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Technical Program

August 3rd, 2023 version

Tuesday, 29 August 2023

Tue, 09:00 - 09:30	OPENING SESSION	Room Sunset
Welcome to Participants **(Conference Co-Chairs)** Welcome Address **Representative of the University of Madeira**		

Tue, 09:30 - 10:15	PLENARY LECTURE I	Room Sunset
Fundamental insights into the hydrogen embrittlement of pipelines in high-pressure gaseous environments **Frank Cheng** University of Calgary, Canada Chair: Pedro Moreira		

Tuesday, 10:15 - 10:50	**COFFEE-BREAK**	**Lounge**

Tue	Session 1A 10:50-12:40	Room Sunset
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#152	Theoretical investigations and QM modelling of hydrogen-based materials Dejan Zagorac, Jelena Zagorac, Milos B. Djukic, Tamara Škundrić, Milan Pejić, Burak Bal, Christian J. Schön	
#019	Phase-field modelling of environmentally induced damage S. Kovacevic, M. Makuch, E. Martinez-Paneda	
#095	First-principles study on the hydrogen absorption energy in Fe-Cr-Ni austenitic systems: Effect of Cr and Ni content Junichiro Moriyama, Osamu Takakuwa, Masatake Yamaguchi, Yuhei Ogawa, Kaneaki Tsuzaki	
#008	Modelling fatigue life and hydrogen embrittlement of bcc steel with unified mechanics theory Hsiao Wei Lee, Milos B. Djukic, Cemal Basaran	

Tue	Session 1B 10:50-12:40	Room Lagoon I
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#046	Fatigue crack growth rate at the interface of steel and structural adhesive in DCB specimens with thick bondline Rahul Iyer Kumar, Wim De Waele	
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#057	Study of Fatigue Crack Propagation in Modified CT Specimens using Artificial Neural Networks B. Santos, T. Barros, V. Infante, R. Baptista	
#063	Fatigue crack closure of nuclear steels: effect of load ratios Théotime Asselin, Gilbert Hénaff, Olivier Ancelet, Guillaume Benoit, Florence Hamon	
#201	Probabilistic Fatigue Resistance Curves for Structural Steel Based on Dislocation Density António M. Mourão, Iara G. Oliveira, J.A.F.O. Correia, Túlio Bittencourt, Rui Calçada	
#183	The Effect of Strain-Rate on the Mechanical Performance of DDED and Hybrid DED, SLM Daniel F.O. Braga, Lucas Azevedo, G. Cipriano, Miguel O. Gomes, Pedro J. Sousa, Pedro M.G.P. Moreira	

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#166	Investigation of full-field material properties of welded joint using DIC Koščo, T., Chmelko, V.	
#171	Experimental characterization of inflation mechanical properties of aortic wall Hugo Mesquita, Rodrigo Valente, Daniela Azevedo, Francisco Queirós de Melo, Pedro Sousa, Tiago Domingues, Paulo Tavares, José Xavier, Pedro Moreira	
#172	Experimental monitoring of falling metallic shelter during seismic simulation Francisco Afonso, Pedro Sousa, Nuno V. Ramos, Alexandre Brás Santos, Paulo Tavares, Pedro Moreira, Sajjad Hosseini, João Gomes Ferreira	
#174	Development of a photogrammetric system for railway retaining walls analysis Francisco Afonso, Pedro Sousa, Nuno Viriato, Francisco Barros, Paulo Tavares, Pedro Moreira	
#176	3D DIC deformation monitoring of rotor blades with moving cameras Pedro Sousa, Francisco Barros, Rodrigo Valente, Tiago Domingues, Paulo Tavares, Pedro Moreira	
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#076	Hydrogen embrittlement determination of L485MB pipeline steel and its heat affected zone via notched tensile tests Laura De Pue, R. Jubica, Lisa Claeys, Somsubhro Chaudhuri, Tom Depover, Wim De Waele, Kim Verbeken, Stijn Hertelé	
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Tuesday, 15:30 - 16:00	COFFEE-BREAK	Lounge

Tue	Session 3A 16:00-17:45	Room Sunset
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Ref:	Title and Author (s)	
#052	Hydrogen-accelerated/decelerated fatigue crack propagation in Ni-based superalloy 718 Osamu Takakuwa, Yuhei Ogawa	
#087	Effect of Nickel on the hydrogen embrittlement, diffusion, and trapping properties of ferritic-martensitic dual-phase low alloy steel in tempered condition Esteban Rodoni, Tom Depover, Kim Verbeken, Mariano Iannuzzi	
#079	Hydrogen interaction with an equiatomic CoCrFeMnNi high entropy alloy Lisa Claeys, Hauke Springer, Mohammadhossein Barati Rizi, Kim Verbeken, Tom Depover	
#075	Advances in Quantitative Hydrogen Embrittlement Assessment Joshua Jackson, Craig Tod, Milos B. Djukic, Bryan Fahimi	
#045	Hydrogen-assisted fatigue crack propagation in ferritic iron: An overview of macroscale behavior and microscale mechanisms Yuhei Ogawa, Osamu Takakuwa	
#089	A Comparison Study on Environmental Effects of Natural and Synthetic Fiber Reinforced Polymer Composite (NFRPC) for their Potential Application Dillip Kumar Bisoyi, Chinmayee Dash	

