

WC-Co hard metals *Cold forging* *Failure analysis*

Abstract In this study, heading dies used for production of fasteners with external 6-lobe head form were investigated. In cold forging, forming dies are generally produced from WCCo hard metals and tool steels. Inserts made of WC-Co hard metals are shrink-fitted with rings made of tool steels to have prestressing. Depending on operation, the choice of WC-Co grade is very crucial and has significant effect on die performance. Based on Co content and WC grain size, mechanical properties such as hardness and transverse rupture strength of WC-Co materials are greatly changing. In this study, according to initial die design and material selection, fasteners were produced and heading die performance was monitored. During production, it was observed that internal socket dimensions of heading dies were enlarged after about 90,000 product and dies were replaced to ensure that produced fasteners were in tolerance limits. After production, failure analysis was performed to used heading dies. It was revealed that main failure mechanism was abrasive wear leading to enlargement in the internal socket form. There was no visible cracking or damage on used dies. In order to improve performance against abrasive wear, WC-Co grade with lower Co content and smaller WC grain size was employed. New heading dies were used in production to investigate the effect of material change. It was revealed that new heading dies were cracked after about 563,000 products. Failure analysis of revised heading dies showed that both abrasive wear and fatigue cracking were contributed to failure. Therefore, it was concluded that use of WC-Co inserts with lower Co content and smaller WC grain size improved the wear resistance leading to improved performance.

Load-bearing and aseismic mechanism of traditional Chinese timber structures

Qingshan Yang [1, 2, ✉] Pan Yu[1], Ke Liu[1]

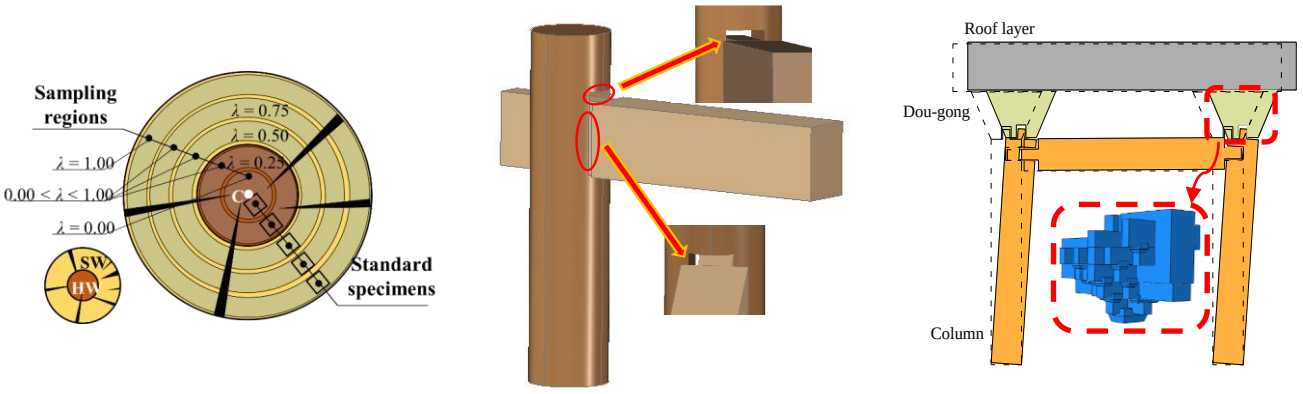
[1] *School of Civil Engineering, Chongqing University, Chongqing, 400044, China*

[2] *Beijing's Key Laboratory of Structural Wind Engineering and Urban Wind Environment, Beijing, 100044, China*

✉ *Corresponding author: qshyang@cqu.edu.cn*

Traditional timber structures *Material degradation* *Column foot*
Statistics of gaps *Mortise-tenon joints* *Dou-gong connection*
Rocking frame

Abstract This paper discusses the bearing mechanism of traditional Chinese timber structure from the aspects of damage and degradation of material, column foot, gaps and performance of mortise-tenon joints, performances of Dou-gong and timber frame. A time-varying model of the timber component was proposed based on the macroscopic and microscopic analysis of the timber properties. Then the mechanical model and the fine analysis method of the timber column with rocking-uplift behavior were established. Also, the probability distribution model of gaps of mortise-tenon joint was established, the model and analysis method of mortise-tenon joints were constructed. And the mechanical properties of single Dou-gong and the synergistic effect of Dou-gong layer were analyzed. Finally, the comprehensive seismic mechanism including the friction energy dissipation of the joints, gravitational potential energy storage of the heavy roof and the energy release of the frame by long period rocking were summarized through the experiment and theoretical analysis of the rocking timber frame.



(a) Sampling position (b) mortise-tenon joint with gaps (c) The model of rocking frame

Figure 1 - *The model of timber material, mortise-tenon joints and rocking frame*

, Modeling method of traditional Chinese timber structures with loose mortise-tenon joints

Qingshan Yang [1, 2, ✉] Pan Yu[1], Ke Liu[1]

[1] *School of Civil Engineering, Chongqing University, Chongqing, 400044, China*

[2] *Beijing's Key Laboratory of Structural Wind Engineering and Urban Wind Environment, Beijing, 100044, China*

✉ *Corresponding author: qshyang@cqu.edu.cn*

Timber structure *Mortise-tenon joints* *Modeling method*

Abstract: Timber frame is the most popular structural form found in traditional Chinese timber buildings which contains different types of loose mortise-tenon (MT) joints. The modeling method of multiple mortise-tenon joints are introduced in this paper detailly. Then one case of simplified timber frame is applied for studying the modeling methods of such structures. The performances of timber frames with loose joints under lateral load is furhter studied with an analytical friction-slip-contact model of the MT joint with gaps where different contact states between the mortise and tenon are described. The gap in the MT joint is found to be the major source of weakness in the lateral resistance of the frame. The nonlinear contact behavior within the joint is modelled via an analytically formulated hybrid finite element with a MT joint or a column foot (CF) joint. Results obtained may serve as reference for the maintenance of heritage timber structures in China.

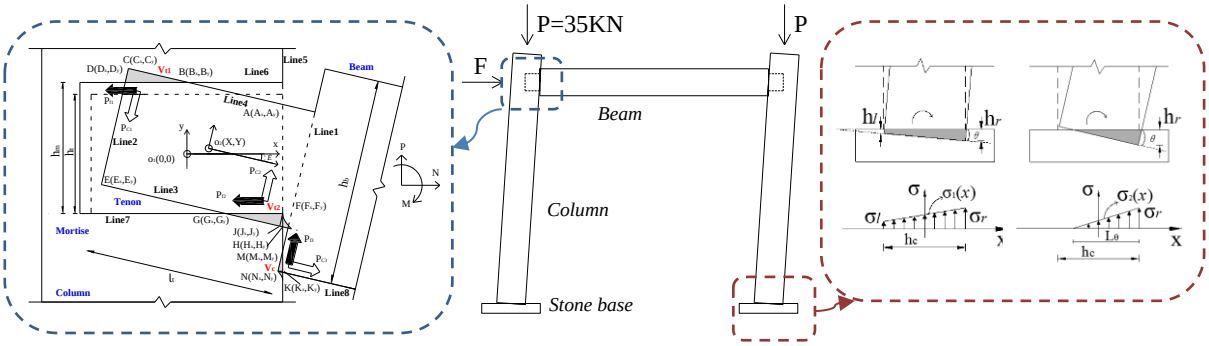


Figure 1 - *Modeling method of timber frame*

, Health indicator development for damage monitoring of composite panels utilizing SHM sensors

Georgios Galanopoulos[1], Dimitrios Milanoski[1], Agnes Broer[2], Dimitrios Zarouchas[2], Theodoros Loutas[1]

[1] *Applied Mechanics Laboratory, Department of Mechanical Engineering & Aeronautics, University of Patras, 26504 Rio, Greece* g.galanopoulos@upatras.gr

[2] *Structural Integrity & Composites Group, Faculty of Aerospace Engineering, Delft University of* Technology, *Kluyverweg 1, 2629HS Delft, the Netherlands*

Structural Health Monitoring *Health Indicators* *Composite Panels*

Abstract Composite materials are being used extensively more in the aerospace industry due to their excellent mechanical properties. However, the inhomogeneous nature of these materials, make them extremely vulnerable to impact damage, which significantly reduces their load baring capability. Especially, barely visible impact damage (BVID), can go unnoticed during routine inspection, compromising the integrity of the entire structure. Structural Health Monitoring (SHM) is an evolving technology which comes to resolve the issue of unseen damage detection. A capable sensor network should be employed to monitor the structure and help with the implementation of a Condition-Based-Maintenance (CBM) paradigm, to reduce aircraft downtimes and grounding costs. Though, the sensor network itself, is not always capable of capturing the necessary information. To this end, Health indicators (HIs) are developed that capture the degradation information of the structure. In this paper, novel HIs from Acoustic Emission (AE) and FBG strain data are introduced to monitor the fatigue behavior of Single Stringered Composite Panels (SSCPs). Two data pre-processing techniques are employed to visualize the rather uninformative raw data. The SSCPs, after an initial damage introduction, in the form of either artificial disbond (Teflon insert) or impact damage, are subjected to constant amplitude fatigue at 65% of their ultimate compression strength. Two types of HIs are introduced, i.e. physical HIs and virtual HIs. The HIs display promising behaviors, with high monotonicity and trendability. The AE based HIs also display average prognosability, something that is very poor in the strain based HIs, especially, the virtual ones. In general, the HIs managed to capture the degradation of the SSCPs highlighting the potential of these HIs as prognostic features.

, Geometrical study of adhesively-bonded T-joints by cohesive models

J.P.M. Lopes[1], R.G.S.G. Campilho[1,2], R.J.B. Rocha[1,2], F.J.G. Silva[1,2]

[1]Departamento de Engenharia Mecânica, Instituto Superior de Engenharia do Porto, Instituto Politécnico do Porto, Rua Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal

[2]INEGI – Pólo FEUP, Rua Dr. Roberto Frias, s/n, 4200-465 Porto, Portugal

raulcampilho@gmail.com

Structural adhesive *T-joint* *Cohesive zone model*

Abstract Adhesive bonding is a widely used joining method applied in several fields from the high-tech aeronautical industry to simpler ones as furniture or shoemakers. A wide variety of joints architectures is available, offering several options to the designers, although the most common are single-lap joints (SLJ), double-lap joints, and scarf joints. Additional designs, less used and studied are the stepped-lap, *T*-joints and tubular joints. *T*-joints find application in different types of industry, such as aircraft to bond stiffeners to skin and in the cars between the B-pillar and the rocker.

This work numerically evaluates the performance of the structural adhesive Araldite® 2015 in an aluminum *T*-joint, after validation with experimental results. A cohesive zone modelling (CZM) numerically study is carried out to capture the behavior of different *T*-joints geometrical configurations when subjected to peel loads. The work includes a parametric study, considering stress analysis, maximum load (P_m) and dissipated energy at failure (U) prediction, considering four geometrical parameters: flat adherend thickness (a), *T*-element thickness (t), overlap length (l) and *T*-element radius (r). A significant effect on P_m was found for the tested parameters, and the CZM method revealed to be a precious method for studying *T* joints with precision and accuracy.

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Adherend effect on the peel strength of a brittle adhesive

J.P.O. Pereira[1], R.G.S.G. Campilho[1,2], F.J.G. Silva[1,2], D.C. Gonçalves[2]

[1]Departamento de Engenharia Mecânica, Instituto Superior de Engenharia do Porto, Instituto Politécnico do Porto, Rua Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal

[2]INEGI – Pólo FEUP, Rua Dr. Roberto Frias, s/n, 4200-465 Porto, Portugal

raulcampilho@gmail.com

Structural adhesive *Floating roller peel test* *Cohesive zone models*

Abstract Due to its wide range of possibilities in material bonding, the use of adhesive joints is increasing in industrial applications. This method offers multiple advantages comparing to others more traditional methods (fastened, welded and riveted joints) since it avoids drilling holes and fasteners, which are often the source of stress concentration and weight increase. More uniform distribution of stresses, ease of manufacture, possibility of joining different materials and low cost are the main advantages of adhesive joints. The main disadvantages are related to the requirement of surface preparation, low peel strength and difficulties in quality control. The aeronautical, naval, automotive and aerospace industries are good examples where adhesive joints are widely applied. With the also growing use of composite materials in these industries, sometimes it is necessary to bond composite materials or even to bond joints of metallic and composite adherends. In order to fulfil this need, adhesive joints have increasingly become a solution when the objective is to bond different materials, even those most susceptible to develop galvanic corrosion.

In this research, the adherend effect on the peel strength of a brittle adhesive is experimentally studied, using the floating roller peel test, with the aim of investigate how the adherend changes affects the adhesion properties on brittle adhesives. The viability of using the floating roller peel test in composite-to-composite and composite-to-aluminium joints is also assessed, and the respective comparison with aluminium-aluminium joints carried out. On the other hand, it is also intended to prove the applicability of this test for quality control of adhesion and determination of peel strength in joints with composite materials. The results show that the Araldite® AV138 performance falls within the characteristic values of peel strength of other brittle structural adhesives, with very small discrepancies in the determined parameters.

Development of a small-scale testing machine for use with interferometric monitoring methods

Pedro J. Sousa[1], Shayan Eslami[1], Frederico Direito[1], Pedro M. G. P. Moreira[1]

[1]INEGI, Institute of Science and Innovation in Mechanical Engineering and Industrial Engineering, Campus da FEUP, R. Dr. Roberto Frias 400, 4200-465 Porto, Portugal.

psousa@inegi.up.pt

Interferometric methods *Machine control* *Material testing*

Abstract Material testing procedures are increasingly using image-based methods for strain field measurements, with extensive usage of Digital Image Correlation in particular. Nonetheless, there is interest in extending this use to other image-based interferometric methods with increased resolution, such as Electronic Speckle Pattern Interferometry (ESPI) and Shearography. In particular, ESPI requires very stable conditions for measurement, usually achieved by assembly on an optical table.

Therefore, this work reports the development of a portable testing machine that can be assembled on INEGI's optical table and is compatible with our previously developed 3D ESPI setup. The machine is an inexpensive custom design for static or quasi-static loading, with the main objective of withstanding a maximum load and velocity of 20 kN and 240 mm/min, respectively. The machine is built around a brushless dc (BLDC) motor and a TMCM-1630 controller, both from Trinamic, with data acquisition and force control being implemented with a DT9816 from Measurement Computing. This machine was built and is currently being successfully used with ESPI methodology.

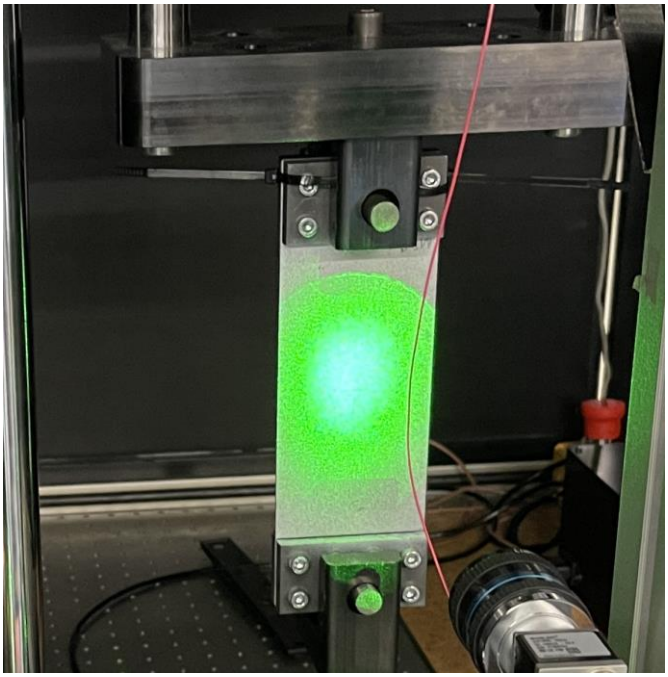

Figure 1 – *Photo of the developed testing machine being used with ESPI measurements*

Annealing effect on mechanical properties of 3D printed composites

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S. Valvez[1], Abílio P. Silva [1], P.N.B. Reis [2], F. Berto [3]

[1] *C-MAST, Department of Electromechanical Engineering, University of Beira Interior, Covilhã, Portugal*

[2] *University of Coimbra, CEMMPRE, Department of Mechanical Engineering, Coimbra, Portugal*

[3] *Department of Industrial and Mechanical Engineering, Norwegian University of Science and Technology, Trondheim, Norway*

Additive Manufacturing *Fused Deposition Modelling* *Thermal annealing*

Abstract

Additive manufacturing (AM) is a term that define all the manufacturing methods in which material is added, by layers, to create three-dimensional parts. Fused Deposition Modelling (FDM) is the most popular additive manufacturing method, with which it is possible to obtain highly complex three-dimensional parts without wasting materials. However, due to poor mechanical performance, the application of this technique is still restricted to components of secondary structures. To overcome this problem and improve the mechanical properties, literature suggests the thermal annealing process. However, geometrical distortion problems can occur, limiting the effectiveness of this post-processing treatment.

In terms of materials, Poly(ethylene terephthalate)-Glycol (PETG) is one of the most used materials in 3D printing technology due to the chemical alkali resistance, transparency, gloss, low haze, good printability, among other benefits. Moreover, with PETG is possible to achieve an excellent layer adhesion and very low shrinkage properties. In particular, when adding carbon fibre reduces the risk of warpage even further, makes the material more resistant and resilient making it an excellent choice for automotive and other industrial applications. However, the addition of carbon fibre extends its field of application because the composite becomes more resistant and resilient, in addition to further decreasing the risk of warping. On the other hand, when reinforced with aramid fibres, the applications can be extended to sectors where high resistance to friction and impact are expected.

Therefore, this work aims to study the effect of thermal annealing on the bending properties of PETG and PETG reinforced with carbon and aramid fibres. For this purpose, the samples were printed using a B2X300 printer, with a hardened steel nozzle of 0.6 mm diameter, and the printing parameters were optimized for each material. Five specimens for each variant were tested according to ASTM D790-17. According to the open literature, three temperatures (90ºC, 110ºC and 130ºC) and three annealing times (30 min, 240 min and 480 min) were used to study the benefits obtained with the thermal annealing. Finally, the samples were evaluated in terms of geometrical parameters, hardness, and flexural properties. Regardless of the materials studied, the best mechanical properties were obtained for the highest temperature and the longest exposure time, but due to the high geometric distortions, a temperature of 90 °C and an exposure of 30 minutes proved to be more effective.

, Probabilistic Method to estimate the Scatter of the Fatigue Strength of Shafts in the HCF-region

Sebastian Vetter[1,*], Alexander Hasse[1]

[1]*Professorship Machine Elements and Product Development, Institute of Design Engineering and Drive Technology, Technische Universität Chemnitz, 09126 Chemnitz, Germany*
**corresponding author: sebastian.vetter@mb.tu-chemnitz.de*

Fatigue strength *Probabilistic method* *Scatter*

Abstract The fatigue strength of shafts is always subjected to scatter. Knowledge of this scatter is essential, especially in the HCF-region, for a safe design of shafts. However, only few detailed literature data exist for the scatter of the fatigue strength. At the same time, experimental determination is extremely time-consuming and cost-intensive. Therefore, this paper shows a possibility to quantify the scatter of the (nominal) fatigue strength in the HCF-region by means of a probabilistic model. The basis for establishing such a model is to identify the influence parameters effecting the damage mechanism. In this context, the scattering influence parameters outer shape, surface and material condition were modelled in a suitable manner statistically. These influence parameters act as input parameters in a local strength concept beside non-scattering parameters (see figure 1). Using a developed probabilistic model based on Monte Carlo simulations, shafts and their surfaces can be randomly generated. Local strength verifications are performed for these generated shafts by means of finite element analyses on the whole failure-critical shaft surface. The stochastically generated shafts and the application of nominal stresses simulate the experimental testing at different nominal stress levels. By statistical evaluation of these fictitious nominal stress levels with respect to calculated failures and run-outs of the shafts, the probability distribution of the fatigue strength of the shaft population and thus its scatter can be determined. The probabilistic model is tested using a shaft population under non-scattering rotating bending load and compared with experimentally determined scatter of the fatigue strength for this shaft population.