Tue	Session 3B 16:00-17:45	Room Lagoon I
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#054	Crack Detection and Crack Length Measurement in Round Specimen using Multiple Potential Drop Measurements Jürgen Bär	
#056	Application of Artificial Neural Networks to Aircraft Mission Classification T. Barros, L. Alexandre, V. Infante, P. Gamboa, A. Moura	
#023	On the use of full-field receptances in inverse vibro-acoustics for airborne structural dynamics Alessandro Zanarini	
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#153	Mechanical Characterization of an Asymmetric Sandwich Composite Composed by Stone and Cork João Marques, Virgínia Infante, Pedro Amaral	
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COCKTAIL RECEPTION VidaMar Hotel		

Wednesday, 30 August 2023

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Roadmaps to Sustainable Civil Engineering Infrastructure through Structural Health Monitoring **Su Taylor** Queen’s University Belfast, Northern Ireland Chair: Paulo Tavares		

Wednesday, 10:15 - 10:50	**COFFEE-BREAK**	**Lounge**

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#187	The HELP+HEDE model for hydrogen embrittlement in metals: New insights and experimental/modeling confirmations Milos B. Djukic, Jovana Perisic, Muhammad Wasim, Gordana Bakic, Aleksandar Sedmak, Bratislav Rajicic	
#149	Investigations of the hydrogen – defect interactions by Molecular Dynamics Mehmet Fazil Kapci, Burak Bal	
#124	A study of the effects of hydrogen on martensitic advanced high-strength steels Carlo Maria Belardini, Giuseppe Macoretta, Marco Beghini, Leonardo Bertini, Bernardo Disma Monelli, Renzo Valentini	
#088	Definition of a test-independent hydrogen embrittlement index for advanced high-strength steels Giuseppe Macoretta, Carlo Maria Belardini, Marco Beghini, Bernardo Disma Monelli, Renzo Valentini	
103	Hydrogen interactions with dislocations in relation to hydrogen embrittlement of metals V.G. Gavriljuk, V.M. Shyvaniuk, S.M. Teus	
#148	Effect of strain rate and hydrogen on the mechanical behaviors of Aluminium alloys Mehmet Furkan Baltacıoğlu Burak Bal	

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#120	Patient-Specific Wall Displacement Analysis: A Comparative Study of Fluid Structure Interaction, Computation Fluid Dynamic, and computation Solid Mechanics on Ascending Thoracic Aorta Aneurysm Rodrigo Valente, André Mourato, José Xavier, Moisés Brito, Stéphane Avril, António Tomás, José Fragata	
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Wednesday, 12:40 - 14:00	LUNCH	Restaurant

Wed	Session 5A 14:00-15:30	Room Sunset
TOPIC: Symposium N.TC21 Hydrogen embrittlement of metals: Problems and solutions Chair: Tom Depover, Masoud Moshtaghi, Margo Cauwels, Esteban Rodoni		
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#083	Application of TCD approach to fatigue life prediction of notched high strength steel specimens Kamila Kozáková, Jan Klusák, Stanislav Seitl	
#086	Modelling Ageing and Fatigue for Structural Integrity Calculations of Large-Scale Pressure Systems Fekete, Tamás	
#092	Very high cycle fatigue behavior of high strength steels subjected to high frequency loading Jan Klusák, Kamila Kozáková, Stanislav Seitl	
#064	Study of Relevance of Alloying Elements in Estimating Cyclic Yield Stress and Ramberg-Osgood Parameters of Steels Tea Marohnić, Ela Marković, Robert Basan	

Wed, 15:30 - 16:00	COFFEE-BREAK	Lounge

Wed	Session 6A 16:00-17:30	Room Sunset
TOPIC: Symposium N.TC21 Hydrogen embrittlement of metals: Problems and solutions Chair: Frank Cheng, Akihiko Fukunaga, Guillermo Álvarez, Tom Depover		
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#112	Hydrogen embrittlement in a 2205 duplex stainless steel plate: Influence of specimen orientation V. Arniella, J. Belzunce, C. Rodríguez	
#115	Hydrogen embrittlement resistance of additively manufactured SS316L: Effects of post-treatments and testing conditions G. Álvarez, Z. Harris, K. Wada, C. Rodríguez, E. Martínez-Pañeda	
#117	Hydrogen embrittlement of tempered S41500 martensitic stainless steel D. Harandizadeh Najafabadi, D. Thibault ,M. Brochu	
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#161	Ballistic Impact Detection via Physics-Informed Machine Learning: A Methodology Integrating Neural Networks with Reduced Order Model Updating Vasiliki Panagiotopoulou, Claudio Sbarufatti, Marco Giglio	
#060	Self-sensing metallic material based on piezoelectric ceramic microparticles envisaging structural health monitoring applications Pedro M. Ferreira, Miguel A. Machado, Marta S. Carvalho, Catarina Vidal	
#162	SAMAS 2: Structural Health and Ballistic Impact Monitoring and Prognosis on a Military Helicopter Vasiliki Panagiotopoulou, Claudio Sbarufatti, Marco Giglio	
#178	Predictive Analysis of Structural Damage in Underwater Structures: A Case Study Approach using Neural Networks Alexandre Santos, Tiago Domingues, Hugo Mesquita, Rogério Lopes, Marco Parente, Pedro Moreira	
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Ref:	Title and Author (s)	
#102	Energy field intensity-based approach for notch fatigue analysis of 7050-T6 aluminium alloy under multiaxial loading R. Branco, J.D. Costa, L.P. Borrego, F. Berto	
#128	An analysis of notch sensitivity in the VHCF fatigue regime of S690 steel Rita Dantas, Michael Gouveia, Filipe G. A. Silva, Felipe Fiorentin, Abílio de Jesus, José A. F. O. Correia, Grzegorz Lesiuk	
#150	Numerical simulation of the processes of cyclic loading of samples made using additive manufacturing technology Mullakhmetov Maksim N., Ilinykh Artem V., Pankov Alexandr M., Lykova Anastasiya V., Permyakov Gleb L.	
#167	Data-driven spectral damage estimator for non-stationary vibration loading Arvid Trapp, David Fräulin, Marcin Hinz, Peter Wolfsteiner	
#186	Tension/Torsion UFT for Different Axial/Shear Stress Ratios Luis Reis, Henrique Lopes, Pedro Costa, Manuel Freitas	
#135	Fatigue behaviour and numerical assessment of welded EN AW 7020 tube joints under multiaxial loading Jenny Köckritz, Thomas Fürstner, Robert Szlosarek, Matthias Kröger	

Thursday, 31 August 2023

Thu, 09:30 - 10:05	PLENARY LECTURE III	Room Sunset
Promoting multiscale fatigue to design reliable and sustainable structures **José Correia** University of Porto, Portugal Chair: Grzegorz Lesiuk		

Thu, 10:05 - 10:40	PLENARY LECTURE IV	Room Sunset
Advanced materials under extreme conditions: Structure prediction, structure-property relationship and mechanical properties **Dejan Zagorac** Institute of Nuclear Sciences "Vinča", University of Belgrade, Serbia Chair: Milos Djukic		

Thursday, 10:40 - 11:10	**COFFEE-BREAK**	**Lounge**

Thu	Session 7A 11:10-12:40	Room Sunset
TOPIC: Symposium N.TC21 Hydrogen embrittlement of metals: Problems and solutions Chair: Lisa Claeys, Liese Vandewalle, Birhan Sefer, Masoud Moshtaghi, Milos B. Djukic		
#029	Characteristics of local plasticity and boundary character in hydrogen-assisted intergranular and intergranular-like fracture paths M. Koyama, T. Chen, T. Chiba, K. Takai	
#050	Damage evolution investigation of two hydrogen-charged pipeline steels using X-ray micro-CT Robin Depraetere, Wim De Waele, Margo Cauwels, Tom Depover, Kim Verbeken, Stijn Hertelé	
#106	Comparative study of hydrogen uptake in low alloyed carbon and austenitic stainless steels under cathodic hydrogen charging in aqueous electrolyte and gaseous hydrogen charging Daria Pałgan, Markus Uhlirsch, Nuria Fuertes, Birhan Sefer	
#053	Study of hydrogen trapping at carbides after gaseous charging at elevated temperatures and its impact on mechanical properties Liese Vandewalle, Tom Depover, Kim Verbeken	
#049	Hydrogen trapping at micro/nano-sized secondary hardening precipitates Stefanie Pichler, Gregor Mori, Mahdieh Safyari, Masoud Moshtaghi	
#066	Fatigue fracture in advanced ultrahigh-strength steels tested under gaseous hydrogen charging Supriya Nandy, Sakari Pallaspuro, Pekka Moilanen, Renata Latypova, Janne Pakarinen, Jukka Kömi, Elina Huttunen-Saarivirta	