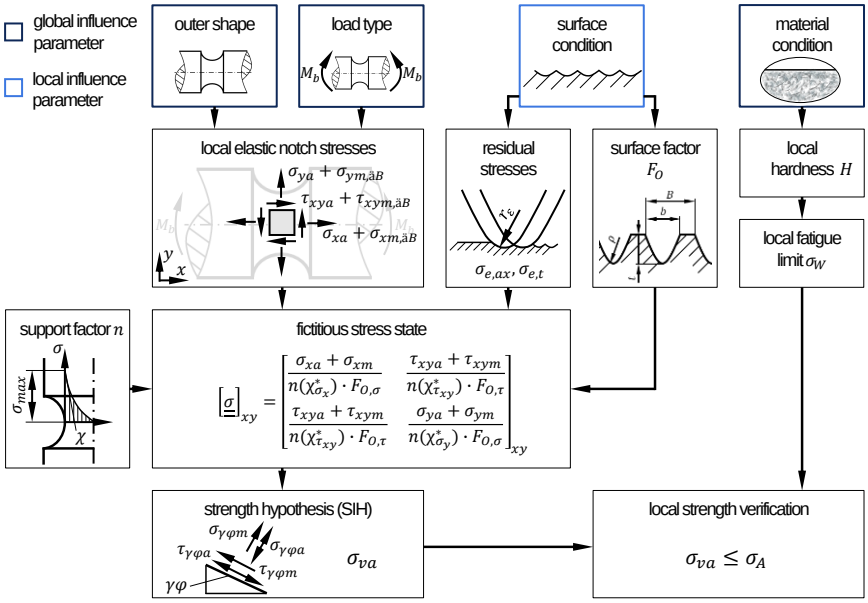

***Figure 1** – local strength concept*

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Multiple Damage Detection of Cantilever Wing using Classification Machine Learning and Neural Network Architecture

Zia Ur Rehman[1]

[1] *Engineering Research Organization, Islamabad, Pakistan, zia17uet@gmail.com*

Machine Learning1 *Damage Detection 2* *Aircraft Wing 3*

Abstract In this paper, changes in modal frequencies and average elemental modal strain energy [1], between damaged and pristine structure are used for identification of multiple damage in cantilever wing [2]. Finite element model of cantilever Goland wing and subsequent modal analysis is performed in MSC Nastran as shown in Figure1.Results of modal analysis are validated with [2] as shown in Table 1. In the forward approach, damage is simulated and induced in the form of stiffness reduction, afterwards, frequencies and strain energies for damaged structure are calculated. Output of forward problem along with corresponding damage scenarios is then used to train the neural network and machine learning model. In the backward solution approach, structural response data is used as input to predict the damage location and severity. Python and MSc Nastran are coupled for the generation of machine learning data. Extensive python scripts are written to generate and analyze more than 1000 damage cases in the form of Nastran input files.

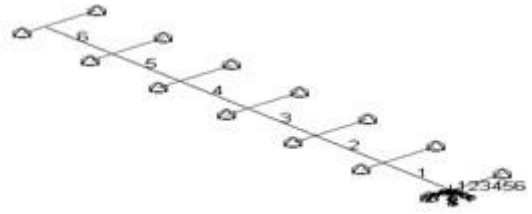

Figure 1*-FE Model of Wing MSC Nastran*

	Modal Frequencies (Hz)	
	Reference [1]	Current Analysis
Mode 1	7.66	7.64
Mode 2	15.24	15.26
Mode 3	38.80	38.75
Mode 4	55.33	54.88

Table 1*-Modal Analysis of Undamaged Wing*

S.no	*Rf1*	*Rf2*	*Rf3*	*Rf4*	*Rf5*	*Se1*	*Se2*	*Se3*	*Se4*	*Se5*	*Se6*	*E1*	*E2*	*E3*	*E4*	*E5*	*E6*
774	*0.86*	*0.81*	*0.88*	*0.85*	*0.76*	*0.44*	*0.71*	*0.52*	*0.72*	*0.24*	*0.74*	*0*	*0*	*8*	*0*	*0*	*6*

Table2*-Random Sample of Data having 11 Input Features and 6 Outputs to Predict*
(Abb): Rf-Relative natural frequency, Se-average Strain energy change ratio, E-element stiffness reduction

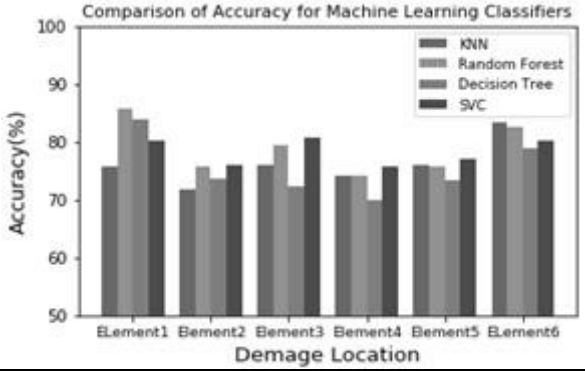

Figure 2*- Supervised ML Models Comparison*

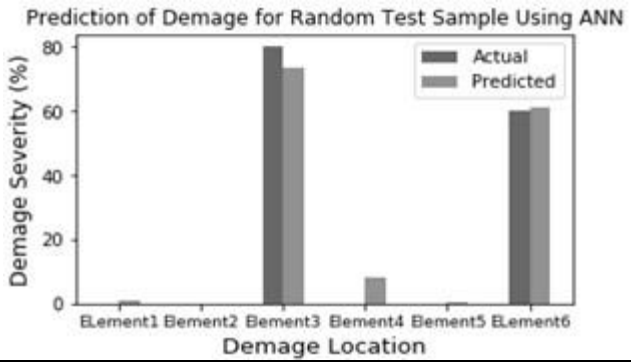

Figure 3*- Damage prediction using Artificial NN*

[1] Shi, Law," Structural Damage Localization from Modal Strain Energy change", Journal of Sound and Vibration, 1998

[2] Palacios, R, "An Intrinsic Description of the Nonlinear Aeroelasticity of Very Flexible Wings," Structures, Structural Dynamics, and Materials Conference, USA, April 2011.

Corrosion characterisation of solid and lattice AlSi10Mg manufactured by laser powder bed fusion

Carlien Taute[1], Heinrich Möller[1], Anton du Plessis[2,3]

[1]*Department of Materials Science and Metallurgical Engineering, University of Pretoria, Pretoria 0002, South Africa, u11200597@tuks.co.za*

[2]*Research group 3DInnovation, Stellenbosch University, Stellenbosch 7602, South Africa*

[3]*Department of Mechanical Engineering, Nelson Mandela University, Gqeberha 6001, South Africa*

Additive Manufacturing *AlSi10Mg* *Corrosion*

Abstract Additive manufacturing can be used to produce complex, custom geometries, consolidating different parts into one. This reduces the required number of assemblies and allows distributed manufacturing with short lead times. Defects, such as porosity and surface roughness, associated with parts manufactured by laser powder bed fusion, can severely limit industrial application. The effect these defects have on corrosion and hence long-term structural integrity must also be taken into consideration. This project aimed to characterise porosity in both solid and lattice cube samples produced by laser powder bed fusion, with the differences in porosity induced by changes in the process parameters, and subsequently, characterising the effect porosity has on corrosion. The alloy used in this investigation is AlSi10Mg, which is widely used in the aerospace and automotive industries. Samples were studied before and after corrosion using X-Ray computed tomography (CT scanning), metallographic examination and scanning electron microscopy (SEM), as well as compression testing for the lattice cubes. It was found that higher laser power leads to more porosity and lower surface roughness. CT scanning was a highly effective method to study corrosion using aligned CT images of before-after states. Porosity did not influence the corrosion during the early corrosion stages (168 hours). The manufacturing process parameters induced differences in porosity and surface conditions but did not strongly affect corrosion. The possibility is that crack initiation sites are filled with corrosion product, delaying the onset of cracking and failure, thereby slightly increasing the compressive strength of the samples.

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Influence of easy repair using plasma sintering and alumina particle on fatigue crack growth

Daisuke Sasaki[1], Tomokazu Kiyonaga[2], Yuki Obukuro[2], Yuji Kawakami[2]

[1]*Materials Science and Engineering Department, National Institute of Technology, Kurume College, 1-1-1 Komorino, Kurume-shi, Fukuoka 830-8555, Japan, d-sasaki@kurume-nct.ac.jp*

[2]*Materials Science and Engineering Department, National Institute of Technology, Kurume College, 1-1-1 Komorino, Kurume-shi, Fukuoka 830-8555, Japan*

Repair *Fatigue* *Pulse sintering*

Abstract Aging of large structures constructed since the 1970s has become a problem. To solve the problem, a simple repair prolonging fatigue life has been required. We have developed a simple repair using pulse sintering and metal powder. In this study, the prolonging effect and fatigue behavior have been investigated. The test material is JIS A6063 aluminum. The specimen has a simulated crack. After filling the simulated crack with aluminum fine particles, pulse sintering was performed. A test piece that was energized after filling with alumina particle is referred to as a repair specimen. A specimen aged after the repair process is called an aging-repair specimen. A test piece without repair nor aging-repair with particle is called an untreated specimen. After sintering, the surface of the specimen was polished to # 1500. Figure 1 shows the optical microscopy result of a simulated crack. As shown in Fig.1, a cross-linked structure of sintered Al particles was confirmed in the simulated crack. After the optical microscopy, an in-situ fatigue test was performed with a maximum load of 6,160 N, a frequency of 0.7 Hz, and a stress ratio R = 0.05. The number of cycles to failure of the untreated specimen, the repair specimen, and the aging-repair specimen were 8,068, 2,321, and 8,235, respectively. It was confirmed that the fatigue life of the aging-repair specimen was longer than the untreated specimen. The in-situ observation shows that the crack initiation cycle does not change with or without the repair, and the crack growth rate of the aging-repair specimen are lower than the untreated specimen. These results indicate that sintering softens the test specimen and induces the fatigue crack propagation. On the other hand, sintered Al particles in the simulated crack reduce the crack propagation. It suggests that sintered Al particles induce crack closure.

Figure 1 – Optical microscopy result of a simulated crack of the aging-repair specimen.

, Pipeline Bending Strain Assessment from IMU Data – A Comprehensive Approach

Enyang Wang[1], Rick Gailing[1], Aaron Dinovitzer[1], Francisco Bernal[2], Juan Mora[2]

[1]BMT Canada Ltd., 311 Legget Drive, Ottawa, ON, CA, K2K 1Z8, Canada

[2]Southern California Gas Company, 555 W Fifth Street, Los Angeles, CA 90013, USA

dwang@fleetech.com

Tensile Strain Limits *IMU Bending Strain* *Strain-based Design*

Abstract The inertial measurement unit (IMU) tools are being widely adopted by the oil and gas industry for monitoring the bending strain variations caused by pipeline movements among each inline inspection (ILI) run. The IMU tool measures the centerline curvature coordinates in a GIS (Geographic Information System) format by utilizing odometers. The bending strains (i.e., vertical, horizontal, and total strains) are calculated for an ILI run from the GIS data (Height, Latitude, and Longitude (or Height, Northing, and Easting)). The strain variations in a pipeline segment can be calculated if more than one ILI run were performed. It should be noted that the bending strains discussed here refer to the global strain rather than the local strain (e.g., through-thickness strains at girth welds or wrinkles). Recently, there is an increase of requirements from the industry to consider the following aspects:

- To understand the impact parameters on the calculated bending strain, e.g., multiplier, accumulative errors in the nonlinear regression analysis, data alignment;
- To include the advanced methods in determining the tensile strain limits (e.g., strain-based design (SBD) method).

Note that the tensile strain limits defined in the current standards and recommended practices are threshold values. For example, three widely used tensile strain limits are listed as follows:

- API 1104 (21st ed.): $< 0.5\%$;
- DNV-RP-F108 (2017): $< 0.4\%$;
- ASME B31.4 (2019): $\leq 2.0\%$.

These values are independent of line pipe dimensions, material properties, operational pressures, year of pipeline construction, crack (or crack-like) dimensions, etc. It is clearly seen that the use of the threshold value(s) may result in inappropriate (conservative or unconservative) recommendations on the site monitoring, mitigation strategies, or immediate action.

In the present study, a comprehensive approach was developed for evaluating the bending strains from IMU data, which includes four improvements: (1) user-defined multiplier; (2) automatic data alignment; (3) more accurate nonlinear regression algorithm; and (4) SBD-based parametric tensile strain limits. The case studies show that more accurate bending strains are obtained by using the comprehensive approach. In addition, a VBA-based software was developed based on this comprehensive approach of the bending strain assessment, where all the above-mentioned new features/enhancements were integrated.

A Study on Tensile Strain Limit Evaluations Using Failure Assessment Diagrams for IMU Pipeline Bending Strain Assessment

Enyang Wang[1], Rick Gailing[1], Aaron Dinovitzer[1], Francisco Bernal[2], Juan Mora[2]

[1]BMT Canada Ltd., 311 Legget Drive, Ottawa, ON, CA, K2K 1Z8, Canada

[2]Southern California Gas Company, 555 W Fifth Street, Los Angeles, CA 90013, USA

dwang@fleetech.com

Tensile Strain Limits Strain-based Design Method Failure Assessment Diagram

Abstract

The oil and gas companies widely adopt the inertial measurement unit (IMU) tools for monitoring the bending strain and corresponding noteworthy changes from different inline inspection (ILI) runs. The bending strain is calculated from Geographic Information System (GIS) data (e.g., Height, Northing, and Easting) using curvature-based strain equations. The changes of the bending strain in a pipeline segment are evaluated from a run-to-run analysis (e.g., first-run and subsequent run). The positive and negative strain variations refer to the tensile and compressive conditions, respectively. In the engineering critical assessment (ECA), tensile and compressive strain variations are compared with strain limits for capturing the pipeline segments that may need further monitoring, mitigation strategies, or immediate action. Note that the tensile strain limit is defined as the threshold value in the current standards and recommended practices, for example:

- API 1104 (21st ed.): $< 0.5\%$;
- DNV-RP-F108 (2017): $< 0.4\%$;
- ASME B31.4 (2019): $\leq 2.0\%$;

In contrast, the compressive strain limit is defined as a function of line pipe dimensions, material properties, and operational pressures (e.g., CSA-Z662 Annex-C and ASME B31.8). It is clearly seen that the use of the threshold value(s) as the tensile strain limit may lead to inaccurate ECA results (i.e., conservative or unconservative).

To this end, the failure assessment diagram (FAD) approach was adopted to evaluate the tensile strain limits in the present study. Both stress-based and strain-based design methods were considered in the evaluation. Note that the dimensions of cracks or crack-like features and the fracture toughness (e.g., K_c, $CTOD_c$, or CVN) are required in the calculation because this is the FAD-based approach. That is different from the compressive strain limit calculations (see CSA-Z662 Annex-C). The case study result shows a difference in calculated tensile strain limits between the two approaches. In general, the values from the strain-based approach are greater than those from the stress-based approach. The experimental validation indicates that the tensile strain limit calculated from the strain-based approach is less conservative and closer to the observed tensile capacity. In addition, a tool was developed for evaluating the tensile strain limit using the strain-based FAD approach and integrated into the software of the IMU bending strain assessment.

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Stiffness optimization through a modified greedy algorithm

Iulian Constantin COROPEȚCHI[1], Alexandru VASILE[1], Ştefan SOROHAN[2], Cătălin Radu PICU[2,3], Dan Mihai CONSTANTINESCU[2]

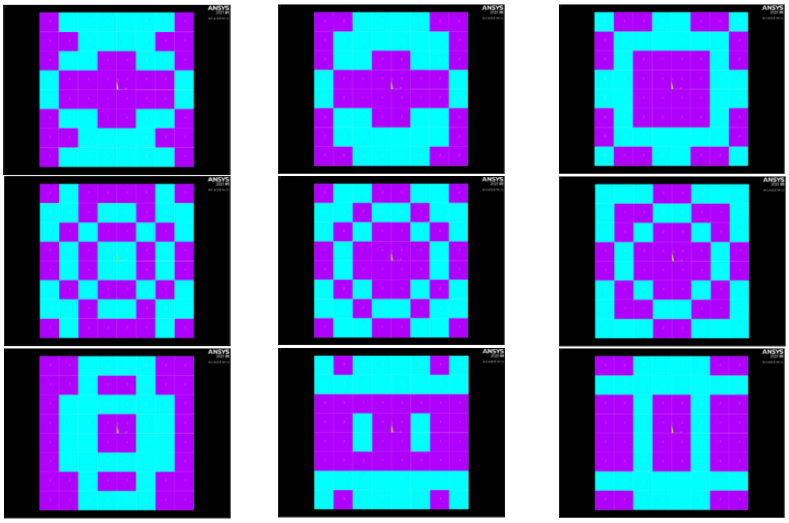
[1] *Military Technical Academy „Ferdinand I", Bulevardul George Coşbuc nr. 39-49, 050141, Bucharest, Romania*

[2] *University POLITEHNICA of Bucharest, Splaiul Independeţei nr. 313, 060042 Bucharest, Romania, dan.constantinescu@upb.ro*

[3] *Rensselaer Polytechnic Institute, 110 Eighth Street, Troy, NY, USA 12180*

Inkjet printing *Modified greedy algorithm* *Stiffness optimization*

Abstract Due to the 3D printing techniques it is possible to create and design components with soft and rigid combinations of materials with different elastic properties which may satisfy multiple material requirements. A soft (purple) and a rigid (blue) material with moduli of elasticity in a ratio 1:10 can be innkjet printed together following an initial pattern. The objectije function is formulated as maximizing the effective stiffness on both in-plane directions. Finite element analyses are performed by using the PyAnsys software under an MIT License and a domain with 16 Q8 elements which represents by symmetry a quarter of a plate. The objective function to be maximized can also reduce the anisotropy of the printed topology.



a) *b)* *c)*

***Figure 1** – Representation of three distributions for soft and hard materials before and after topology optimization: a) initial; b) intermediate; c) final.*

The materials' topology at microscale have a significant influence on the global response of the structural components.

Acknowledgements

This work was supported by a grant of the Romanian National Authority for Scientific Research and Innovation, CCCDI - UEFISCDI, project number ERANET-M-RIPE4TEC-1, within PNCDI III.

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A constitutive equation for the kinetics of high temperature hydrogen attack and its use for structural life prediction

R.J. Mostert[1], T. W. Mukarati[1,] C.C.E. Pretorius[1] and VM Mathoho[1]

[1]Department of Materials Science and Metallurgical Engineering, Lynnwood Road, Pretoria, roelf.mostert@up.ac.za

HTHA *Kinetics* *Structural life prediction*

Abstract The damage due to high temperature hydrogen attack (HTHA) accumulates over time through the formation, growth and coalescence of methane-filled cavities, followed by microcrack formation. Attempts at the prevention of this damage mechanism – specifically from occurring in steels in hydrogen service at high temperatures – followed the first publication of the Nelson Curves in 1949; however, these have not always been successful. The consequence of HTHA failures have often been disastrous and, as such, much work is currently being done with a view to better predict the course of HTHA and prevent failures.

In the current work, high-temperature strain gauging was used on samples exposed to accelerated HTHA conditions in an autoclave. The strain gauges were applied to various zones of a C-0.5Mo welded joint in order to track the damage evolution in the base metal, HAZ and weld metal. Over time, the process of HTHA damage gave rise to steadily increasing strain due to the formation and growth of voids. This continued through the subsequent HTHA steps until a *saturation point*; beyond which the strain remained static. These curves were subsequently converted to Damage-Time curves, with the damage fraction ranging from 0 to 1, similar to the MPC-Omega creep curves as published in API 579. It was found that the kinetics of HTHA damage evolution could be described by a single sigmoidal equation, with different constants for the various weld zones. The results of published strain-time curves for a carbon steel and another C-0.5 Mo steel were similarly analyzed and similar findings were made.

Analysis of the HTHA damage evolution rate vs time curves, indicate that the damage rate steadily increases with increasing time up to a maximum value; whereafter it decreases steadily until reaching a *zero*-damage rate at the end of the HTHA damage evolution process. The time corresponding to maximum damage evolution was found to be midway through the HTHA damage process. This behavior was attributed to the depletion of carbides with increasing damage evolution, resulting in declining damage rates at times beyond the time corresponding with the maximum damage rate.