Thu	Session 7B 11:10-12:40	Room Lagoon I
TOPIC: Symposium D. SHM and Damage identification – prediction of structural response Chair: Andrzej Katunin, Hernani Lopes and Jürgen Bär		
Ref:	Title and Author (s)	
#090	Experimental investigation of modulation transfer technique for damage detection of structures Andrzej Klepka, Jakub Górski, Kajetan Dziedziecch	
#134	The thermal influence on the material durability of additive manufactured glass fibre reinforced polymer with embedded fiber Bragg grating sensor Magdalena Mieloszyk, Ruta Rimasauskiene, Marius Rimasauskas, Anita Orłowska	
#145	On the identifiability of sheet metal anisotropic plasticity constitutive parameters using the Arcan test and full-field measurements J. Henriques, A. Andrade-Campos, J. Xavier	
#184	Savitzky-Golay Smoothing and Differentiation Filters for Damage Identification in Plates J. V. Araújo dos Santos, H. Lopes	
#073	Advanced Acoustic Emission Signal Processing Techniques for Structural Health Monitoring Claudia Barile, Giovanni Pappalettera, Vimalathithan Paramsamy Kannan, Caterina Casavola	
#125	Residual mechanical properties and damage accumulation of fiberglass pipes during proportional multiaxial cyclic tests Artur Kuchukov, Artur Mugatarov, Oleg Staroverov, Elena Strungar, Ekaterina Chebotareva	

Thu	Session 7C 11:10-12:40	Room Lagoon II
TOPIC: Symposium E. Structural Integrity of steel/FRP & concrete composite structures Chair: Xin Haohui, Jose Correia, Jun He, Rong Liu and Zhihua Xiong		
Ref:	Title and Author (s)	
#099	Effect of polymer shot addition on mechanical and physical properties of cement composite mortar Marcin Małek, Waldemar Łasica, Michał Gregorczyk, Emil Kardaszuk	
#035	Investigation of the hybrid beam behaviour during three-point bending test Jaroslav Václavík, Jan Chvojan	
#036	Damage analysis of the prestressing strand-wires from a 40 years old urban viaduct Maricely de Abreu, Mihaela Iordachescu, Andrés Valiente	
#175	Experiments for a Reliability-Based Fatigue Analysis Applied in Leaf Spring Suspensions of Freight Wagons V.M.G. Gomes, N.M.P. Pinto, P.A Montenegro, J.A.F.O Correia, R. Calçada, A.M.P de Jesus	
#096	Effect of CFRP Wraps on the Compressive Strength of Normal and Structural Lightweight Concrete Rami A. Hawileh, Hind Alharmoodi, Abdallah Hajjaj, Abdulaziz Aljarwan, Jamal Abdalla	
#202	Investigating the use of CFRP retrofitting techniques to extend the lifespan of existing metallic railway bridges João Arrojado, Anis Mohabeddine, José A. F. O. Correia, Diogo Ribeiro, Anna Rakoczy	

Thursday, 12:40 - 14:00	LUNCH	Restaurant

Thu	Session 8A 14:00-15:30	Room Sunset
TOPIC: Symposium N.TC21 Hydrogen embrittlement of metals: Problems and solutions Chair: Tom Depover, Jun Song, Masoud Moshtaghi, Dejan Zagorac, Milos B. Djukic		
Ref:	Title and Author (s)	
#130	The critical expansion strain for the onset of structural integrity degradation due to high-temperature hydrogen attack of a carbon manganese steel R.J. Mostert, A van Zyl, C.C.E. Pretorius, V.M Mathoho	
#189	Effect of seawater corrosion on the mechanical behavior of S690 steel Ana Dantas, Rita Dantas, Gonçalo P. Cipriano, Abílio de Jesus, Grzegorz Lesiuk, Carlos Fonseca, Pedro Moreira, José A.F.O. Correia	
#195	The role of hydrogen in the corrosion-induced reduction of plane-stress fracture toughness and strain-induced intergranular cracking of AA2024 C.C.E. Pretorius, R.J. Mostert, C-M. Charalampidou, N.D. Alexopoulos	
	Round table with a panel discussion 14:45 - 15:30 h	

Thu	Session 8B 14:00-15:30	Room Lagoon I
TOPIC: Modelling Chair: Luís Borrego		
Ref:	Title and Author (s)	
#140	Multiscale modelling of mechanical behaviour of 3D printed continuous carbon fibre polymer composites under thermal loading Isyna Izzal Muna, Magdalena Mieloszyk	
#144	Kissing Bond and Interfacial Quality Detection in Adhesive Bonds Using Hsu-Nielsen Source and AE Sensors Callum Selfridge, Cameron Gerrie, Sean Gerrie, Anil Prathuru, Ghazi Droubi	
#160	Properties and applications of cold sprayed Ti-6Al-4V coatings in additive manufacturing Wojciech Żórawski, Medard Makrenek, Anna Góral, Dominika Soboń	
#071	Predicting pure and mixed mode plastic zones using finite elements and artificial neural networks analysis R. Baptista, V. Infante	
#182	Crashworthiness topology optimisation of a crash box to improve passive safety during a frontal impact Christian J.G. Silva, Rogério Lopes, Tiago Domingues, Marco Parente, Pedro Moreira	
#181	Exploring Structural Simulation Methods for Railway Systems: A Review Tiago Domingues, Job Silva, Alexandre Santos, Pedro Moreira	

Thu	Session 8C 14:00-15:30	Room Lagoon II
TOPIC: Symposium E. Structural Integrity of steel/FRP & concrete composite structures Chair: Xin Haohui, Jose Correia, Jun He, Rong Liu and Zhihua Xiong		
Ref:	Title and Author (s)	
#100	Ultimate Strength Evaluation of Woven Fiber Reinforced Polymer Composites Using Homogenization Theory Wang Dan, Xin Haohui, Gao Qinglin, Zhang Hengyu	
#190	Finite Element Modeling of Concrete Prisms Strengthened with NSM and EBR CFRP Laminate Systems Ahmed H. Selim, Shahed Alhomsi, Haider Hasan, Jamal A. Abdalla, Rami A. Hawileh	
#093	Performance of a polymeric coating material applied to a concrete structure affected by internal expansive chemical reactions João Custódio, Helena Silva, Maria Paula Rodrigues, Susana Cabral-Fonseca, António Bettencourt Ribeiro, Filipa Morais	
#191	Behaviour of normal and recycled aggregates beams strengthened with different types of externally bonded shear reinforcement Jamal A. Abdalla, Rami A. Hawileh, Maha Ass'ad, S. S. Ahmed, A. Omer, O. Abdulkadeer	
#097	Effect of increasing the number of anchors on the flexural performance of FRP-strengthened RC beams Rami A. Hawileh, Maha Assad, Jamal Abdalla	
#203	Probabilistic Fatigue Analysis of Riveted Bridge Connections: Evaluating the Effect of Fatigue Accumulation Rules João Nuno Silva, António Mourão, Cláudio Horas, J.A.F.O. Correia, Rui Calçada	

Thursday, 15:30 - 16:00	COFFEE-BREAK	Lounge

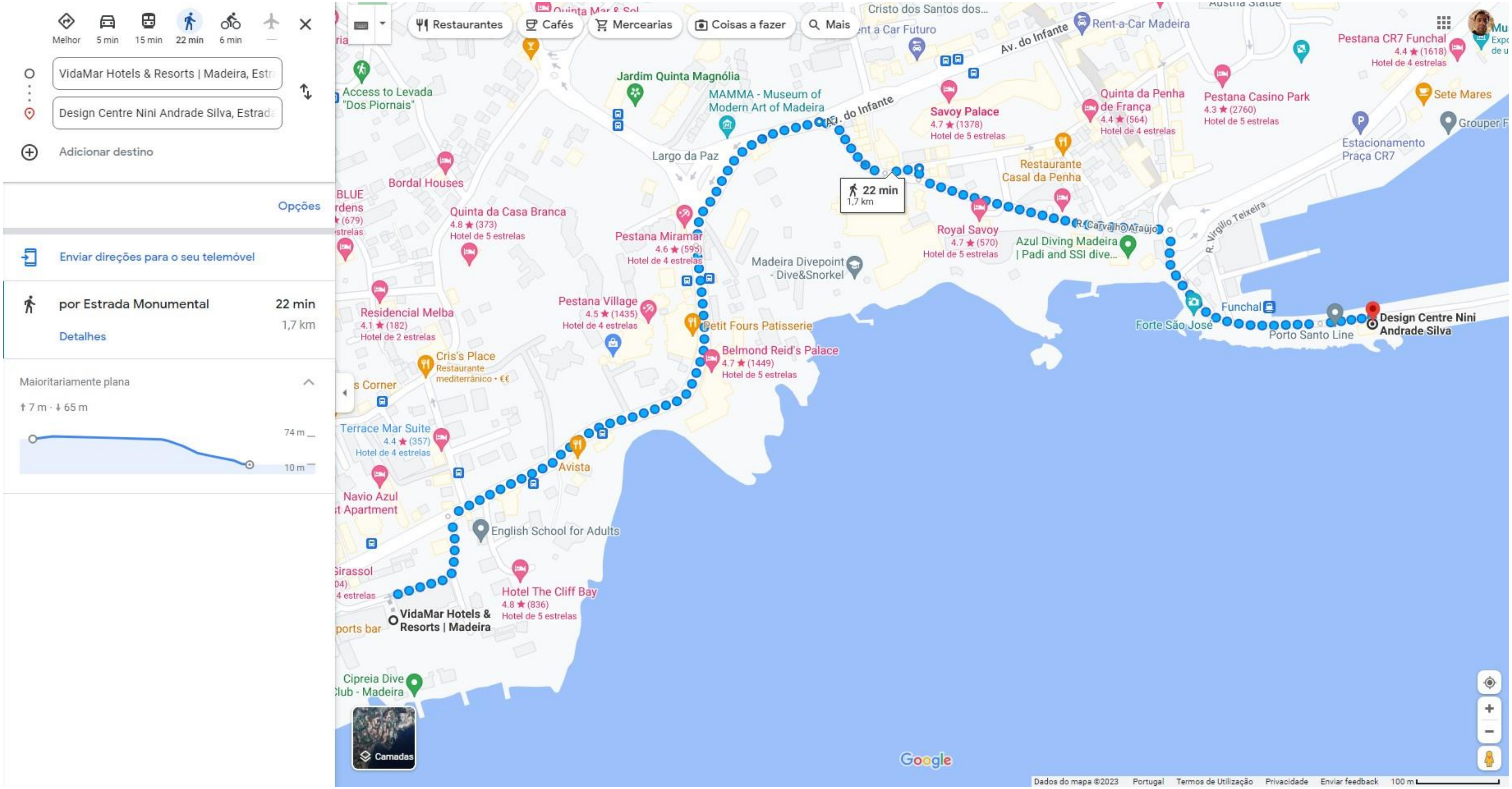
Thu	Session 9A 16:00-17:30	Room Sunset
TOPIC: Manufacturing Chair: Virginia Infante		
Ref:	Title and Author (s)	
#059	Joint Efficiency of Friction Stir Welded Additively Manufactured Thermoplastic Components Pedro Rendas, Lígia Figueiredo, Pedro Melo, Bruno Soares, Catarina Vidal	
#116	Microstructure and hardness properties of a s690ql Steel welded joint Paulo Mendes, Mário Monteiro, Rui Pedro Silva, José A.F.O Correia, Abílio de Jesus, Manuel Vieira, Tiago Pereira, Ana Reis	
#132	Application of the dual-adhesive technique for static improvement of single-step joints D.F.T. Carvalho, R.D.S.G. Campilho, L.D.C. Ramalho, R.D.F. Moreira, K. Madani	
#013	Experimental and numerical analysis of FSW process control effects on morphology and strength of dissimilar aluminum to polymer joints Arménio N. Correia, Ricardo Baptista, Daniel F.O. Braga, Virginia Infante	
#136	Influence of the rivet-die offset on the integrity of self-piercing-riveted joints J. Domitner, Z. Silvayeh, J. Stippich, P. Auer, N. Gubeljak, J. Predan	
#180	Optimization of 3D Printing Parameters for PEI Using Design of Experiments Rodrigo Praça, Tiago Domingues, Gonçalo Cipriano, Pedro Sousa, Pedro Moreira	
#199	Effect of post-production heat treatment on SLM-produced AlSi10Mg components tested at high strain rates G.P. Cipriano, G. Monteiro, D.F.O. Braga, H. Lopes, J. Jesus, L.P. Borrego, P.M.G. Moreira	