The HTHA damage plots and results were compared to calculated MPC-Omega creep curves – since it is commonly believed that the HTHA mechanism is related to creep – with the internal methane pressure of the cavities providing the stress required for creep damage accumulation in the absence of applied or residual stress. It was, furthermore, discussed how the in-situ application of the high-temperature strain gauges to structural elements in HTHA service can be used as an aid in HTHA life prediction.

Solution for consolidation and retrofitting an historical steel bridge

Dorin Radu[1], Radu Băncilă[2], Dorel Bolduș[2], Simon Sedmak[3], Mihajlo Aranđelović[3]

[1]Transilvania University of Brașov, Faculty of Civil Engineering
[2]Politehnica University of Timișoara, Faculty of Civil Engineering, Romania
[3]Innovation Centre of the Faculty of Mechanical Engineering, Belgrade, Serbia

Structural integrity *Steel structures* *Historical steel bridges*

Abstract Sustainable development is a fundamental goal of the European Union and seeks to meet the needs of the present, without compromising the future. The rehabilitation of historic steel constructions and old steel bridges in operation is part of the maintenance and conservation of existing heritage, thus considering a sustainable development concept, while constituting an act of culture.

In Romania, in present there are a relatively small number of steel bridges older than 100 years, especially in Transylvania; they can be considered "witnesses of the past". Two important aspects are highlighted: rehabilitation costs are lower than for a new structure and the rehabilitated bridge can receive a new, modern functional role that fits functionally into the landscape.

The paper is presenting a study case for an existing steel bridge build in the beginning of twentieth century (around year 1925). There are presented solution for consolidation of the bridge and retrofitting, taken into account fatigue design and structural integrity assessment. Critical flaws values were determined for each case type using the failure assessment diagrams. These values are used as limit values for fatigue analysis based on fracture mechanics principles, to determine the number of cycles for a crack to extend from initial to critical dimension, i.e. failure. For the assessment was used the code cyclic loading as a block independent iterative solver – applying the specified stress ranges sequentially line by line, repeating the entire cyclic loading - entire group of cycles for a number of blocks (one block representing all the applied cycles of stress ranges).

Following the fatigue assessment, resulted the number of cycles until reaching the critical flaw dimension.

***Figure 1** – (a) Existing bridge; (b) Retrofitting solution*

, Analytically based time reversal damage imaging in plate-like structures with a sparse piezoactive sensor network

Artem Eremin[2], Ilia Bareiko[2], Evgeny Glushkov[1], Natalia Glushkova[2],

[1]*Institute for Mathematics, Mechanics and Informatics, Kuban State University, 350040, Stavropolskaya st. 149, Krasnodar, Russia,* eremin_a_87@mail.ru

[2]*Institute for Mathematics, Mechanics and Informatics, Kuban State University*

Time reversal method *Lamb waves* *Damage characterization*

Abstract Localization of damage and estimation of its extent are among prior research questions in the field of elastic guided wave-based structural health monitoring (GW SHM) of extended plate-like structures. Corresponding methods addressing these problems should have sufficient accuracy and speed, as well as allow diagnosing both single and multiple inhomogeneities of various types. Moreover, their functioning is supposed to rely on probing wave signals available only at a limited set of points (for example, using a distributed network of piezoactive sensors). Along with well-established techniques such as delay-and-sum method, probability-based approach, tomography-related imaging, etc., one of the promising approaches for defect visualization is the time reversal method. It is based on the reversibility of the wave operator with respect to the time variable in the case of a medium without dissipation. The latter allows focusing the wave field at the original source of oscillations after re-emission from the sensor positions of time-reversed signals received from it.

In the current talk, theoretical and practical aspects of the developed passive (or virtual) time reversal technique for GW damage imaging in thin-walled metallic and composite structures are discussed. The input data for the algorithm are time-reversed voltages acquired with a sparse network of piezoactive sensors mounted on the specimen surface for pristine and damaged states. The theoretical modeling of the re-emitted GW propagation is performed in the context of general linear elastodynamics for three-dimensional isotropic and anisotropic media. It is based on the efficient explicit analytical representations of cylindrical guided waves in terms of the Green's matrix of the infinite layered elastic structure considered. To visualize the possible damage location, a specific test function of RMS-type is constructed. Employing Parseval's identity, it is evaluated solely in the frequency domain, providing high computational efficiency. The results of the practical implementation of the developed method are illustrated by examples of the location and size estimation of various surface artificial damages in thin-walled aliminium plates. Previously published results for metal and anisotropic composite plates are also discussed in this context. The influence of actuator/sensor number used for time reversal process, damage location within the sensor network, and excitation signal type on the algorithm performance is investigated. Moreover, the capability of resolving several damages simultaniously is also illustrated.

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The Fundaments of Structural Integrity of Large-Scale Pressure Systems

Fekete, Tamás[1]

[1]*Centre for Energy Research, H-1121 Budapest, Konkoly-Thege M. str. 29-33., Hungary*
fekete.tamas@ek-cer.hu

Structural Integrity *System Engineering* *Methodology*

Abstract: The objective of Structural Integrity (*SI*) is to assure the fail-safe operation of an operating Large-Scale Pressure System (*LSPS*) during its entire service lifetime. The efficiency of *SI* depends on the predictive capability of the underlying theoretical framework used at *SI* computations. Today, *SI* calculations for *LSPS*s are largely based on standards and guidelines, which bear footprints of hundred-year-old mechanistic theoretic concepts encoded within them.

There are various attempts, to overcome limitations of current *SI* calculation methodologies of *LSPS*s, but these days, the results of different research activities do not form a coherent system yet. Currently, a research is being conducted, in order to develop a new, generalized methodology for future *SI* calculations of *LSPS*s. The current goal of the research is to develop a stable, robust theoretical background system for *SI*, which has a clear and coherent philosophical basis, which has a strong theoretical background –based on our up-to-date knowledge in the various relevant scientific and engineering disciplines–, using which the models and calculation methods for engineering calculations and also for future industrial practice directives can be deduced.

The first fundamental question of the research was to clarify the position of *SI* of *LSPS*s in the context of basic-, applied- and engineering sciences, and everyday industrial practice. Based on our current research, we state that *SI* has its right place in the frame of the new, scientifically founded 'Systems Engineering' (*SE*) paradigm. This paradigm is built on the very general principles of 'General Systemology Theory' (*GST**), and using the *SE* paradigm, the engineering activities performed during design and operation can be integrated into a single coherent system, in which the two types of activities are built on and complement each other. The *SE* paradigm also provides a natural framework for the so-called Conceiving – Designing – Implementing – Operating – Decommissioning (*CDIOD*) paradigm therefore.

Our Conceptual Structure of *SI* borrows the Structure proposed in the book 'General Systemology' by Rousseau, Wilby, Billingham and Blachfellner (2018), according to which a system theory problem can be conceptually divided into four levels: (1) philosophical, (2) scientific, (3) engineering, (4) practical level. Philosophical considerations can be used as an aid in developing the foundations of a scientific field; philosophy helps in clear problem formulation, and in clear explanation for some 'why' type of questions, which cannot be answered by the sciences alone. Based on philosophical considerations, it is stated that large-scale pressure systems are complex, non-equilibrium systems, structural materials of which exhibit aging, which is manifested in time-evolving physical properties during operation. Turning to scientific level, we looked for a physical theory that could describe these phenomena in a unified framework. After extensive research, modern Nonequilibrium Thermodynamics –more precisely, Generalized Thermomechanics with Internal Variables– seems the best choice as a theoretical umbrella framework for *SI*. Within the framework of Nonequilibrium Thermodynamics, a unified, scientific description of fracture and aging becomes feasible; it is the theoretical framework, by which the simultaneous effects of several aging mechanisms can be described and in which the concept of structural health and its significance can be interpreted.

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Modelling superelastic SMA bars using OpenSees

Mariana Jesus[1,2], Paulo Silva Lobo[1,3], Rui Marreiros[2]

[1]CERIS, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal

[2]DEC, NOVA School of Science and Technology, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal

[3]Departamento de Engenharia Civil e Geologia, Faculdade de Ciências Exatas e da Engenharia, Universidade da Madeira, Campus Universitário da Penteada, 9020-105 Funchal, Portugal

SMA *Reinforced Concrete* *OpenSees*

Abstract In the past decades, strong earthquakes have demonstrated the weaknesses of reinforced concrete structures. Superelastic smart materials alloys (SMA), with superior properties as recentring capacity, large recoverable strain, reduced residual deformation, and good fatigue properties, have been numerically and experimentally studied with the objective of making reinforced concrete structures safer, more resilient and sustainable. A sensitivity analysis was performed using Open System for Earthquake Engineering Simulation (OpenSees) for modelling SMA bars. Advantages and limitations of the approach adopted using OpenSees are presented and discussed.

Accuracy of models of concrete in circular columns using different proposals for the prediction of failure of the confining FRP

Paulo Silva Lobo[1,2], Mariana Jesus[1,3]

[1]*CERIS, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal*

[2]*Departamento de Engenharia Civil e Geologia, Faculdade de Ciências Exatas e da Engenharia, Universidade da Madeira, Campus Universitário da Penteada, 9020-105 Funchal, Portugal*

[3]*DEC, NOVA School of Science and Technology, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal*

Fiber Reinforced Polymers *Failure Strain* *Concrete Confinement*

Abstract Confinement of concrete columns with fiber reinforced polymers results in an increase of strength and ductility. For this reason, the use of aramid, carbon and glass-based composites for confinement of reinforced concrete columns has significantly increased over the last decades. Nevertheless, few models adequately predict the failure strain of the fiber reinforced polymer, which has a determinant influence on the computed results. In this paper the accuracy of existing models of confined concrete using different proposals for the prediction of the failure strain of the confining composite is assessed. This is based on the comparison of analytical results with experimental test results of concrete columns with circular cross-section reported in the literature. The comparison focusses on different parameters such as strength, maximum strain and strain energy density.

Figure 1 - *Failure of GFRP on a reinforced concrete circular column*

, Evaluation Framework for Tensile Measurements, based on Full-Field Deformation Measurements and Digital Twins

Antók Dániel[1], Fekete Tamás[1], Tatár Levente[1]

[1]*Centre for Energy Research, H-1121 Budapest, Konkoly-Thege M. str. 29-33., Hungary*
fekete.tamas@ek-cer.hu

Full-field measurements *Digital Twin* *Methodology*

Abstract: The objective of Structural Integrity (*SI*) is to assure the fail-safe operation of operating large-scale pressure systems during their entire service lifetime. The efficiency of *SI* computations depends on the predictive capabilities of the underlying theoretical framework and the amount and the quality of information obtained from material tests that support the calculations. In order to increase the amount of information extracted from tensile tests, a material testing equipment was supplemented with an optical system, using which full-field geometric images of a specimen during measurement are recorded. Using in-house software, full-field tensile deformation measurements are also performed, results of which complement the 'classic' results of tensile tests. Based on the information extracted from the tests, the measurements are evaluated using the digital twin of the specimen + measurement. The measurement system and the digital twin are organized into a unified system, the sketch of which is presented on Figure 1. The first results of tensile tests evaluated using the digital twin based system show

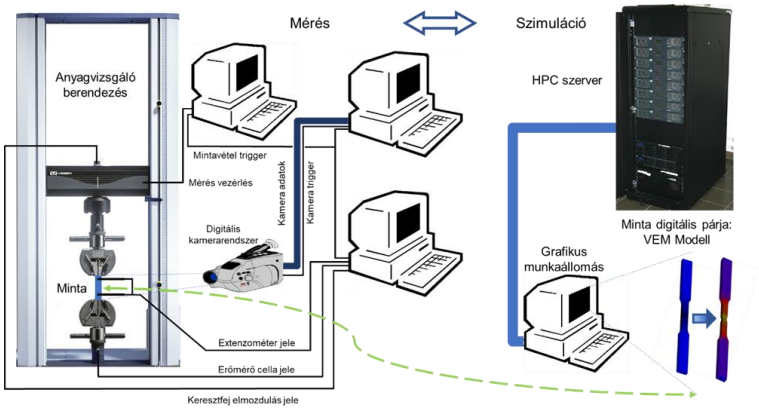

Figure 1 - *Sketch of the developed measurement and evaluation system*

that the performance limits of the new system are far beyond the limits of classic evaluation methods. On Figure 2., the digital twin of a tensile specimen is compared with the optical image.

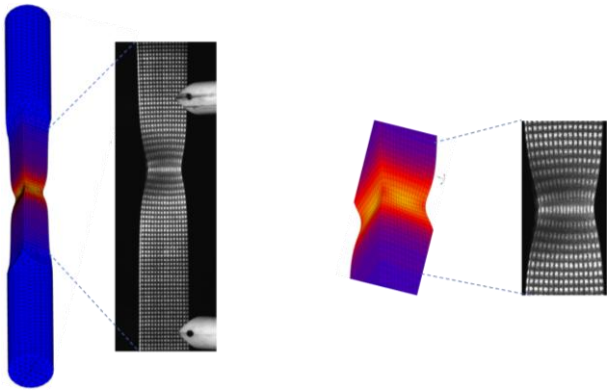

Figure 2 – *The digital twin vs. the optical image of a tensile specimen*

Estimation of residual fatigue life of polymer composites after preliminary low-velocity impact

Oleg Staroverov[1], Dmitrii Lobanov[2]

[1]*Perm National Research Polytechnic University, 614990, 29 Komsomolsky prospect, Perm, cem_staroverov@mail.ru*

[2] *Perm National Research Polytechnic University*

Composite materials *Residual strength* *Fatigue after impact*

Abstract Composites are replacing traditional metals and alloys in many industries, including aviation, space, building, automotive, petrochemical, due to their lower weight and physical and mechanical characteristics, which allows them to be introduced into critical high-loaded structures and parts. At the same time, in the process of operation, composite structures can be in conditions of complex thermomechanical action. Data on changes in the residual mechanical characteristics, available damages allow increasing the prediction life, survivability and safety of destruction of composite structures.

The paper presents the results of studying the processes of accumulation of fatigue damage and destruction of CFRP specimens with layouts $[0^o/90^o]_n$ and concentrators of an operational nature. The study was carried out with the implementation of a preliminary transverse impact by a falling load according to the three-point bending and subsequent cyclic stretching. In accordance with the developed technique, the value of the ultimate strength (σ_B) of the carbon fiber under study was determined from quasi-static tensile tests. The nominal fatigue life (N_{max}) is obtained from tests with the parameters with the maximum stress in the cycle $\sigma_{max}=0.75\cdot\sigma_B$, the asymmetry coefficient R=0.1 and the frequency ν=20 Hz. During the cyclic tests, the frequency and amplitude of the loading were selected in such a way that the heating of the sample did not exceed 20°C relative to the temperature of the beginning of the test. From experiments on impact bending, the potential energy (E_{max}) was determined, at which the samples were destroyed. Further tests for preliminary impact according to the three-point bending were carried out in the range from 0.3 to 0.9 of the destruction energy (e'). Single blows were made across the entire width of the samples. After each impact, a visual inspection of the samples was carried out. Microstructural studies and analysis of fracture patterns of prototypes under complex shock impacts and cyclic loading were performed using a Carl Zeiss SteREO Discovery V12 stereomicroscope.

As a result, experimental dependences of the influence of different intensity of impact bending on the residual fatigue life of carbon fiber specimens were obtained. Analysis of the diagram of the change in the residual fatigue life versus the impact bending intensity made it possible to reveal the presence of a shock sensitivity threshold. Impact actions with energies exceeding the threshold value led to a significant decrease in fatigue life, by more than 10% of the nominal value of N_{max}, for the studied CFRP composites.

Results of the experimental study was carried out in Perm National Research Polytechnic University with financial support of grant of President of Russian Federation for government support of young Russian scientists (Grant MK-1222.2020.8).

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A risk-based approach for timber building decay prediction

Andrea Gaspari[1,a], Ivan Giongo[2,b], Maurizio Piazza[2,c]

[1]University of Trento (IT), Department of Civil, Environmental and Mechanical Engineering,
[a]andrea.gaspari.1@unitn.it, [b]ivan.giongo@unitn.it, [c]maurizio.piazza@unitn.it

Timber structures *Decay prediction* *TSafe project*

Abstract. The durability of timber structures subjected to biotic attacks is becoming of increasing concern due to several recent examples of failures caused by early degradation. Therefore, the design process of a timber building cannot prescind from accounting for the possible degradation due to biotic attack, especially in light of the recent spread of high-rise timber buildings. Furthermore, it is of extreme importance that reliable models to foresee possible sources of degradation in existing buildings are made available so that retrofit interventions can be programmed before it is too late.

In the work presented herein, the decay due to fungal attack was predicted through a risk-based approach where decision trees were created to address all the possible scenarios where water or moisture can intrude within the construction details that most affect the durability. These decision trees allow to assign a risk class, defined based on a thorough review of the major European standards addressing timber "use-classes". The trees also lead to the selection of a proper prediction function for estimating the decay depth, chosen among suitable functions available in the literature.

Figure 1 - *Example of decay observed in a perimeter wall of a CLT building after just 2 years from construction*

The proposed methodology was applied to selected case studies where a good correlation was found between the decay level detected onsite and the results from the prediction model. In order to facilitate the application of the methodology to both the design of new durable timber buildings and the assessment of existing timber structures, an ad hoc software tool named TSafe was developed.

, Effect of graphene nanoparticles on suspension viscosity and mechanical properties of epoxy-based nanocomposites

J.M. Parente[1], R. Simões[2], P.N.B. Reis[3]

[1] C-Mast, Dep. of Electromechanical Engineering, University of Beira Interior, Calçada Fonte do Lameiro, 6201-100, Portugal, Email: joao.miguel.parente@ubi.pt

[2] Fiber Materials and Environmental Technologies Research Unit (FibEnTech-UBI), University of Beira Interior, Rua Marquês d'Ávila e Bolama, Covilhã, 6201-001, Portugal

[3] University of Coimbra, CEMMPRE, Department of Mechanical Engineering, Coimbra, Portugal

Graphene Mechanical properties Nanocomposites Pre-cure temperature

Abstract: The use of nanocomposite materials in many industrial applications has been increasing in recent years due their superior mechanical characteristics and reduced weight. Among the nanoparticles available for use in this type of nanocomposite, graphene appears has one of the most promising due to its excellent mechanical and electrical properties. Therefore, the objective of this work was to study the properties of epoxy resin and how they were affected by the presence of graphene. Epoxy resin viscosity, contact angle between graphene particles and resin, effect of mixture condition on polymerization rate and shrinkage tests were performed. The effects of the pre-cure temperature, between 7ºC and 40ºC, and hardener mixing times on the mechanical properties of the nanocomposite were studied. It was observed that the presence of graphene (0.5 wt. %) in the epoxy resin increased the viscosity by 4.2% and the shrinkage increased from 3.2 % to 5.7%. Regarding the mechanical performance, it was possible to conclude that higher hardener mixing times and lower pre-cure temperatures had a very positive impact on mechanical properties. Concerning graphene content, the best mechanical properties were obtained with 0.5 wt. % and represented an increase of maximum bending stress between 8% and 31%, depending on the pre-cure temperature.

Acknowledgement:
Fundação para a Ciência e a Tecnologia (FCT—MCTES) for its financial support via the project UIDB/00151/2020 (C-MAST).

Mechanism of fireside corrosion deteriorating creep rupture life of Super304H in simulated coal-fired power plant environment

Yaxin Xu[1], Xiaofeng Yang[1], Jintao Lu[2*], Zhiqi Guo[1], Wenya Li[1]

[1]1State Key Laboratory of Solidification Processing, Shaanxi Key Laboratory of Friction Welding Technologies, Northwestern Polytechnical University, Xi'an 710072, Shaanxi, PR China

2National Energy R&D Center of Clean and High-Efficiency Fossil-Fired Power Generation Technology, Xi´ an Thermal Power Research Institute Co., Ltd., Xi´ an, 710032, Shaanxi, PR China

Super304H *Fireside corrosion* *Creep fracture*

Abstract The failure mechanism of commercial Super304H under the synergistic impact of fireside corrosion and stress was investigated in a simulated environment for boiler tubes in advanced ultra-supercritical thermal power plants. The creep rupture life of Super304H in fireside corrosion and air was tested at 650 °C, respectively. The oxidation products were characterized, as well as the microstructure of the sublayer including the phase structure, elemental distribution and precipitates evolution. Results indicate that the creep rupture life can be substantially decreased by 65% due to fireside corrosion at the same stress level of 220MPa. Both the surface products and the microstructure of sublayer are responsible for the deteriorated rupture property. The oxide scale formed during corrosion-creep test is detached from the substrate, causing surface pits and cracks. The occurrent of dynamic recrystallization and phase transformation from fcc to bcc in the sublayer also count for the surface damage, which is more significant in the corrosion condition than in air-creep condition.