Thu	Session 9B 16:00-17:30	Room Lagoon I
TOPIC: Fracture and Fatigue Chair: Paulo Tavares		
Ref:	Title and Author (s)	
#101	Notch effect on the fatigue behaviour of AlSi10Mg aluminium alloy obtained by additive manufacturing R. Fernandes, L. Borrego, J.S. Jesus, J.A.M. Ferreira, J.D.M. Costa	
#188	The concept of the stress dead zones formulating the line spring model as an approach to the behaviour of a part through crack in an elastic plate Francisco Q. Melo, Vasco Amorim, Hugo Mesquita, Francisco Afonso, Paulo J. Tavares, Pedro G. Moreira.	
#007	Investigation of the fracture mechanical behavior of amorphous polymers considering crack tip heating Johannes Kaiser, Christian Bonten	
#039	Fracture toughness of polyurethane materials: experimental and numerical investigation on the size effect Daniela Scorza, Andrea Carpinteri, Liviu Marsavina, Camilla Ronchei, Sabrina Vantadori, Andrea Zanichelli	
#004	Bending fatigue of high-strength seven-wire monostrand Gang Shen, Harry Coules	
#197	Fatigue testing of fibre inforced composite material on 1000 Hz testing frequency Markus Berchtold	
#126	J-R curve evaluation using CMOD measured by Digital Image Correlation Aleksandar Sedmak, Blagoj Petrovski, Nenad Milosevic	

Thu	Session 9C 16:00-17:30	Room Lagoon II
TOPIC: Computational and Analytical Chair: Luís Reis		
Ref:	Title and Author (s)	
#041	Finite element analysis of unnotched and notched functionally graded steel specimens Ela Marković, Robert Basan, Jelena Srnec Novak, Andrej Žerovnik	
#021	Thermal analysis for testing underground battery location E.S. Gonçalves, J. Gonçalves, H. Rosse, J. Costa, L. Jorge, J.A. Gonçalves, J.P. Coelho, J.E. Ribeiro	
#164	Aerodynamic optimization of UAV Wojciech Skarka, Bartosz Rodak	
#020	Static analysis of a lamp post according to Eurocode EN-40 E.S. Gonçalves, J. Gonçalves, H. Rosse, J. Costa, L. Jorge, J.A. Gonçalves, J.P. Coelho, J.E. Ribeiro	
#156	Delamination of multilayered viscoelastic inhomogeneous beams under moving loading Victor Rizov	
#157	Longitudinal fracture of functionally graded beams with non-linear rheological behaviour Victor Rizov	

Thursday, 17:30 – 18:00	CLOSING SESSION	Room Sunset
	Conference Organizing Committee	

Thursday, 19:30 - 23:00	BANQUET	
CONFERENCE BANQUET *Design Centre Nini Andrade Silva, Funchal*		



Friday, 1 September 2023		
Friday, 09:00	Conference Tour	departure at the hotel
"Madeira Sight Seeing, Tour to Porto Moníz"		

EDITORIAL

Pedro Moreira, Paulo Tavares

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

pmoreira@inegi.up.pt; ptavares@inegi.up.pt

Since the virtual ICSI2021, two years ago, research activity in Structural Integrity has seen an exponential increase, spilling over a number of exciting areas in materials, methods and applications. For the most part, this has been fuelled by both the necessity of diversifying energy sources and the societal pressure to cope with climate change and the issues brought about by the required technological development. Research into metal (mis)behaviour in the presence of Hydrogen, to cite an example, which has long been an important topic in Structural Integrity, gradually came under the focus of a growing number of scientists due to its importance in Hydrogen storage. In testimony of the importance of this topic, nearly one fourth of all ICSI2023 accepted abstracts focus on Hydrogen Embrittlement related topics. Concomitantly, the experimental activity related to experimental validation in new simulation concepts and applications, and novel applications for validated simulation models which, for instance, enable sensor virtualization, together with disruptive sensing technologies from the realm of science fiction a mere couple of years ago, are paving the way for a revamped R&D arena, with implications in most Engineering fields.

From the very start, five editions ago, ICSI has focused 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 in the realm of Structural Integrity targeted by ICSI2023 include, but are not limited to Fracture and Fatigue, Stress Analysis, Damage Tolerance, Durability, Crack Closure, Joining Technologies, Nano mechanics and Nanomaterials, Ageing, Coatings Technology, Environmental Effects, Structural Health Monitoring, New materials, Surface Engineering, Integrity of biomechanics structures in and many other exciting research topics.

In 2023, the ICSI organization focused on inviting lecturers related to topics that dominate the contemporary status in Structural Integrity, such as Prof. Frank Cheng from the University of Calgary, working in the field of corrosion engineering and pipeline reliability, Prof. Su Taylor from Queen's University in Belfast, devoted to the development of structural health monitoring of sustainable infrastructure; Prof. José Correia from Porto University, fully engaged in Structural Integrity of energy infrastructure; Prof. César Azevedo well known for his contribution in structural failure and Prof. Zagorac, from Belgrade University, working in the field of material behaviour under extreme conditions. Similar to previous editions, ICSI2023 has been organized into a general track and a number of thematic symposia. Apart from Procedia Structural Integrity, a special issue from Engineering Failure Analysis will cover ICSI2023.

The response to the organization's efforts has been outstanding: Thirteen symposia were proposed; the number of abstract submissions was kept at a similar level to previous editions, around 200 approved for oral communication.

These are very challenging times for the organization of meaningful conferences, but the organizers strived to make this 5th Edition a memorable one, which will stimulate both young and well-known researchers in the field to contribute further to ICSI.

Conference Chairs,

Pedro M. G. P. Moreira
Paulo J. S. Tavares
INEGI – Institute of Science and Innovation in Mechanical and Industrial Engineering

Effect of Sensors Locations and Magnitudes of Dynamic Loads on Dynamical Properties in Structural Health Monitoring

Mohammad Shamim Miah*, Werner Lienhart

Institute of Engineering Geodesy and Measurement Systems (IGMS), Graz University of Technology (TU Graz), 8010 Graz, Austria