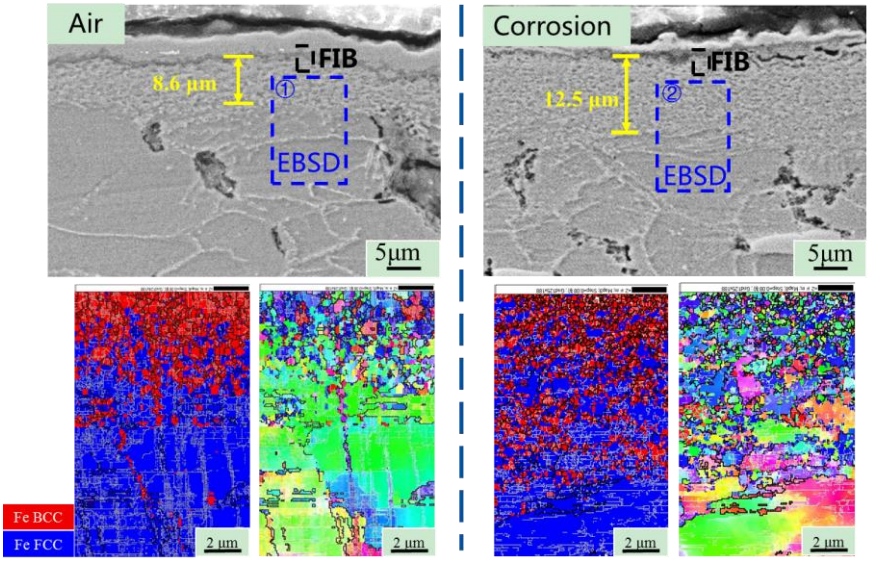

Figure 1 Cross-sectional morphology and EBSD maps of rupture specimens in air and corrosion condition

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Custom control system for Split Hopkinson Pressure bars

Pedro J. Sousa[1], Rogério Lopes[1], Pedro M. G. P. Moreira[1]

[1]INEGI, Institute of Science and Innovation in Mechanical Engineering and Industrial Engineering, Campus da FEUP, R. Dr. Roberto Frias 400, 4200-465 Porto, Portugal.

psousa@inegi.up.pt

Machine Control *Material testing* *High strain rate testing*

Abstract In order to ensure the requirements for safe usage, materials that are used for structures that withstand extreme loading conditions require high-strain rate tests. A common apparatus for these is the Split Hopkinson Pressure Bar (SHPB), which uses a split bar architecture that can be set up either in compression or tension configurations.

These tests are currently performed in the Advanced Monitoring and Structural Integrity unit of INEGI which uses a custom-built pneumatic setup, comprising two compression and two tension bars. Originally, these bars were manually controlled using a couple of buttons and a pressure gauge. This makes the system prone to user error and requires manual synchronization of the multiple acquisition systems.

Thus, in order to improve the aforementioned system, this work reports the development of a custom control system for an SHPB, not only to ensure repeatability in the firing mechanism, but also to automatically synchronize the data acquisition, namely the acquired voltage signals with the high-speed image acquisition for use with Digital Image Correlation (DIC).

The control system is based around a dsPIC33EV256GM102 microcontroller, which is responsible for not only implementing the control loop, but also for providing two configurable trigger pulses, to be used with the high-speed cameras and the illumination system. Additionally, the pneumatic circuit was also reformulated, and it was possible to simplify the system by reducing the number of valves.

The developed system was already implemented, being capable of succesfully controlling the trigger pressure with a customizable acceptable error through a computer's user interface.

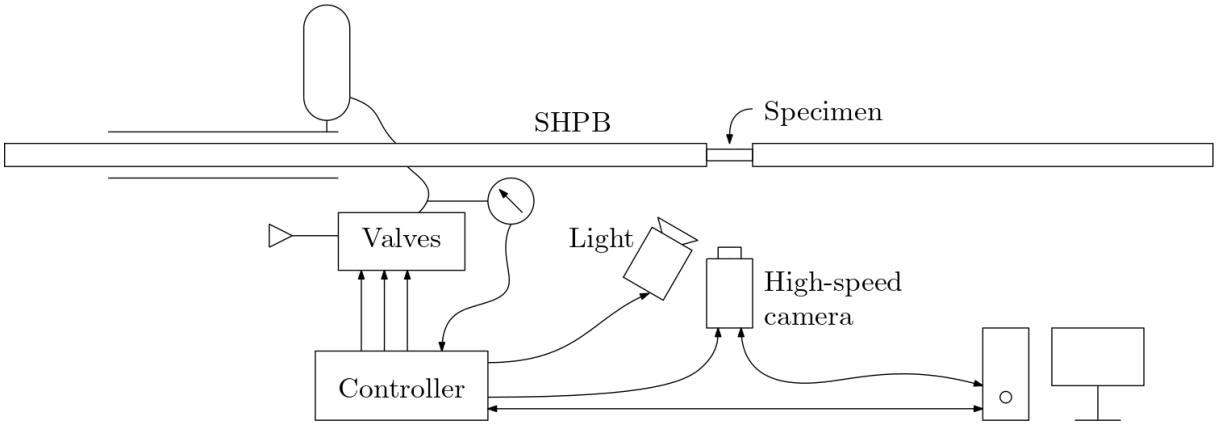

***Figure 1** – Schematic of the developed control system*

, Impact characterization of bio-based sandwich panels with cork core

P. Santos [1], N. Bouhemame [2,3], P.N.B. Reis [4], A. Bezazi [2]

[1] *C-Mast, Dep. of Electromechanical Engineering, University of Beira Interior, Calçada Fonte do Lameiro, 6201-100, Portugal, Email:* paulo.sergio.santos@ubi.pt

[2] *Laboratoire de Mécanique Appliquée des Nouveaux Matériaux (LMANM), Université 8 Mai 1945, Guelma, Algeria*

[3] *Université Kasdi Merbah Ouargla, Route de Ghardaia, Algeria*

[4] *University of Coimbra, CEMMPRE, Department of Mechanical Engineering, Coimbra, Portugal*

Mechanical properties Impact strength Sandwich panels Cork

Abstract: Currently, for ecological and economic reasons, cellulosic fibers obtained from plants have enormous advantages for industrial applications. For example, the automotive sector suggests the use of composites reinforced with natural fibers due to their biodegradability, availability, low cost, and non-abrasive properties. However, due to the low resistance to localized impact loads, the use of composite materials is still a problem for many applications. In this context, sandwich composites can be a solution to overcome this problem, especially when they incorporate cork in their core. Cork has an alveolar structure and it presents high specific strength and stiffness, near zero Poisson coefficient, high tolerance to the impact loads, impervious to liquid and gases, resistance to reactive agents and microorganisms, resistance to wear and fire, very low thermal conductivity, good acoustic insulation capacity and excellent damping characteristics. Therefore, this work intends to produce and characterize a sandwich panel with a cork core and date palm leaves reinforced polymer facings. The benefits of this sandwich, in terms of impact strength, will be determined by comparison with a composite involving the same resin reinforced with date palm leaves. The results will be discussed in terms of load-time, load–displacement, energy-time diagrams and evaluation of the damage. It was possible to conclude that the cork core was responsible for lower impact loads and higher restored energy.

Acknowledgements

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Impact of moisture content on tropical wood under opening mode

Stanislas Malfait[1], José Xavier[2], Rui F. Martins[2], Rostand Moutou Pitti[1], Claude Nziengui[1],

1 Université Clermont Auvergne, Clermont Auvergne INP, Institut Pascal, Clermont-Ferrand, France

stanislas.malfait@etu.uca.fr, rostand.moutou_pitti@uca.fr, claude_feldman.pambou_nziengui@uca.fr *2 UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, NOVA University Lisbon, 2829-516 Caparica, Portugal*

jmc.xavier@fct.unl.pt, rfspm@fct.unl.pt

Tropicals woods *Moisture Content* *Mode I*

Abstract: This study presents an experimental work on opening mode fracture loading of two tropical woods as a function of moisture content. *Aucoumea klaineana* (Okoume) and *Pterocarpus osun* (Padouk) wood species were analysed. The Mixed Mode Crack Growth specimen was selected to generate mode I, Figure 1. Fracture tests were coupled with digital image correlation (DIC) for evaluating both crack length variation and crack tip opening displacement during. The strain energy release rate (G) was then estimated from the compliance method, and the cohesive law reconstructed by numerical differentiation. A Python script was developed to post-processing the displacement and strains fields including the *P-δ* curves. Three levels of moisture content (MC) were target under the fibre saturation point. A first experiment at room MC (9%) was carried out and then at 20% and 27% MC tests were achieved on Okoume specimens, whereas 15% and 20% MC were reached for Padouk specimens. The results show a difference in the necessary G value involving the collapse of the specimens. Padouk samples need more energy than Okoume ones to permit crack propagation. The MC influence these results. It was observed that the G was higher for a MC around 15%. It is significant for Padouk (0.5 N/mm) and visible for Okoume (0.02 N/mm).

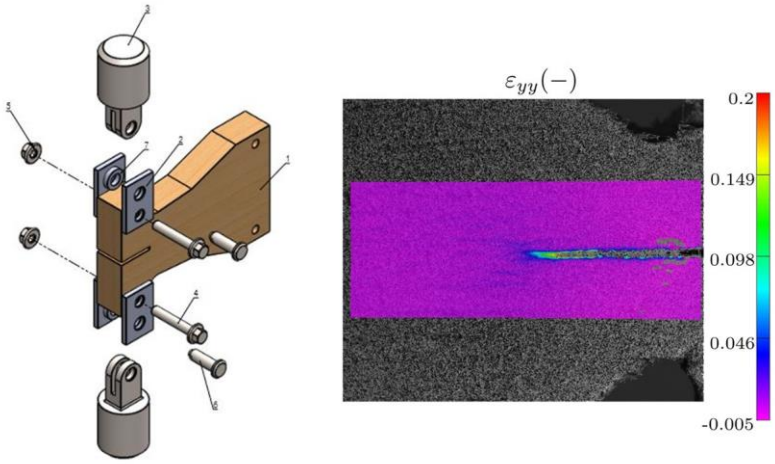

Figure 1 - Digital Image of Mixed Mode Crack Growth specimen

Effect of different hostile solutions on mechanical properties of composite materials

M.P. Silva[1], P. Santos[2], J.M. Parente[2], S. Valvez[2], P.N.B. Reis[3]

[1]*C-Mast, Dep. of Electromechanical Engineering, University of Beira Interior, Calçada Fonte do Lameiro, 6201-100, Portugal*

[2]*University of Coimbra, CEMMPRE, Department of Mechanical Engineering, Coimbra, 3030-788, Portugal*

marco.silva@ubi.pt

Composite laminates *Ageing* *Mechanical behaviour*

Abstract Due to their excellent performances in terms of high specific strength and stiffness, good static and dynamic properties, good corrosion resistance, adjustable properties, competitive cost, and quick manufacture, fibre-reinforced composites have been used in a variety of engineering fields, and this trend is expected to continue. As a result, in this context, these materials are subjected to a variety of environmental conditions, which have a major impact on their mechanical characteristics. Although several studies have been published on the influence of hostile solutions on low velocity impact response, the flexural fatigue performance of composite laminates exposure to corrosive solutions still has some lack of studies. As a result, the goal of this research is to investigate the low velocity impact and flexural fatigue evaluation of Kevlar/epoxy laminates after immersion in Sulphuric acid (H_2SO_4), diesel and seawater. For this purpose, static three point bending tests were performed according to ASTM D790-2, using a Shimadzu AG-10 universal testing machine equipped with a 5 kN load cell and TRAPEZIUM software at a displacement rate of 2 mm/min. The low velocity impact tests were made using a drop weight testing machine IMATEK-IM10. An impactor with a diameter of 10 mm and mass of 2.827 kg was used. Flexural fatigue tests were carried out in flexural mode using an Instron servohydraulic machine, model 1341, equipped with a 100 kN load cell and controlled by a computer with data acquisition. Constant amplitude loading tests were performed at room temperature, under a stress ratio of R = 0.05 and frequency of 2 Hz. It was concluded that the different solutions affects flexural and impact behaviour of the studied materials, but the exposure time was determinant on the mechanical properties' degradation.

, **Development of a custom setup for additive manufacturing of high-performance thermoplastics**

Tiago Domingues[1], António Cachaço[1], Pedro J. Sousa[1], Fernando Carneiro[2], Job Silva[1], Shayan Eslami[1], Pedro M. G. P. Moreira[1]

[1]INEGI, Institute of Science and Innovation in Mechanical Engineering and Industrial Engineering, Campus da FEUP, R. Dr. Roberto Frias 400, 4200-465 Porto, Portugal

[2]Graduate School of Engineering The University of Tokyo, Tokyo, Japan

tdomingues@inegi.up.pt

Additive Manufacturing *High-performance plastics* *Machine Design*

Abstract Fused Filament Fabrication (FFF) is an addictive manufacturing process based on the extrusion of a continuous filament of thermoplastic material. There are several materials that are suitable for this production process, including high performance plastics such as Polyether Ether Ketone (PEEK) or Polyetherimide (PEI). These high-performance thermoplastics produce components with higher strength and toughness than the standard printing plastics, as well as optimized thermal properties.

A machine was designed and developed to produce specimens in these high-performance thermoplastics for further study of their physical and mechanical performance. This machine was designed using the CubeX 3D printer produced by 3D Systems as a base, retaining the main essential structure and kinematics to which several modifications were made so that it can work under the extreme operating conditions required for printing these materials. The main changes made to the original machine were the control board, that was replaced by the Duet 2 Wifi Board, the extruder, changed to the E3D Titan Aqua and the heating pads which were replaced by with the E3D High Temperature Heated Beds. In addition, a custom glycol-based cooling setup was implemented to cool both the extruder and the machine's stepper motors, along with the development of a custom heating system for the printing environment.

The proposed system has been successfully constructed, being able to produce functional parts in both PEEK and PEI plastics. Further research on the mechanical properties of the specimens produced is in progress.

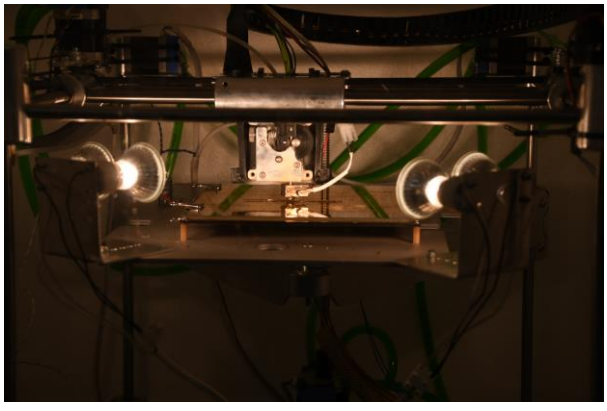

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Figure 1 - *Developed machine producing a component in PEI*

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A simulated annealing algorithm for stiffness optimization

Alexandru VASILE[1], Iulian Constantin COROPEȚCHI[1], Ştefan SOROHAN[2], Cătălin Radu PICU[2,3], Dan Mihai CONSTANTINESCU[2]

[1] *Military Technical Academy „Ferdinand I", Bulevardul George Coşbuc nr. 39-49, 050141, Bucharest, Romania*

[2] *University POLITEHNICA of Bucharest, Splaiul Independeţei nr. 313, 060042 Bucharest, Romania, dan.constantinescu@upb.ro*

[3] *Rensselaer Polytechnic Institute, 110 Eighth Street, Troy, NY, USA 12180*

Inkjet printing *Simulated annealing algorithm* *Stiffness optimization*

Abstract A domain of 1x1 mm was chosen and divided in 4x4 squares on each side. A soft (purple) and a rigid (blue) material with moduli of elasticity in a ratio 1:10 (E_{soft} = 1000 MPa and E_{rigid}=10000 MPa) can be innkjet printed together in equal parts following an initial pattern. Loading is on horizontal direction. The simulated annealing algorithm is similar to the greedy algortithm but accepts less favorable solutions at a current iteration in order to make possible further calculations. The objective function is formulated as maximizing the effective stiffness on both in-plane directions. Finite element analyses are performed by using the PyAnsys software under an MIT License and a domain with 16 Q8 elements which represents by symmetry a quarter of a plate. Variation of the global equivalent stiffness [MPa] at various iterations is shown in Fig. 1.

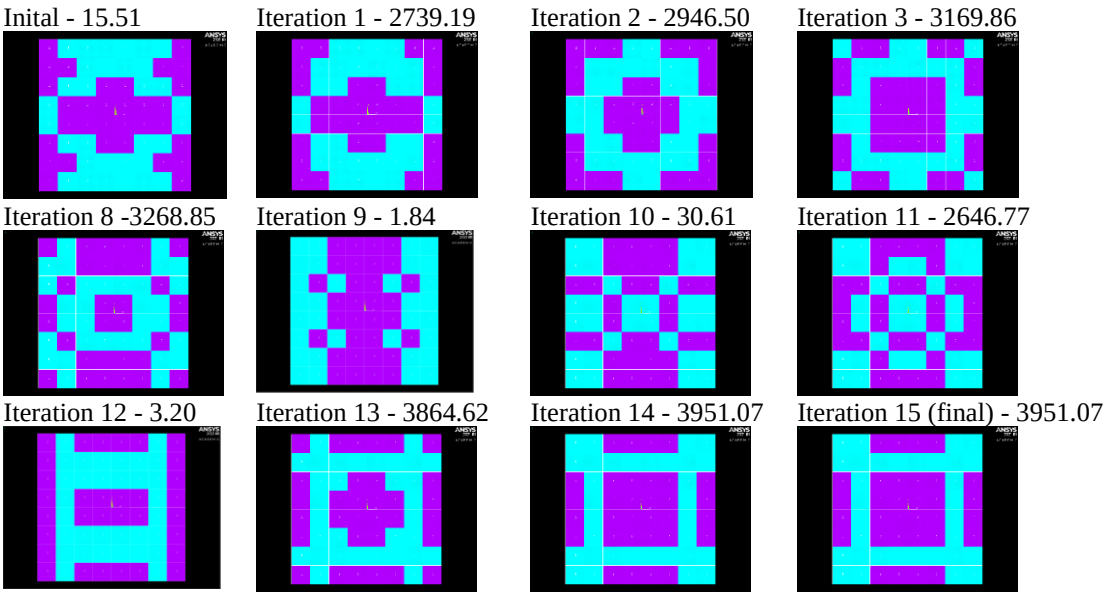

***Figure 1** – Evolution of materials' distribution at different iterations by following a simulated annealing algorithm.*

Acknowledgements

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Combined approach for fatigue crack characterisation in metals

J. M. Robles[1], J. M. Vasco-Olmo[2], A. S. Cruces[1], F. A. Diaz[2], M. N. James[3, 4], P. Lopez-Crespo[1*]

[1] *Department of Civil and Materials Engineering, University of Malaga, C/Dr Ortiz Ramos, s/n, 29071 Malaga, Spain, plopezcrespo@uma.es*

[2] *Departamento de Ingeniería Mecánica y Minera, Escuela Politécnica Superior de Jaén, Universidad de Jaén*

[3] *School of Marine Science & Engineering, University of Plymouth, Plymouth, UK*

[4] *Department of Mechanical Engineering, Nelson Mandela Metropolitan University, Port Elizabeth, South Africa*

Fatigue crack Digital Image SEM CJP model growth Correlation

Abstract In this work a comprehensive characterisation of the fatigue crack growth of an Al 2024 alloy is presented. A powerful Christopher-James-Patterson (CJP) model is used for multi-parameter characterisation of the crack state at a few different locations through the fatigue crack growth. The CJP model of crack tip displacements and stress fields was proposed in order to better capture the influences on the applied elastic stress field of the plastic enclave that is generated around a growing fatigue crack. The model does this through a set of elastic stresses applied at a notional elastic-plastic boundary, and it has been shown to accurately model plastic zone shape and size, whilst its ability to predict the effective range of stress intensity factor during a fatigue cycle has been verified. Thus, the model can predict the driving force component of the crack and additional components that account for different shielding mechanisms. CJP model is combined with full-field non-contact Digital Image Correlation (DIC) so that the model can be fed at any moment with real experimental information. The results are then correlated with Paris law data for Al 2024 alloy through Scanning Electron Microscopy (SEM) observations of the fracture surface. In this work the effect of crack length and load level are thoroughly studied and validated with fatigue crack growth rate measurements.

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Crack Tip Monitoring by Multiscale Optical Techniques

Frederico P. Direito, Behzad V. Farahani, Pedro J. Sousa, Paulo J. Tavares,

Pedro M. G. P. Moreira

INEGI – Institute of Science and Innovation in Mechanical and Industrial Engineering, Campus of FEUP, R. Dr. Roberto Frias 400, 4200-465 Porto, Portugal

fdireito@inegi.up.pt

Fracture Mechanics *DIC* *ESPI*

Abstract This study aims to monitor the multiscale crack tip through contactless optical methods. Middle Tension (MT) specimens were prepared, being submitted to a cyclic fatigue loading, in order to generate cracks with different lengths. Then, they are statically loaded under a uniaxial tensile condition, and two non-contact full-field optical techniques, Digital Image Correlation (DIC) and Electronic Speckle Pattern Interferometry (ESPI), are employed. While the specimens are being loaded with incremental force values, the behaviour of the cracked area is being monitored, with the displacement and deformation fields characterized for each load increment. The obtained data can be used to calculate fracture parameters, such as Stress Intensity Factor (SIF). For that purpose, an overdeterministic algorithm was developed to calculate SIFs for each measured crack length. The main contribution of the present work is adopting two optical contactless techniques with different system resolutions to monitor the crack tip, drawing a comparison between the calculated parameters for each system, validating the proposed methodologies. In the end, the obtained SIF values are compared to the reference solution proposed by ASTM E647, an acceptable agreement has been verified amongst the results.

Displacement monitoring of a pedestrian bridge using 3D digital image correlation

Francisco Barros[1], Susana Aguiar[1], Pedro J. Sousa[1], António Cachaço[1], Paulo J. Tavares[1], Pedro M. G. P. Moreira[1], D. Ranzal[2], N. Cardoso[2], N. Fernandes[2], R. Fernandes[2], R. Henriques[2], P.M. Cruz[2], A. Cannizzaro[2]

[1]INEGI, Institute of Science and Innovation in Mechanical Engineering and Industrial Engineering, Campus da FEUP, R. Dr. Roberto Frias 400, 4200-465 Porto, Portugal.

[2]Bosch Security Systems SA, EN109 – Zona Industrial de Ovar, 3880-728, Ovar, Portugal.

fbarros@inegi.up.pt

Digital image correlation *Structural monitoring* *Bridge deflection*

Abstract: Using computer vision methods for monitoring the behaviour of structures in urban environments, especially if it is intended to be a long term operation, requires the vision system and the preparation of the structure to be set up with minimal disruption to the surroundings and the use of the structure itself. With this concept in mind, 3D digital image correlation was used to evaluate the deflection caused by a static load on a pedestrian bridge, using cameras installed by windows in different floors of an adjacent building.

The measurements were performed using IP cameras designed for video surveillance and security applications, capturing the bridge's surface from above. Rather than preparing the surface with a custom speckle pattern, the DIC processing was performed using the pattern appearing naturally due to the irregularities on the surface. A 2D DIC test was performed simultaneously with an industrial camera capturing the same section of the bridge from a horizontal position inside a lower floor of the same building. The results from the 3D and 2D tests were in close agreement with each other and with the expected displacement profile.

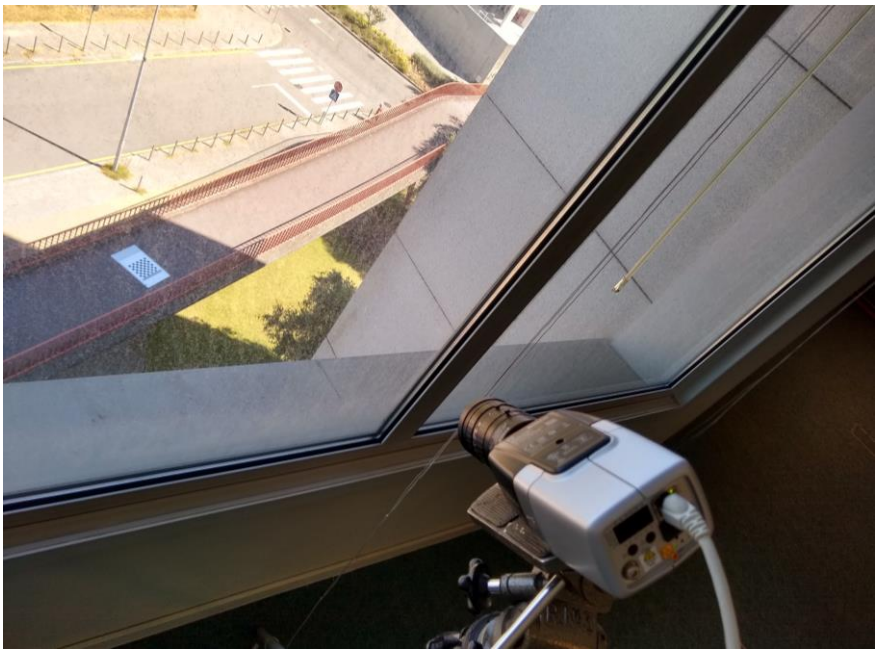

***Figure 1** – Camera capturing the surface of the bridge from a window*

Experimental evaluation of the stress intensity factors, T-stress and higher order coefficients of the Williams series expansion by digital photoelasticity method and finite element analysis

Larisa Stepanova[1], Oksana Belova[1]

[1]*Department of Mathematical Modelling in Mechanics, Samara National Research University, Moskovskoy shosse, 34, Samara 443086, Russia*

Stress intensity factors *Multi-point Williams series* *Higher order terms*

Abstract In this study digital photoelasticity method is applied for estimation of the crack tip linear fracture mechanics parameters for a plate with double edge notches and other different other cracked specimens such as a plate with two inclined cracks, a plate with two parallel cracks. The overarching objective of the study is to obtain the coefficients of the Williams series expansion for the stress and displacement fields in the vicinity of the crack tip by the digital photoelasticity technique with high accuracy keeping terms of higher orders. With this aim the digital image processing tool for the assessment of experimental data obtained from the photoelasticity experiments is developed and utilized. The digital image processing tool is based on the Ramesh approach but allows us to scan the image in any direction and to analyze the image after any prescribed number of logical operations. In the digital image processing isochromatic fringe analysis, the optical data contained in the transmission photoelastic isochromatics were converted into text files and then the points of isochromatic fringes with minimum light intensity were used for evaluating fracture mechanics parameters. The multi-point stress field approximation of Williams is used. The mixed mode fracture parameters, especially stress intensity factors (SIF) are estimated for specimen configurations like double edge notches and inclined center crack using the proposed algorithm based on the classical over-deterministic method. Moreover, along with the over- deterministic method the Broyden – Fletcher – Goldfarb – Shanno (BFGS) algorithm is used either allowing us to compute the coefficients with high accuracy. The effects of higher-order terms in the Williams expansion were analyzed for different cracked specimens. It is shown that the higher order terms are needed for accurate characterization of the stress field in the vicinity of the crack tip. The experimental SIF values estimated using the proposed method are compared with finite element analysis (FEA) results, and are found to be in good agreement.
The novelty of the proposed algorithm consists in 1) new filters used in Java code (the Frost filter, bilateral filter); 2) possibility of the algorithm to scan the image in any direction. The novelty of our approach consists either in the Broyden – Fletcher – Goldfarb – Shanno (BFGS) algorithm which is an iterative method for solving nonlinear optimization problems.
The novelty of our approach consists in the determination of the higher-order terms of the Williams series expansion. We computed all coefficients up to and including the 15th order.

Acknowledgements

The work is supported by the Russian Foundation for Basic Research (project 19-01-00631).

Stress intensity factors, T-stress and higher order coefficients of the Williams series expansion and their evaluation through molecular dynamics simulations

Larisa Stepanova[1], Oksana Belova[1]

[1]*Department of Mathematical Modelling in Mechanics, Samara National Research University, Moskovskoy shosse, 34, Samara 443086, Russia*

Molecular Dynamics Study *Multi-point Williams series* *Stress Intensity Factors*

Abstract The main purpose of the study is to compare two approaches of description of the near crack-tip fields in isotropic linear elastic materials. The first approach of characterizing the stress filed is based on the multi-point Williams series expansion in which the higher order terms are kept. The second one is based on the powerful computational technique of molecular dynamics (MD). To estimate the stress distributions in the vicinity of the crack tip and the coefficients of the Williams series expansion the large sequence of molecular dynamics simulations with different number of atoms in models is implemented. It is shown that the MD computational experiments and the conventional fracture mechanics result in the similar stress distribution around the crack tip (Figure 1).

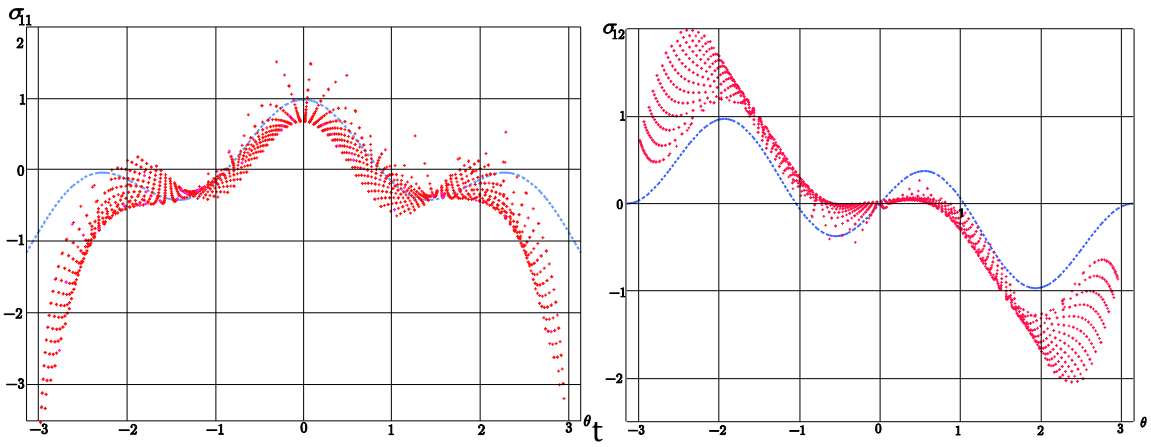

***Figure 1** – circumferential distributions of stress components in the vicinity of the crack tip: blue line shows the analytical solution with the obtained coefficients and red points show the atomistic distributions*

Based on the procedure of the over-deterministic method the continuum fracture mechanics parameters for Mode I and Mixed Mode loading are found. Reconciliation of continuum and atomistic models is demonstrated. Atomistic simulations clearly show that the angular distributions of the stress tensor components are very similar to the analytical solution.

Acknowledgements

The work is supported by the Russian Science Foundation (project 21-11-00346).

Nonlinear eigenvalue problems arising from nonlinear fracture mechanics problems

Larisa Stepanova[1], Ekaterina Yakovleva[1]

[1]*Department of Mathematical Modelling in Mechanics, Samara National Research University, Moskovskoy shosse, 34, Samara 443086, Russia*

Mode III problems *Power constitutive law* *Analytic solution*

Abstract The overarching objective of the study is to obtain the stress-strain state in the vicinity of the crack tip under antiplane shear in materials with power law constitutive equations. The boundary value problems for mode III cracks and notches in power-law materials are classical problems for nonlinear fracture mechanics. Despite an intense scrutiny carried out in the previous century the antiplane shear crack is still attracting the interests of researchers. The Rice's analytical solution for the mode III crack problem in a power-law hardening material (Rice (1967)) is well-known. The problem can be tackled by hodograph transformation. M. Anheuser and D. Gross (Anheuser and Gross (1994)) found singular fields and higher order fields near a sharp notch in a power-law material under longitudinal shear by the perturbation method. They reduced the problem to the nonlinear eigenvalue problem and used the artificial small parameter which was the difference between the eigenvalue of the "undisturbed" linear problem and the eigenvalue corresponding to the nonlinear problem. Using this technique, the whole set of eigenvalues was analytically determined. However, in the best of the authors' knowledge, the whole set of eigenfunctions has not been obtained yet. The analytical study of the whole set of eigenfunctions has received far less attention so far.

In the present study the exact solution for the whole set of eigenfunctions is found. Relevant, exact expressions for mode III stress field corresponding to the whole spectrum of eigenvalues are obtained. The exact solution is derived by two approaches. The first approach is based on the classical hodograph transformation whereas the second one relies on the artificial small parameter and on the perturbation theory. It is shown that it is possible to reduce the series obtain by the perturbation technique to the analytical expression.

Acknowledgements

The work is supported by the Russian Science Foundation (project 21-11-00346).

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An effective scheme for solving a class of nonlinear boundary value problems of stress concentration through quasilinearization approach

Larisa Stepanova[1], Ramil Zhabbarov[1]

[1]*Department of Mathematical Modelling in Mechanics, Samara National Research University, Moskovskoy shosse, 34, Samara 443086, Russia*

Quasilinearization method *Power constitutive law* *Analytic solution*

Abstract The study deals with a class of stress concentration problems in power – law materials. The main objective of the study is to obtain approximation solutions of nonlinear stress concentration problems such as a uniaxial tension of the plate weakened by a circular hole in a power law material, a problem for a spherical cavity in a power law material under uniaxial tension (compression).

To derive approximate analytical solutions of the aforementioned problems the quasilinearization method is utilized. The analytical solution is sought in the form of series in which each term is a product of two functions. One function depends on the radial coordinate whereas the second one depends on the polar angle. The structure of the approximate solution is determined by the structure of the solution for a linearly elastic material. Then, the system of nonlinear equations is linearized. The procedure allowing us to reduce nonlinear equations of the problem to a sequence of linear problems is shown. The convergence analysis of the method is also discussed. To demonstrate the efficiency of the approach various numerical examples performed by finite element method in the commercial programme Simulia Abaqus are considered. Numerical results obtained are compared with the approximate analytical solutions. The numerical simulations justify the efficiency of the quasilinearization method and verify the approximate solutions. It is shown that the method is effective and provides a highly accurate convergent series solution by starting with a solution for the linear elastic isotropic material.

The approximate analytical solutions obtained can be used for problems of parameter identification for embedded defects in a nonlinear body with power-law constitutive equations.

Acknowledgements

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Constraint effect on fracture toughness resistance curves of an X60 pipe steel

Cheng Qian [1], Jie Liang [1], Yifan Huang [2], Jidong Kang [1], Jim Gianetto [1]

1 CanmetMATERIALS, 183 Longwood Road South, Hamilton, Ontario, L8P 0A5, Canada

2 Candu Energy Inc., 2251 Speakman Drive, Mississauga, Ontario, L5K 1B2, Canada

Cheng.Qian@NRCan-RNCan.gc.ca Jidong.kang@nrcan-rncan.gc.ca

Fracture toughness *Constraint effect* *X60 pipe steel*

Abstract The fracture toughness resistance curve (e.g. *J-R* curve and crack tip opening displacement (CTOD) or δ-*R* curve) is important in facilitating strain-based design and integrity assessment of oil and gas pipelines, where influence of ground movement and presence of planar weld flaws must be accounted for.

In this paper, duplicate single edge bend (SE(B)) and clamped single edge tension (SE(T)) specimens with two different initial crack lengths were prepared from an X60 pipe steel. The longitudinally-oriented specimens were notched in the through-thickness direction and experimentally tested at room temperature. In general, the results showed the expected trends of higher resistance curves for both shallow-notched specimen types and bending versus tension loading modes.

Eleven constraint parameters (i.e. Q_{HRR}, Q_{SSY}, Q_{LM}, Q_{BM}, A_2, A_{2BM}, h, T_z, C_p, A_p, V_p) were calculated based on three-dimensional finite element analyses (FEA) for various tested SE(B) and SE(T) specimens. The results and analysis indicated that the shallow-cracked SE(B) specimens exhibit a constraint condition similar to the intrinsically low-constraint deep-notched SE(T) specimens. Among all of the constraint parameters, the A_p and V_p parameters based on the normalized equivalent plastic strain contour were found to have the most promising trend in terms of correlating the material's toughness to constraint level for currently tested specimens.

Further on-going investigations are underway to extend this evaluation to *R* curves for SE(B) and SE(T) specimens made from an X100 pipe steel to allow for the characterization of strain hardening effect.

Creep and stress relaxation behaviour of 3D printed nanocomposites

P.N.B. Reis [1], S. Valvez [2], J.A.M. Ferreira [1]

[1] *University of Coimbra, CEMMPRE, Department of Mechanical Engineering, Coimbra, Portugal*

[2] *C-MAST, Department of Electromechanical Engineering, University of Beira Interior, Covilhã, Portugal*

paulo.reis@dem.uc.pt

Additive Manufacturing *Fused Deposition Modelling* *Creep* *Stress relaxation*

Abstract: More than design considerations, conventional manufacturing technologies are a real obstacle to the production of some structures. In this context, additive manufacturing (AM) is a recent technique capable of overcoming these limitations, in which they are produced layer by layer directly from a CAD file and without requiring multi-steps, labour intensive processes, high costs for moulds and long processing time. Nowadays different additive techniques have been explored like: stereolithography (SLA), selective laser sintering (SLS), laminated object manufacturing (LOM) and fused filament fabrication (FFF). The last one, is one of the most widely used additive manufacturing processes. This technique is based on the extrusion of heated feedstock plastic filaments through a nozzle tip to deposit layers onto a platform to produce parts layer by layer directly from a computer-aided design model.

As consequence of the inherent viscoelasticity of the matrix phase, polymer composites are prone to creep and stress relaxation, making it a great challenge when they are used in long-term applications. Therefore, a better understanding of the stress-relaxation and creep behaviour of composites enables us to predict the dimensional stability of load-bearing structures. In this context, the main goal of the present study is to analyse the time-dependent behaviour of hybrid nanocomposites, and, for this purpose, experimental tests were carried out in compression, tensile and bending modes in which the stress (for stress relaxation tests) and the displacement (for creep tests) are recorded during the loading time. G6-Impact™ was the filament used that is a composite consisting of a HiPS matrix with carbon fibre and graphene (20%). With this architecture of matrix reinforced, it is possible to achieve a strong composite with a certain degree of flexibility and an exceptional impact performance. From the stress relaxation tests, and regardless of the loading mode, it is possible to conclude that there was a decrease in stress with time, while from the creep tests the displacement increased with the time. This trend has been shown to increase with the increase in strain and stress values.

The effect of artificial ageing on the corrosion-induced mechanical properties degradation of aeronautical aluminum alloy 2198

Christina Margarita Charalampidou[1], Dimitris Georgoulis[2], Angeliki Proiou[2] , Stavros K. Kourkoulis, Nikolaos D. Alexopoulos

[1]Department of Financial Engineering, School of Engineering, University of the Aegean, Kountourioti 41 str, 82132, Chios, Greece

[2]Laboratory of Testing and Materials, Department of Mechanics, National Technical University of Athens, 9 Heroes Polytechniou Str,15773, Athens, Greece

Corrosion *Aluminium alloy* *Artificial ageing*

Abstract The increasing demand for improvement in energy efficiency and performance in the aviation industry lead to the development of new, lighter metallic structures. Third generation Al-Cu-Li alloys were developed to replace the conventional aluminum alloys since they can offer approximately 5 % weight reduction of the structure as well as improved property balance and corrosion resistance. Their improved mechanical properties are often attributed to their precipitation hardening system including δ (Al3Li), θ (Al2Cu), T1 (Al2CuLi) and S (Al2CuMg) phases. Nevertheless, these precipitates may influence the electrochemical behaviour of the alloys and therefore increase their corrosion susceptibility. The formation of such IM phases can be significantly accelerated by the artificial ageing heat-treatment. Heat treatment is usually performed in order to change the metallurgical structure, the mechanical properties, or even the residual stress state of the metal sheets. Artificial ageing heat treatment also affects the corrosion behaviour of the aluminum alloys due to the different electrochemical behaviour of the precipitated intermetallic phases and the matrix [1]-[3]. The 2xxx aluminum alloys were found to have higher corrosion resistance when artificially aged at certain tempers, such as T6 or T8, than at T3 [4]. Hence, it is of major importance to investigate the effect of artificial ageing on the corrosion behaviour Al-Cu-Li alloys.

The material used was a wrought aluminum alloy 2198-T3 which was received in sheet form of 3.2 mm nominal thickness. Machined specimens were exposed to artificial ageing heat-treatment for different ageing times in order to simulate the different ageing tempers named as under-ageing (UA), peak-ageing (PA) and over-ageing (OA). Exposure of the specimens to exfoliation corrosion solution (EXCO) according to ASTM G34 specification was performed for different exposure times in order to investigate the effect of artificial ageing on the corrosion evolution. The corroded specimens were examined with light optical microscopy in order to measure the depth of corrosion attack for the evaluation of corrosion-induced mechanical properties degradation. Finally, tensile specimens with prior heat treatment and corrosion exposure were tested to quantify the degradation on the mechanical properties. It was found that the corrosion exposure caused a significant degradation of the mechanical properties of AA2198 specimens that was correlated with the distribution of the depth of attack of the exposed surfaces to the corrosion environment.

Mechanical, electrical and piezoresistive properties of a ternary cement-based restoration paste with incorporated carbon-based nanomaterials

Christina Margarita CHARALAMPIDOU[1], Angeliki Eirini DIMOU[1], Zoi S. METAXA[2], Z., Stavros K. KOURKOULIS[3], Ioannis KARATASIOS[4] and Nikolaos D. ALEXOPOULOS[1]

[1] *University of the Aegean, School of Engineering, Department of Financial Engineering, 821 32 Chios, Greece, c.charalampidou@fme.aegean.gr*

[2] *International Hellenic University, School of Science and Technology, Department of Chemistry, Hephaestus Laboratory, St. Luke 654 04, Kavala, Greece*

[3] *National Technical University of Athens, Department of Mechanics, Laboratory of Testing and Materials, 9 Heroes Polytechniou Str., 15780 Athens, Greece*

[4] *NCSR ''Demokritos'', Institute of Nanoscience and Nanotechnology, Laboratory of Ceramics and Composite Materials, Aghia Paraskevi 153 41, Attica, Greece*

Carbon-based nanomaterials *Lime pastes* *Piezoresistivity*

Abstract The aim of the present work is to study a ternary, cement-based paste matrix for the restoration of Cultural Heritage Monuments with incorporated carbon-based nanomaterials, namely Graphene Oxide (GO) and Reduced Graphene Oxide (rGO). More specifically, a mixture of lime (L), cement (CEMI) and metakaolin (MK) is examined. The lime content is 35 wt %, the CEMI content is 35 wt % and the content of MK is 30 wt %, while the water to binder ratio is 0.55. The above-mentioned nanomaterials are added at a concentration of 0.15 wt % of the binder. In order to evaluate the performance of these pastes, mechanical tests to evaluate compressive strength were performed, as well as electrical resistance measurements. Finally, the piezoresistive properties were examined under cyclic loading, i.e. simultaneous measurement of compressive stress and electrical resistance. The mechanical results indicate that the compressive strength is increased when GO and rGO are added, while the electrical resistance drops significantly. Also, the composite materials possess piezoresitive properties, which is very important for potential applications in damage monitoring.

Acknowledgment: *This research has been co‐financed by the European Regional Development Fund of the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH‐CREATE‐INNOVATE (project code: T1EDK-03069, MIS 5031866).*

, Autofrettage of component-like ultra high Strength Steel Specimens with intersecting Holes

Carl Fällgren[1], Dr.-Ing. H. Thomas Beier[2], Prof. Dr.-Ing. Michael Vormwald[2]

[1]Technical University of Darmstadt, Department of Civil and Environmental Engineering Sciences, Materials Mechanics Group, Franziska-Braun-Straße 3, 64287 Darmstadt, Germany. faellgren@wm.tu-darmstadt.de

[2]Technical University of Darmstadt, Department of Civil and Environmental Engineering Sciences, Materials Mechanics Group, Darmstadt, Germany

ultra-high strength steels *Autofrettage* *residual stress*

[1]Materials Mechanics Group

Abstract This work is primarily concerned with the fatigue life of high-pressure bearing components with intersecting holes, typically used in Diesel engine fuel injection systems. The investigation focuses on specimens with orthogonally intersecting holes that have undergone the process of Autofrettage (single mechanical overload), which is typically used to extend the fatigue life of components loaded by cyclic internal pressure. The Autofrettage process induces advantageous, life-time prolonging residual compressive stresses in the highly stressed areas of the components. The resulting residual stress distribution thus influences the fatigue failure and especially the crack propagation behavior of the components.

In previous works, fracture mechanics-based approaches were used to describe the crack propagation behavior for autofrettaged specimens made of the quenched and tempered steel 42CrMo4. Results showed that crack arrest has to be taken into account when calculating fatigue lives of autofrettaged specimens as the endurance limit is otherwise underestimated. As efforts are made to increase the injection pressures of fuel injection systems, in this work, the benefit of using ultra high strength steel for the application described is investigated.

In order to achieve reliable results, material testing with samples made of the ultra high strength steel W360 was performed. The resulting test data were used to describe the initial loading and cyclic loading behavior of the material with a suitable material model. Finite element analysis was then performed to simulate the Autofrettage process and subsequent cyclic loading. Based on the simulation results, possible crack initiation was determined. For predicted crack initiation, the simulated residual stress distribution was used to investigate the crack propagation behavior with fracture mechanics-based approaches of different complexity in order to identify possible crack arrest or crack propagation. Calculated results were compared to experimental test data from component-like specimens. The comparison to the test results showed an overestimation of the predicted fatigue lives. The modelled material behavior and consequently the residual stress distribution from the simulation models was identified as the decisive factor for the deviation. Still, the comparison showed that the fracture mechanics based approaches are capable of describing the crack arrest and propagation behavior reliably. Further investigation regarding the modeling of the material behavior with focus on the Autofrettage process is still required.

This work is part of an AiF/iGF project under the funding code 19790 N and is supported by the Federal Ministry for Economic Affairs and Energy on the basis of a decision by the German Bundestag.

, Influence of ester on the mechanical hysteresis characteristic of power transformer insulation components

Daniel F.O. Braga[1], E. E. Almeida[2], Shayan Eslami[1], Ricardo Lopes[2], Pedro M.G.P. Moreira[1]

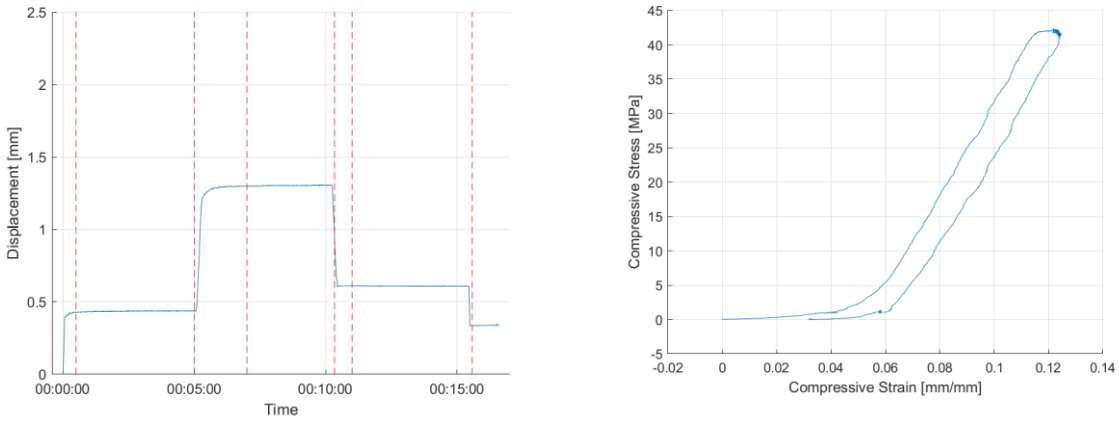
[1] INEGI, Institute of Science and Innovation in Mechanical Engineering and Industrial Engineering, Campus da FEUP, R. Dr. Roberto Frias 400, 4200-465 Porto, Portugal

[2] EFACEC Energia S. A., São Mamede de Infesta, Portugal

dbraga@inegi.up.pt

Experimental Mechanics *Low Temperature Testing* *Composite Materials*

Abstract Currently, the majority of electrical transformers make use of mineral oil as a dielectric and cooling medium. Due to security concerns flammability of these fluids restrains the installation of power transformers in high population density zones. These fluids are also non-biodegradable and therefore require replacement today by more greener alternatives, such as esters. To enable the development of high-power electrical transformers immersed in ester, the mechanical performance of insulation materials, especially those components that are highly stressed, must be assessed. To this end various insulation materials embedded in either ester or mineral oil, under several different conditions were submitted to compression hysteresis testing following IEC 60641-2 standard. Testing equipment was developed to perform the experimental tasks. The performed tests provide information on the mechanical behavior of pressboard and aramid insulation components, under varying temperature and operational conditions, for both mineral oil and ester fluids.



a) b)

***Figure 1** – Displacement history during hysteresis testing a) and resulting compression stress vs. strain b)*

Acknowledgment This paper is a result of Project GreenEst, supported by the Competitiveness and Internationalization Operational Program (POCI), under the PORTUGAL 2020 Partnership Agreement, through the European Regional Development Fund (ERDF)";

Crack growth rate deceleration effect in constructional steel caused by artificial crack closure effect (ACCE)

Lesiuk G.[1], Nykyforchyn H.[2], Zvirko O.[2], Duda Sz.[1], Zielonka P.[1], Correia J.A.F.O[3], Seitl S.[4], De Jesus A.M.P[3]

[1]*Wroclaw University of Science and Technology, Faculty of Mechanical Engineering, Department of Mechanics, Materials Science and Engineering, Wroclaw, Poland*

[2] *Karpenko Physico-Mechanical Institute of the National Academy of Sciences of Ukraine, Lviv, Ukraine*

[3] *University of Porto, Faculty of Engineering, Porto, Portugal*

4 Institute of Physics of Materials, Czech Academy of Science, Žižkova 513/22, 616 00 Brno, Czech Republic

5 Brno University of Technology, Faculty of Civil Engineering, Veveří 331/95, 602 00 Brno, Czech Republic

grzegorz.lesiuk@pwr.edu.pl

Pearlitic steel *Crack retardation* *Fatigue fracture*

Abstract This paper presents the results of research on the phenomenon of artificial fatigue cracking closure using a new elaborated liquid medium. Preliminary results from the Authors' work [1] became the background for further studies on the effectiveness of the applied method for groups of structural steels with different mechanical properties (microstructures) and chemical composition. The positive effect of crack retardation has also been discussed in detail in light of the physics of the fatigue crack growth process from a materials science point of view.

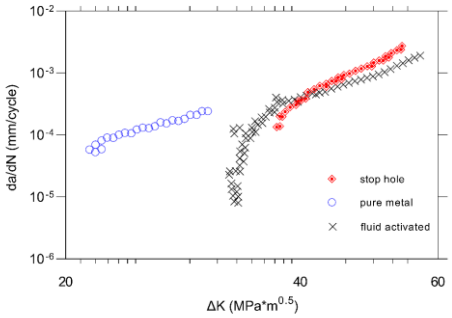


Figure 1 Crack retardation effect in pearlitic rail steel after fluid treatment [1]

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Damage detection and localization in imperfect bolted joints

Reza Soleimanpour[1], Sayed Mohamad Soleimani[1], Naser Khaled Mahmoud Mohammad[1]

[1]Department of Civil Engineering, Australian College of Kuwait, Mishref, Kuwait

reza.soleimanpour@gmail.com

Guided waves *Loose Bolted Joints* *Damage localization*

Abstract In this paper damage detection and damage localization of imperfect bolted joints is studied experimentally and numerically using three-dimensional explicit finite element simulations. The study is focused on using contact acoustic nonlinearity (CAN) due to interaction of asymmetric guide waves (A_0) with imperfect joint surfaces for detecting and locating imperfect joints. Experimentally obtained data are processed and it is shown that the CAN can detect and locate defects. The finite element model is validated using experiment. It is demonstrated that finite element can predict propagation of guided waves in bolted joints. Several numerical case studies with various defect sizes are created and studied using validated FE model. It is demonstrated that FE model followed by signal processing approach used in this study can successfully and accurately detect and locate the imperfect joints. Overall, the findings of this study provide improved physical insights into using CAN for detecting and locating imperfect joints, which can be used to further advance damage detection techniques using nonlinear guided waves

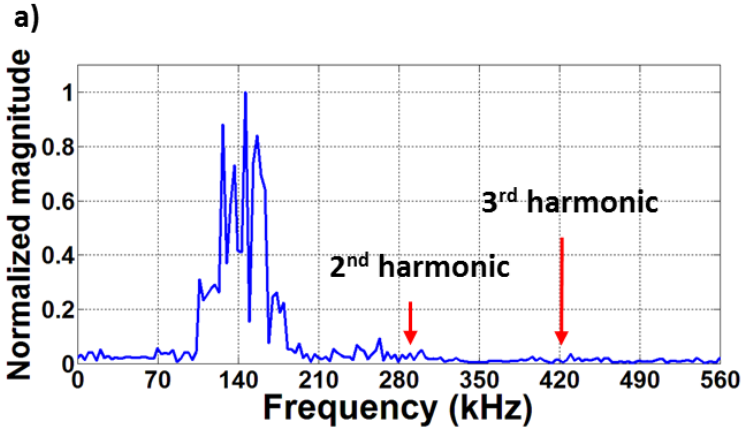

***Figure 1** – Higher harmonics generation due to CAN*

On material identification of *Pinus pinaster* Ait. at high strain rate loading by the image-based inertial impact test

F.G. Cunha[1], R. Nunes[1] , L.C. Fletcher[2], J. Xavier[1*], F. Pierron[2]

[1]*UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, NOVA University Lisbon, 2829-516 Caparica, Portugal*

[2]*Mechanical Engineering, Faculty of Engineering and Physical Sciences, University of Southampton, Southampton, United Kingdom*

Wood *Virtual Fields Method* *High strain rate*

Abstract Understanding the material behaviour over a spectrum of strain rates regimes is of great importance for structural applications. Several experimental test methods apply for data collection and analysis at different loading regimes. At high strain rates, the Split Hopkinson pressure bar (SHPB) technique has been extensively applied on different materials. However, this method presents some disadvantages namely: (i) the quasi-static stress equilibrium assumption, where inertial effects in the sample are neglected; (ii) experimental verification of one dimensional (1D) wave propagation assumption. Eventually, these limitations have led to new approaches, namely by incorporating advanced full-field optical techniques. Taking advantage of ultra-high-speed imaging (> 1 Mfps), with a suitable balance between temporal and spatial resolutions, a new test method so-called Image-Based Inertial Impact (IBII) test was developed under the PhotoDyn project. In this test, a rectangular-shaped specimen is loaded over one edge, creating a compressive stress pulse followed by wave reflection in tension at the opposite free edge, which eventually will cause failure of the material. The data reduction in this test method relies exclusively on full-field deformation measurements. Displacements are measured across the region of interest by the grid method. Reconstructed acceleration and strain fields are then input in the virtual fields method (VFM) to extract the activated stiffness components and strength properties at high strain rate regime. One of the advantages of the IBII test, in comparison with the SHPB, is the possibility to overcome the direct measurement of external forces applied to the specimens during the dynamic test, since the average stress state at each cross-section is obtained from the acceleration field provided the material density is known. However, this is only possible with a camera offering enough temporal (MHz regime) and spatial resolution.

This work studied the strain sensitivity of the mechanical properties of Pinus pinaster Ait. wood, in the longitudinal-radial (LR) and radial-longitudinal (RL) orthotropic planes, by means of the IBII test. The grid method and the VFM were used to identify relevant mechanical properties. The LR specimens were analysed through a general orthotropic constitutive model, whilst in the RL specimens a simplification by a reduced orthotropic model was chosen. A failure stress identification routine was also used to obtain the strength at high strain rate regime. The dynamic tests based on the IBII test were carried out at average strain rates on the order of 1000 s-1. On the one hand, it was observed that the elastic properties did not vary significantly at high strain rate when compared to quasi-static (QS) reference values. The identified parameters were E_L=12.0 GPa, E_R=1.88 GPa and ν_{LR}=0.4. On the other hand, the strain rate dependency for the strength of the LR specimpens was significant, with an increase of 55.5 % compared to QS reference values. However, failure of LR specimens was not consistently reached.

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On the use of the plastic component of the CTOD for fatigue analysis in austenitic stainless steel

M. Ajmal[1,2], C. Lopez-Crespo[1,3], A. S. Cruces[1], F. V. Antunes[4], P. Lopez-Crespo[1*]

[1] Department of Civil and Materials Engineering, University of Malaga, C/Dr Ortiz Ramos, s/n, 29071 Malaga, Spain, plopezcrespo@uma.es

[2] Yanbu Industrial College, Alnahdah, Al-Nahdah, Yanbu 46452, Saudi Arabia

[3] Politechnic Institute Jesus Marin, C/Politecnico, 1, 29007 Malaga, Spain

[4] CEEMPRE, Department of Mechanical Engineering, University of Coimbra, Portugal

Fatigue crack growth | *Digital Image Correlation* | *CTOD* | *Austenitic stainless steel*

Abstract In this work, a new methodology for characterising the fatigue crack propagation of metallic alloys is proposed. The methodology is based on the plastic component of the Crack Tip Opening Displacement ($CTOD_p$) as a driving force. This $CTOD_p$ parameter is evaluated from full-field displacement maps obtained by Digital Image Correlation (DIC). The method is applied on austenitic stainless steel but appears to be very suitable to a wide range of metal alloys. The methodology appears to improve some of the issues related to Linear Elastic Fracture Mechanics predictions for fatigue crack growth.

More Steps Towards an Innovative Concept of Structural Integrity: Between Leonardo da Vinci and Galileo Galilei

Jesús Toribio*

[*] *Fracture & Structural Integrity Research Group (FSIRG), University of Salamanca (USAL) E.P.S., Campus Viriato, Avda. Requejo 33, 49022 Zamora, Spain*

Material versus structure | *Concept of structural integrity* | *Giga to nano-structural integrity* | *Material integrity*

Abstract This paper develops other by the author on a novel and forward-looking approach to the concept of structural integrity, comprising and covering all length scales in the theoretical framework of the innovative terms of giga-, mega-, macro-, micro- and nano-structural integrity, and thus the science of fracture mechanics & structural integrity can be seen as a branch of material science & engineering, and the novel idea of material integrity can also be discussed. In addition, the concept of structural integrity is extended to fields such as the biology, or to the case of non-material structures. The paper is also a tribute to the artist and engineer Leonardo da Vinci, as well as to the physicist Galileo Galilei for their pioneering works in the fields of material strength, fracture and structural integrity

Structural integrity of hot bituminous mixtures for road pavements: mechanical and environmental factors governing fatigue & fracture

Jesús Toribio*, Rubén Tino, Beatriz González, Juan-Carlos Matos

[*] Fracture & Structural Integrity Research Group (FSIRG), University of Salamanca (USAL) E.P.S., Campus Viriato, Avda. Requejo 33, 49022 Zamora, Spain

Hot bituminous mixtures | *Mechanical behaviour* | *Mechanical variables* | *Environmental variables*

Abstract This paper summarizes scientific research by the authors on mechanical and environmental variables governing the mechanical behavior of hot bituminous mixtures, with special emphasis on damage, degradation and fracture. With regard to the mechanical factors affecting the structural performance of the mixtures, the following ones can be mentiones: (i) cyclic loading (mechanical fatigue), (ii) laboratory boundary conditions to test the specimens. In the matter of environmental factors influencing such a mechanical (damage & fracture) performance, the list is as follows: (i) de-icing salts, (ii) weather conditions including temperature cycles (thermal fatigue), rainfall and presence of ice. Results are presented in systematic manner to draw conclusions and recommendations applicable to real traffic of vehicles in roads.

Review and synthesis of stress intensity factor (SIF) solutions for annular outer cracks in round bars under tension loading

Jesús Toribio*, Beatriz González, Juan-Carlos Matos

* *Fracture & Structural Integrity Research Group (FSIRG), University of Salamanca (USAL) E.P.S., Campus Viriato, Avda. Requejo 33, 49022 Zamora, Spain*

Stress Intensity Factor | *Finite Element Method* | *J-integral* | *circumferentially-cracked round bar*

Abstract In this paper, the stress intensity factor (SIF) is computed in a circumferentially-cracked round bar (CCRB) subjected to tensile load or to axial displacement, considering that the resistant ligament is circular and exhibits certain eccentricity in relation to the cylinder axis. The computation was performed by means of the finite element method (FEM) using a three-dimensional (3D) model and the J-integral, the analyzed variables being the diameter and the eccentricity of the circular ligament. Results show that the SIF is higher at the deepest point of the crack and that an increase of eccentricity (in relation to the bar axis) raises the difference between the SIF values at the deepest and surface points of the crack. Furthermore, the maximum SIF is higher for tensile load than for axial displacement, mainly for high eccentricities and small diameters of the ligament, as a consequence of a greater rotation of the bar.

Review and synthesis of stress intensity factor (SIF) solutions for circular inner cracks in round bars under tension loading

Jesús Toribio*, Beatriz González, Juan-Carlos Matos

* *Fracture & Structural Integrity Research Group (FSIRG), University of Salamanca (USAL) E.P.S., Campus Viriato, Avda. Requejo 33, 49022 Zamora, Spain*

Cracked bar *Eccentric circular inner crack* *J-integral* *Stress Intensity Factor*

Abstract In this paper, stress intensity factor (SIF) was calculated in a bar subjected to tensile loading, considering a circular inner crack that exhibited certain eccentricity in relation to the cylinder axis. The computation was performed by means of the finite element method (FEM) using a three-dimensional (3D) model and the J-integral, the analyzed variables being the diameter and the eccentricity of the circular inner crack. Results show that the SIF is higher at the point of the crack front closest to the bar surface and that an increase of relative crack eccentricity or of relative crack diameter raises the difference between the SIF values at the crack point closest to the bar surface and the crack point furthest from it, thus the existence of eccentricity in the initial crack leads to an increase of such a parameter when fatigue propagation occurs.

Environmentally-assisted microstructural integrity of commercial cold drawn pearlitic steel wires

Jesús Toribio*, Francisco-Javier Ayaso, Antonio Fernández-Viña

[*] Fracture & Structural Integrity Research Group (FSIRG), University of Salamanca (USAL) E.P.S., Campus Viriato, Avda. Requejo 33, 49022 Zamora, Spain

Microstructural integrity | *Commercial prestressing steel wire* | *Cold drawn pearlitic steel wire* | *Environmentally assisted failure*

Abstract This paper contains a quantitative fractographic analyses of the fracture surface of initially-smooth samples of commercial prestressing steel wires subjected to tensile tests in aggressive environment promoted by a corrosion cell. Two testing rates were used: one moderately fast (0,1 mm/min) and another moderately slow (0,01 mm/min). The electro-chemical potential used covers a wide range (from –400 to –1400 mV SCE), thus including from anodic to cathodic conditions. The main objective is focused on the study of the fracture surface for those specimens that failed due to the aggressive environment (inside corrosion cell). The analysis of the fracture surface is made from a quantitative and qualitative point of view.

Micro- and nano-structural integrity of cold drawn pearlitic steels: drawing-induced evolution of intracolonial micro-defects

Jesús Toribio*, Francisco-Javier Ayaso, Rocío Rodríguez

* *Fracture & Structural Integrity Research Group (FSIRG), University of Salamanca (USAL) E.P.S., Campus Viriato, Avda. Requejo 33, 49022 Zamora, Spain*

Pearlitic steel *Cold drawing* *Intracolonial micro-defects*

Abstract This article deals with the analysis of the evolution of intracolonial micro-defects produced in pearlitic steel wires as a direct result of the cold drawing process. The study was carried out from the observation of the microstructure of wires belonging to the different steps of a real cold drawing chain, formed by seven stages of cold drawing. The evolution of intracolonial micro-defects can be key in the subsequent fracture process of the cold drawn pearlitic steel. The analysis of these micro-defects has been carried out after the observation and study of micrographs belonging to these wires. Scanning electron microscopy (SEM) techniques have been used to obtain micrographs.

A fracture criterion for cold drawn pearlitic steel cracked wires with elliptical surface cracks of different aspect ratios:

A Tribute to Eduardo Torroja

Jesús Toribio*

* *Fracture & Structural Integrity Research Group (FSIRG), University of Salamanca (USAL) E.P.S., Campus Viriato, Avda. Requejo 33, 49022 Zamora, Spain*

Fracture criterion *Crack-shaped defects* *Cold-drawn pearlitic steel* *High-strength steel*

Abstract In this paper a fracture criterion is proposed for cracked cylindrical samples of high-strength prestressing steels of different yield strength. The surface crack is assumed to be semi-elliptical, a geometry very adequate to model sharp defects produced by any subcritical mechanism of cracking: mechanical fatigue, stress-corrosion cracking, hydrogen embrittlement or corrosion fatigue. Two fracture criteria with different meanings are considered: a global (energetic) criterion based on the energy release rate G, and a local (stress) criterion based on the stress intensity factor KI. The advantages and disadvantages of both criteria for engineering design are discussed in this paper on the basis of many experimental results of fracture tests on cracked wires of high-strength prestressing steels of different yield strength and with different degrees of strength anisotropy.

A fracture criterion for cold drawn pearlitic steel notched wires with circumferentially-shaped notches of different geometries:

From Eduardo Torroja to José Antonio Torroja

Jesús Toribio*, Francisco-Javier Ayaso

* *Fracture & Structural Integrity Research Group (FSIRG), University of Salamanca (USAL)*
E.P.S., Campus Viriato, Avda. Requejo 33, 49022 Zamora, Spain

Fracture criterion *Notch-shaped defects* *Cold-drawn pearlitic* *Structural integrity*

Abstract This paper deals with the formulation and development of fracture criteria for high-strength structural members containing surface damage in the form of notches (i.e., blunt defects). The important role of the yield strength of the material and its strain hardening capacity (evaluated by means of the constitutive law or stress-strain curve) is analysed in depth by considering the fracture performance of notched samples taken from high-strength steels with different levels of cold drawing (the most heavily drawn steel being commercial prestressing steel used in prestressed concrete). The final aim of the paper is to establish fracture-based design criteria for structural members made of steels with distinct yield strength and containing very different kinds of notch-shape surface damage.

Review and synthesis of stress intensity factor (SIF) solutions for elliptical surface cracks in round bars under tension loading:

A Tribute to Leonardo Torres-Quevedo

Jesús Toribio*, Beatriz González, Juan-Carlos Matos

* *Fracture & Structural Integrity Research Group (FSIRG), University of Salamanca (USAL) E.P.S., Campus Viriato, Avda. Requejo 33, 49022 Zamora, Spain*

Round bar *Elliptical crack* *Crack aspect ratio* *Stress Intensity Factor (SIF) solution*

Abstract In this paper different stress intensity factor (SIF) solutions numerically obtained by previous research on transversely cracked cylinders subjected to tension loading are analyzed. Solutions are compared in the matter of stress intensity values at the centre of the crack front and at the external surface of the cylinder, and a wide range of crack aspect ratios and relative crack depths are studied, in order to provide the engineer with solutions applicable to different real situations in fracture mechanics or damage tolerance analyses such as static or cyclic (fatigue) loading, environmentally assisted cracking or corrosion-fatigue.

Review and synthesis of stress intensity factor (SIF) solutions for elliptical surface cracks in bolts under tension loading:

A Tribute to Juan de la Cierva

Jesús Toribio*

[*] *Fracture & Structural Integrity Research Group (FSIRG), University of Salamanca (USAL)*
E.P.S., Campus Viriato, Avda. Requejo 33, 49022 Zamora, Spain

Bolt *Elliptical crack* *Crack aspect ratio* *Stress Intensity Factor (SIF) solution*

Abstract In this paper different stress intensity factor (SIF) solutions numerically obtained by previous research on transversely cracked bolts subjected to tension loading are analyzed. Solutions are compared in the matter of stress intensity values at the centre of the crack front and at the external surface of the bolt, and a wide range of crack aspect ratios and relative crack depths are studied, in order to provide the engineer with solutions applicable to different real situations in fracture mechanics or damage tolerance analyses such as static or cyclic (fatigue) loading, environmentally assisted cracking or corrosion-fatigue.

, **Fatigue life estimation of CFRP reinforced puddle iron structural details using fatigue local approach**

Anis Mohabeddine[1], João Arrojado[1], José Correia[1,2], Abilio de Jesus[2], José Miguel Castro[1], Rui Calçada[1], Filippo Berto[3]

[1]Construct, Department of Civil Engineering, Faculty of Engineering University of Porto, Portugal.

[2]INEGI, Department of Mechanical Engineering, Faculty of Engineering University of Porto, Portugal.

[3] Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology (NTNU), Norway.

Riveted connection *Puddle iron* *CFRP*

Abstract In Europe and around the world, a large number of old riveted metallic bridges approach the end of their fatigue life. These bridges were constructed around 100 years ago with puddle iron material that exhibit a brittle behavior due to its quality and the long-term operational loading cycles. The replacement of old metallic bridges is economically unfeasible. Therefore, bridge owners usually seek for local repair interventions at components level. The structural elements that are identified to be deficient will be retrofitted to upgrade their performance. Carbon fiber-reinforced polymer (CFRP) is a very attractive material for repairing old metallic structures. The application of CFRP increases the stiffness and strength of the structural elements without modifying their mechanical and fatigue behavior as in it the case of drilling or welding. Besides due to the lightweight of the CFRP laminates no additional load is added to the structure. Past research has shown that the application of CFRP can be very efficient in delaying the crack growth rate of deficient structural elements with existing crack. However, little attention is given to the fatigue resistance of non-damaged metallic members approaching the end of their fatigue life. This is particularly relevant for old metallic riveted bridges, where many critical components do not have existing cracks. This paper presents a numerical investigation on the fatigue behavior of non-cracked metallic plates bonded with CFRP using epoxy resin. Nonlinear finite element analyses are performed using the commercial software ABAQUS. The cyclic elasto-plastic behavior and the fatigue strain life of puddle iron metal are obtained from previous experimental results conducted on specimens extracted from Luiz I Bridge (Porto, Portugal). Debonding failure of the adhesive joint is simulated through the use of cohesive zone model with traction separation law. The cohesive behavior was calibrated using fracture mechanic tests results on the adhesive, conducted in a previous related study. The fatigue crack initiation life was estimated using local approach based on material fatigue strain life. Fatigue resistance curves that relate the number of cycles to failure and the applied nominal stress for unreinforced and reinforced elements are derived. The results show that the application of CFRP can significantly increase the fatigue crack initiation life of a metallic structural component significantly.

, Comparison between brittle and ductile adhesives in steel/CFRP joints

Anis Mohabeddine[1], Ghassan Malik[2], José Correia1[1,3], Nciholas Fantuzzi[2], Abilio de Jesus[3], José Miguel Castro[1], Filippo Berto[4]

[1]Construct, Department of Civil Engineering, Faculty of Engineering University of Porto, Portugal.

[2]Department of Civil Engineering, University of Bologna, Portugal.

[3]INEGI, Department of Mechanical Engineering, Faculty of Engineering University of Porto, Portugal.

[4] Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology (NTNU), Norway.

CFRP/steel Adhesive joint Brittle and ductile adhesives Bi-adhesive joints

Abstract The use of CFRP/steel adhesively bonded joints is well is established to repair fatigue cracked metallic lightweight structural elements in aerospace industry for more than three decades. Despite some few exceptions, this technology has yet not been exploited for streel construction industry where there is a great need to rehabilitate metallic bridges. For instance, in Europe more than 30% of the railway bridge stock operated for more than 100 years. These bridges are made of old mild steel or puddle iron that exhibit poor behavior due to the quality of the material itself and degradation caused by the long-term loading or environmental effects. The application of CFRP is very common to repair concrete structures. To extend this technology to steel structures, several satisfactory research results have been reported in the literature. However, this result has not been successful enough to convince industry parties such as practicians and bridge owners. The modest results obtained maybe due to the type of adhesive used. In fact, most of previous studies related to steel/CFRP adhesive joints utilized brittle adhesives commonly applied for concrete structures. Recent ductile adhesives made for the automotive industry especially developed for metallic joints should be more appropriate. In this study, an experimental investigation on the behavior of CFRP/steel adhesively bonded joints is presented. A comparison between brittle adhesives and ductile adhesive is conducted. The results show that the ductile adhesive achieve much higher performance than the brittle ones. The brittle adhesives provides more stiffness to the adhesive joint. But the maximum strength of the adhesive joint with ductile adhesives can be the double of brittle ones. In the specimens with the ductile adhesives, the failure pattern started by yielding of the steel bars first than the adhesive joint. These results are very promising since it can facilitate the design procedure significantly, the steel yielding can be used as design criterion. The main disadvantage of the ductile adhesives is they are usually much more expensive than brittle ones. In order to solve this issue, bi-adhesive joints, which the joint is mainly made of brittle adhesive and ductile adhesive in stress concentration region, are proposed. The results revealed very high improvement up to the yielding strength of the steel bars and with a balanced stiffness.

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Application of Sandwich Panels in Steel Structures

Aditya Vidwans[1], José A.F.O. Correia[1,2]

[1] Department of Civil Engineering and Geosciences, Delft University of Technology, Netherlands. aditya.vidwans94@gmail.com

[2]INEGI & CONSTRUCT, Faculty of Engineering, University of Porto, Portugal.

Sandwich panel *Lightweight structure* *Extra high strength steel*

Abstract In steel structures, a lot of attention is paid to lightweight structures, i.e. reduction of dead load without compromising structural safety, integrity, and performance as well as cost-effectiveness. Thanks to modern steel aluminium foam sandwich panel manufacturing technology a new possibility became available for lightweight structural design. The most simple type of sandwich panel consists of two strong, stiff, thin plates/sheets of highly dense material separated by a thick layer of low-density material that can be much less strong and stiff. The objective of this study is to evaluate the application of sandwich panels in the construction of steel structures with the aim of weight reduction without affecting other parameters like safety, performance, cost, etc. In this study, both column and plate buckling theories are considered and applied to the sandwich panel to evaluate its behaviour under in-plane compressive load. Effects of various material models and imperfections on buckling strength of sandwich panel are evaluated. Material models used in this study for steel are bilinear material mode. For aluminium foam, bilinear material model with no strain hardening is considered. Both local and global imperfections, modelled by ANSYS software, are considered in this study. In this study, stiffened plate and sandwich panel are compared in terms of buckling resistance and self-weight.

Three different sandwich panels made from faceplates of steel grade, S355, S690 & S1100, are used for the replacement of the S355 stiffened plate. Efforts were made to understand the effect of various physical parameters on buckling resistance of sandwich panel in both column and plate buckling theories. Finally, as a case study, sandwich panel technology is used to redesign the Huisman structure. The objective is to investigate whether applying sandwich panels in redesign makes it possible to obtain a sufficient weight reduction without losing its performance. For this case study, sandwich panels with faceplates of steel grade S355, S690, and S1100 are used. The static and buckling strength of the new design is evaluated. Also, the cost of the new design and original design is evaluated, and results are compared. Cost analysis is done to evaluate whether a sandwich panel is an economical solution.

The findings of this study are that in the future it is possible to use sandwich panels in steel structures to save a significant amount of weight while taking considerations into account. Sandwich panels can be successfully used to replace stiffened plates. Sandwich panels with faceplates made from extra high strength steel can give significant weight reduction. But the use of sandwich panels also increases the overall cost of the structure. So, in terms of costs, it is questioned whether or not using sandwich panels is economically beneficial.

, **Effects of normalizing heat treatment on the mechanical and magnetic properties of an ancient iron bridge**

Lucas Benini[1], Iara Oliveira[2], Juan Pardal[2], Leosdan Noris[2], José Correia[3], Filippo Berto[4]

[1]*Department of Mechanical Engineering – PGMEC, Fluminense Federal University, Niterói – Brazil. lucasbenini@id.uff.br*

[2]*Department of Mechanical Engineering – PGMEC, Fluminense Federal University, Niterói – Brazil.*

[3]*INEGI & Construct, University of Porto, Portugal.*

[4] *Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology (NTNU), Norway.*

Ancient material *Magnetic Barkhausen Noise* *Microstructure degradation*

Abstract The object of interest of this paper are parts of an ancient iron bridge with over 150 years of operating. The material identified as puddle iron, is known to suffer a microstructural degradation process during time, changing its mechanical properties. In order to evaluate the impact of degradation, it is suggested in literature to accept the normalizing heat treatment on puddle iron as a way to obtain similar properties to when it was manufactured. In this research work, microstructure analyses, hardness and impact tests were carried out prior and after the normalizing heat treatment. The microstructural characteristics were compared between the as received and normalized state, revealing a bigger grain size on the second. Both hardness and tenacity values suffered a slight decrease. Finally, measurements of Magnetic Barkhausen Noise (MBN) were carried out on both states, confirming the previous results, and allowing the distinction of an easy magnetization axis aligned with the conformation direction of the evaluated components. Hysteresis loops obtained with variable magnetic field and fixed minimum and maximum values also denoted differences in the behavior between the as received and thermally treated conditions. Therefore, a great potential is exhibited in the non-destructive characterization of this class of material, although several standards are needed to obtain a calibration curve with the evaluated properties.

A review of fatigue damage in offshore wind turbine structures

Danial Haselibozchaloee[1], José A.F.O. Correia[1,2], Paulo Mendes[2], Miguel Correia[3], Abílio M.P. Jesus[2], Filippo Berto[4]

[1]*CONSTRUCT, Faculty of Engineering, University of Porto, Portugal.*
up201911748@edu.fe.up.pt

[2]*INEGI, Faculty of Engineering, University of Porto, Portugal.*

[3] *Department of Advanced Engineering, FORCE Technology Norway AS, Norway.*

[4] *Department of Mechanical and Industrial Engineering, Norwegian University of Science and Technology (NTNU), Norway.*

Fatigue *Offshore wind turbines* *Support structures*

Abstract Renewable energy is of outstanding importance to many countries, and the desire to use this type of energy has been increasing in the world. The wind turbine is one of the tools to provide zero carbon energy. Onshore and offshore wind turbines are employed throughout the world in various sites where subjected to higher wind speed. However, in comparison of onshore wind turbines, offshore wind turbines (OWTs) have a main superiority that is naturally the higher wind speed in the sea or ocean. Since OWTs are subjected to cyclic loadings such as waves and winds, exciting fatigue damage is inevitable in these engineering structures. In a seawater environment, some factors accelerate fatigue damage, which is named corrosion, temperature, marine growing, etc. There are two main and classical approaches S-N curve and Fracture Mechanics which are recommended by numerous codes. However, as the major time of fatigue life is allocated for creating crack initiation, the investigation of exciting and growing micro cracks for varied materials is necessary. It can be surveyed by the multiaxial fatigue approach. Various criteria are employed for approximation multiaxial fatigue lifetime and numerous methods are recommended for quantifying the fatigue damage based on the Palmgren-Miner rule. The proportionality and non-proportionality of loadings particularly influence the results of multiaxial fatigue prediction. However, diversity in material and the criteria which are employed are not sufficient to determine the precise theoretical procedure for multiaxial fatigue life prediction. Thus, this procedure needs to be developed for dissimilar materials in offshore industry.

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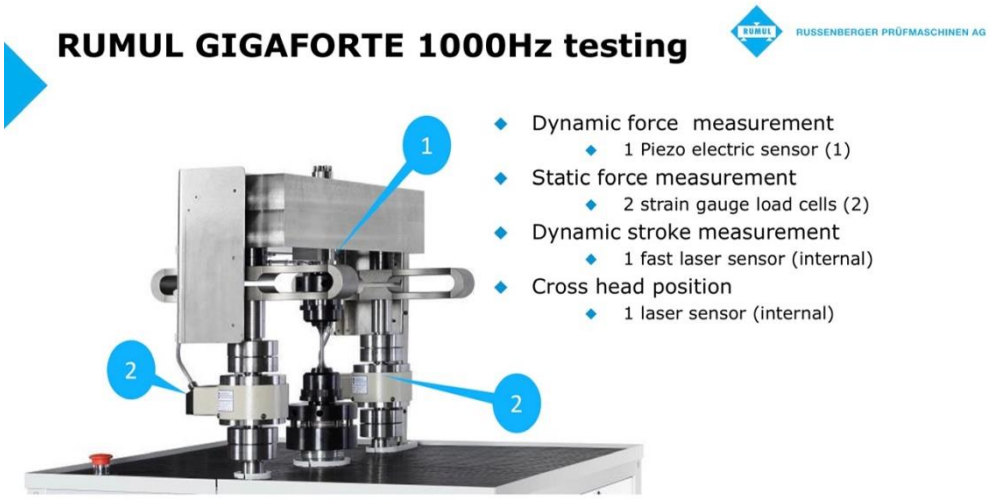
Fatigue Testing at 1000Hz Testing Frequency

Markus Berchtold
RUMUL Russenberger Prüfmaschinen AG Switzerland
mberchtold@rumul.ch

New Resonant Fatigue Testing Machine *Giga cycle (VHCF)* *Frequency effects*

ABSTRACT

There is no infinite fatigue life. In the recent decades we learned that fatigue testing with higher number of load cycles is required in some areas. The development of faster testing techniques e.g. Ultrasonic systems testing on 20kHz have allowed the conduction of many research activities in the giga cycle regime in the recent decades. In 2014 RUMUL could present a new resonant fatigue testing machine, with a testing frequency of 1000Hz. The dynamic load of maximum 50kN peak-peak is produced with an electromagnetic system. The static portion of the load is provided by two mechanical spindles, the maximum load of the system is +/- 50kN. Any load ratio can be selected. Flat and round specimen types that are normally used in fatigue testing can be used. The actually tested material volume is larger than the material volume that is tested on ultrasonic systems. The new testing machine offers new possibilities for investigations of material properties in the very high cycle fatigue (VHCF) regime.
In the past years the new testing machine was intensively used in several laboratories in Germany for example at the laboratory of the Fraunhofer institute IWS Dresden in Germany. Some effects of the 1000Hz testing frequency on the fatigue behavior of the material have been observed. This paper provides a summary how the frequency of an alternating load affects fatigue life of a material. And it highlights some of the found frequency related effects on fatigue strength. Some examples of heating up of the specimen related to the 1000Hz testing frequency are shown. Normally continuous fatigue testing is possible, without stopping for cooling down the specimen.



measurement equipment (e.g. cameras, pyrometer, …) or an induction heating system can be installed on the decoupled table

, An Automatic System for Residual Stress Measurements by Hole Drilling

Alessio Benincasa[1], Emilio Valentini[1], Simone Gulisano[1], Enrico Boccini[1]

[1]*SINT Technology srl, via delle Calandre 63, 50041, Calenzano, Firenze, Italy*

alessio.benincasa@sintechnology.com, emilio.valentini@sintechnology.com,

simone.gulisano@sintechnology.com, enrico.boccini@sintechnology.com

Residual stress measurement *Hole drilling method* *ASTM E837*

Abstract The life expectancy of a mechanical component is mainly determined by the interaction between defects in the part and the stresses to which it is subjected. These stresses are the result of stresses applied in service, compounded with those that develop in the object during all the machining and manufacturing processes. The residual stresses can add to operating loads, thus accelerating the growth rate of defects and leading, in some cases, to premature failure of parts, with very serious economic implications. Applied stresses are generally taken into account in design engineering, but residual stresses are often overlooked, being closely correlated with the material, the manufacturing processes and its heat treatment. The hole drilling method is the most effective approach to evaluate the residual stresses; this method has been standardized in ASTM as E837-20. MTS3000-Restan is the automatic system for the measurement of these stresses, by means of the hole drilling strain gauge method. With a suitable acquisition strategy and an appropriate analysis method, it is also possible to back-calculate the residual stress variation with depth even very close to the surface. The full control of the device during the drilling and the acquisition process guarantees high accuracy of the results and reduction of the measurement uncertainty connected with the measurements. The MTS3000-Restan system is a complete and customizable solution for any hole-drilling residual stress measurement: thanks to various configurations, it can be used in several testing conditions and with different materials.

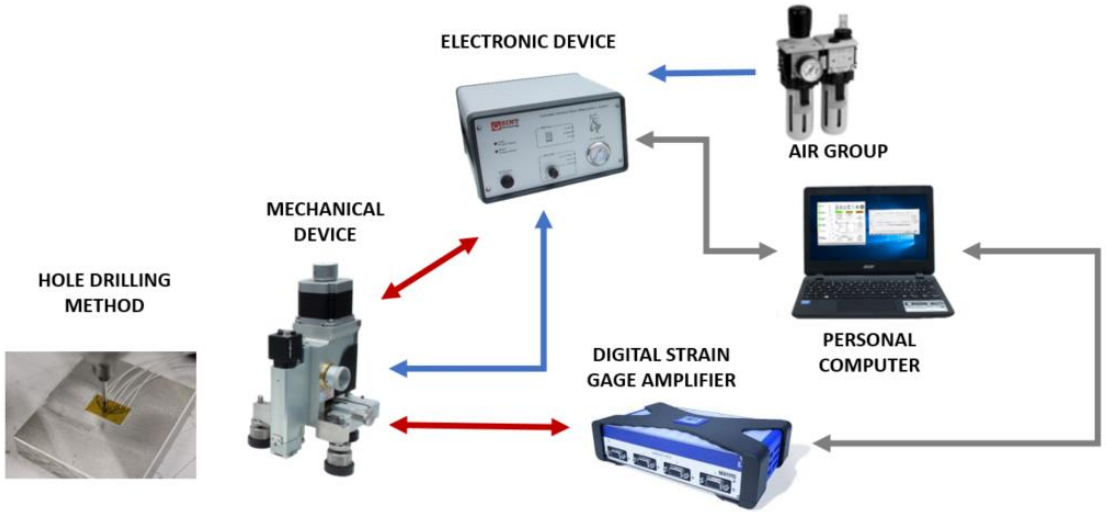


Figure 1 - *Automatic measurement chain for hole-drilling residual stress measurements*

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High-speed imaging options in material and component testing

Tim Nicholls[1]

[1]*Photron (Europe) Ltd., The Barn, Bottom Road, West Wycombe, Bucks, HP144BS, tnicholls@photron.com*

High-speed camera *Qualitative imaging* *Digital Image Correlation*

Abstract High-speed imaging has become commonplace in many mechanical engineering departments. Its ease of application to numerous test methods of varying scale both in terms of object area and speed yields image sequences that are both easy to interpret and discuss by engineers and lay persons alike; furthermore, with the introduction of digital image correlation (DIC), the application of a simple speckle pattern to a sample can output not just qualitative images but numerical values for full field deformation and strain. Of course, developments in high speed camera technology – most notably sensor specification and to some extent a reduction in the cost of "mid-range" performance cameras has driven the uptake of this hardware. This presentation will highlight some of these improvements along with other considerations such as illumination, triggering and data acquisition options.

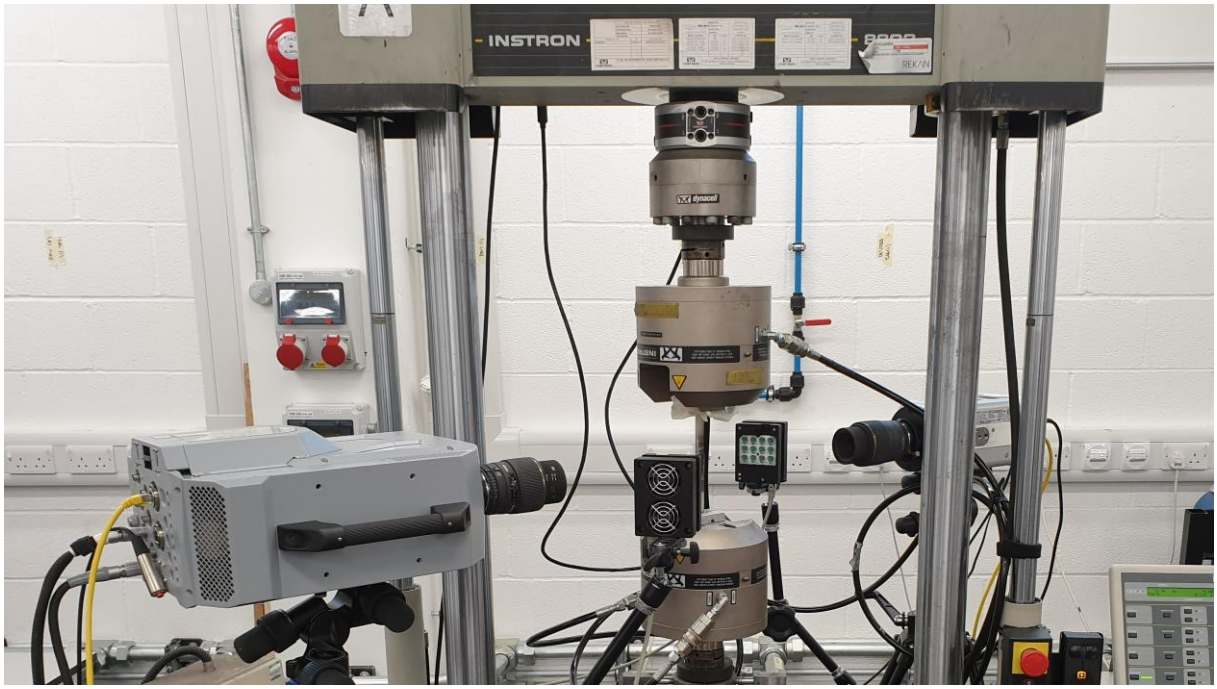

Figure 1 – *Typical application of high-speed imaging to a tensile test*

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Advanced Mechanical Surface Characterization

João Cascalheira

[1]*MT Brandão, Rua de Serralves 599 4150-708 Porto joao.cascalheira@mtbrandao.com*

Surface *Materials* *Characterization*

Abstract The third generation of Anton Paar's mechanical surface testers measure a wide range of mechanical properties of materials ranging from the hardest diamond-like carbon (DLC) coating to the softest hydrogel. The high-precision instruments measure what others estimate. Anton Paar covers four of the most important test methods for mechanical surface characterization. Instrumented indentation testers provide mechanical properties of thin films, coatings, or substrates such as hardness and elastic modulus, creep, fatigue, stress-strain, elastic and plastic energies. Scratch testers are used to characterize film-substrate systems and to quantify parameters such as adhesive strength and friction force for determining coating adhesion, scratch resistance, and mar resistance for research and quality control. With tribometers you can study friction, wear, lubrication, and abrasion. Additionally, abrasion testers like Calotest provide quick, simple, and inexpensive determination of coating thicknesses.

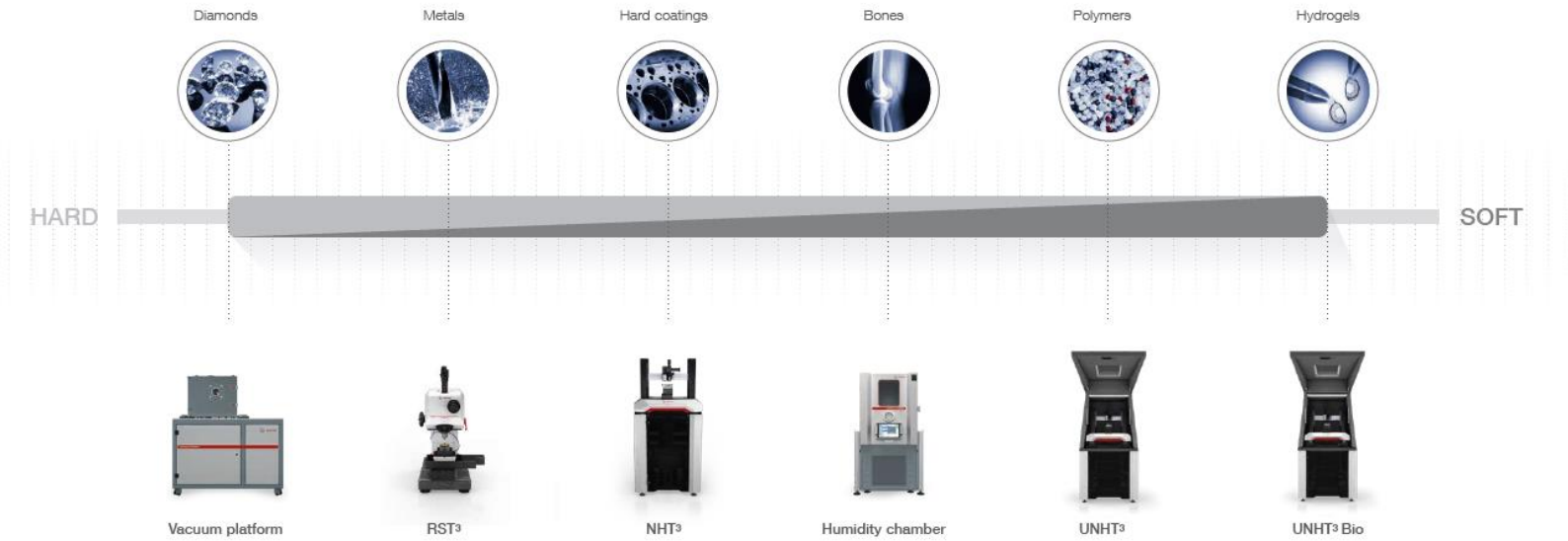

Figure 1 – Anton Paar Instruments for mechanical surface testers

Friction based spot joining method for thermoplastic based materials

Shayan Eslami[1], Pedro J. Sousa[1], Pedro M. G. P. Moreira[1]

[1]*INEGI, Institute of Science and Innovation in Mechanical Engineering and Industrial Engineering, Campus da FEUP, R. Dr. Roberto Frias 400, 4200-465 Porto, Portugal*

seslami@inegi.up.pt

Spot Welding *Joining method* *Composites*

Abstract Joining methods of lightweight materials, particularly polymers and thermoplastic based composites, are becoming progressively important in the manufacturing of lightweight structures for engineering applications. The available joining methods for thermoplastic based materials are usually limited to specific applications, configuration and materials. The advantages of friction based joining technologies led to development of a new technological path for joining thermoplastic based materials. In this study, an innovative spot joining concept was developed that benefits from the combination of Friction Stir Spot Welding (FSSW) and riveting techniques in a single process. Friction Stir Spot Riveting (FSSR) method combines two of the most reliable joining techniques, benefiting the advantages of both methods.

FSSR aims at developing a new joining technique by introducing a consumable probe made of thermoplastic composite material. The consumable rotating probe penetrates and feeds into the base material, generating frictional heat and stirring the plasticized material under an axial force. Simultaneously, the riveting effect is achieved by moulding the plasticized materials under the optimized axial force. The consumable probe material varies depending on the base materials to be joined. Short fibre thermoplastic or nanocomposite materials are ideal alternatives to reinforce the welded joints. This spot joining method attempts to eliminate the disadvantages of FSSW and riveting by merging into a single process, such as avoiding hole drilling process and keyhole formation. Using this method, dissimilar and identical short carbon fibre thermoplastic were welded successfully. The produced joints showed a promising result as it stirs the base materials with the rotating filler probe, and the rivets on the two sides create a secondary bonding condition, which enhanced the joint efficiency. A new welding tool with adaptive parameter control and sensory feedback is under development to ensure a defect free process.

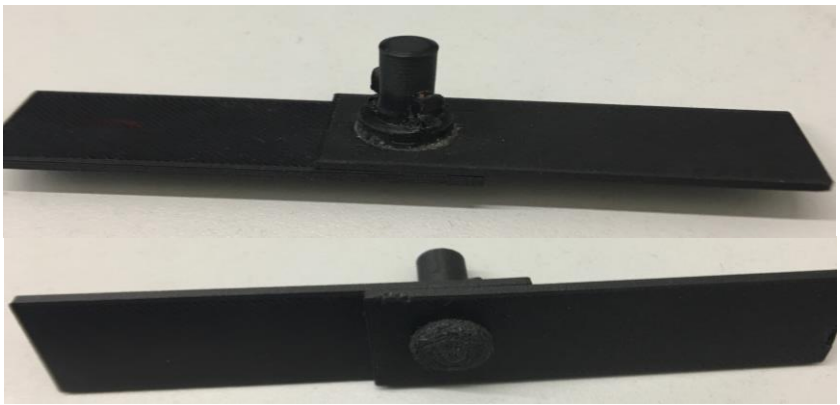

Figure 1 – *FSSR specimen for joining 30% short glass fibre composite*

, **Effect of Voids Shape on Deformation of 3D Printed Closed-Cell Porous Structures**

Mikhail Tashkinov[1], Yulia Pirogova[1]

[1] *Perm National Research Polytechnic University, Komsomolsky Ave., 29, Perm, Russia, m.tashkinov@pstu.ru*

Morphology *Statistical measures* *3D printing*

Abstract The large class of materials used in modern industrial and technological applications can be considered as heterogeneous at certain scale levels. For successful investigation of mechanical behavior of heterogeneous materials with tailored characteristics, it is necessary to take into account complex interactions of internal microscale constituents. In most heterogeneous material systems microstructure embodies some degree of randomness (e.g., grain size distribution in crystals or particle dispersion in composites). Due to that, it is obvious that its formal characterization can generally be performed as a model of a random system (or a stochastic process). This means that microstructural images corresponding to this material system can be considered as independent realizations of some random field. Such description of the microstructure allows to go beyond the point where empirical data is available and to find implementations of the structure that lead to certain predetermined properties.

The aim of this work is to investigate the influence of the shape of voids in porous 3D printed closed-cell porous structures on their elastic properties and mechanical behavior using comparative analysis of the results of morphological analysis of microstructure based on multipoint statistical characterization, finite element modelling and experimental data. The geometrical models of representative volume elements (RVEs) for structures with non-overlapping inclusions of different shapes and parameters were created and produced using FDM/FFF 3D printing technology. Evaluation of various morphological parameters has been performed based on the analysis of multipoint statistical characteristics. The elastic behavior and properties of the studied RVEs were modelled using finite element analysis. Some experimental results were obtained during compression testing of samples with the digital image correlation technique. The relationship between mechanical properties and statistical characteristics has been analyzed.

Structure Integrity and Fracture Prediction of PLA 3D-Printed Eye Grab Hooks with Different Cross Sections

Mohammed Zwawi[1]

[1] *Mechanical Engineering Department, Faculty of Engineering, King Abdulaziz University, Saudi Arabia*
mzwawi@kau.edu.sa

3D printing *Modelling* *Fracture*

Abstract This research studied various eye grab hook models with different cross sections that were made using a fused deposition modelling (FDM) technique with polylactic acid (PLA) material and fixed printing parameters. The study aimed to analyse the mechanical strength and integrity performance, fracture behaviour of five different eye grab hook models. The eye grab hook models were tested under tensile loading until failure with a 2mm/min displacement rate. The scope of the study was to validate the finite element analysis (FEA) results with the experimental results in terms of load capacity, strain behaviour, maximum displacement, and crack initiation points. The load capacity of all eye grab hook models ranged from 1.5 kN to 2.6 kN, and the strain varied from 3.2% to 4.4%. The maximum displacement results of all eye grab hook models in the FEA and in the experiment were very close. Similarly, the FEA well predicted the fraction initiation point as in the experimental results. The study concluded with a failure analysis for each eye grab hook model and presented the best performance of different models that can be 3D-printed with less material and, therefore, reduced time and cost.