miah@tugraz.at

Sensors *Structural Health Monitoring* *Dynamic Excitations*

Abstract The monitoring of civil structures and infrastructures are gaining momentum due to the recent technological developments of the various sensors. Typically, almost all structures are vulnerable to dynamic loads which even add more challenges due to the variation of the input excitations amplitudes. Among available alternatives, accelerometers are widely used due to its performance and feasibility in the area of monitoring. After the selection of the sensor, it is a challenge to select and place those sensors in appropriate location (e.g., node must be avoided) to get the meaningful information for the structural health monitoring (SHM). To understand the aforementioned issues, herein, sensors (e.g. accelerometers) are placed on a laboratory setup on a steel bridge of 2m long. And various dynamic type loads have been employed to evaluate their effects experimentally. As for example, the estimated first resonant frequency from all sensors (e.g., locations 01-04) data was found about 5.4Hz under an abrupt impulse type loading condition (for the duration of 36-46 secs in Figure 1). However, the magnitudes in frequency spectrum plot differs quite a lot -46.33, -8.71, -5.79, and -5,01dB, respectively for the sensor locations 01-04. Further, it is observed that the magnitudes of the accelerations vary significantly for different sensor locations (01-04) such as 0.0108, 0.8137, 1.1347, and 1.1472 m/s^2. The measured data was recorded with a sampling frequency of 4.80kHz and all the analyses have been performed via MATLAB. The observed behavior shows the critical (e.g. resonant frequencies, damping) dynamical properties of the bridge can be changed significantly due to the magnitudes of the applied excitations. Further, in addition to the magnitudes or variation of the input excitations, the implemented sensors in different location of the bridge shows that the aforementioned critical parameters can also be altered.

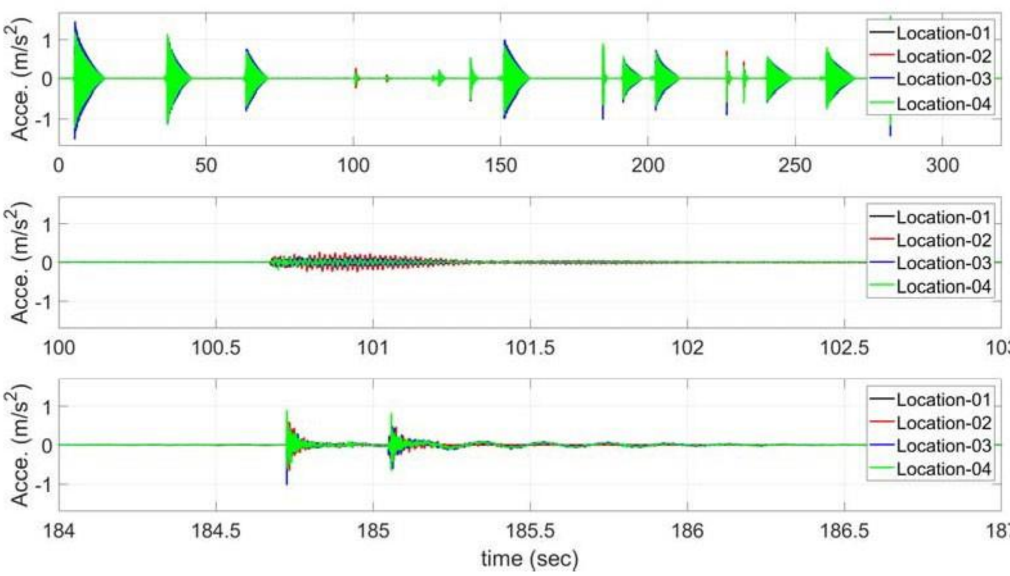


Figure 1 *– Sample measured time-history at different locations of tested bridge.*

Bending fatigue of high-strength seven-wire monostrand

Gang Shen; Harry Coules

Faculty of Engineering, University of Bristol, Queens Building, University Walk, Bristol BS8 1TR, United Kingdom.

harry.coules@bristol.ac.uk

Bending fatigue *Cable-stayed bridge* *Dynamic loading*

Abstract Modern cable-stayed bridges commonly use cable bundles containing polymer-sheathed seven-wire steel monostrand to suspend the bridge deck from one or more towers. Since a long length of monostrand has a high aspect ratio, and since the individual wires can slip axially relative to one another, the bending stiffness of monostrand in typical applications is relatively low. However, dynamic lateral movement of cables due to wind or traffic loading can cause significant cyclic bending stresses to occur, which introduces a risk of bending fatigue. Guide deviator structures are used resist bending ahead of the cable anchorages and prevent non-axial loads from being transmitted to them. As a result, cyclic bending stresses are greatest at the guide deviators and fatigue damage has been observed here.

The factors which affect bending fatigue of monostrand are not well understood, with most experimental studies on cable fatigue focusing on cyclic axial loading. In bending, fatigue crack initiation has been observed experimentally at the fretting contact between wires and at the extreme fibre in the monostrand cross-section which experiences the greatest cyclic bending stress. To identify controlling factors in cable bending fatigue, we performed large-scale experimental tests on seven-wire monostrand using a custom-build loading machine designed to apply simultaneous cyclic axial and bend loading.

Analysis of monostrand fatigue endurance and post-test examination of fatigue damage revealed that the bending fatigue life is strongly affected bending load amplitude, but also by axial tensioning and cyclic tension amplitude. Significantly, initial over-tensioning for a small number of cycles, as may occur during bridge construction, did not reduce the monostrand's subsequent fatigue life in the range investigated. This provides confidence that cable fatigue life is relatively tolerant to the construction technique used.

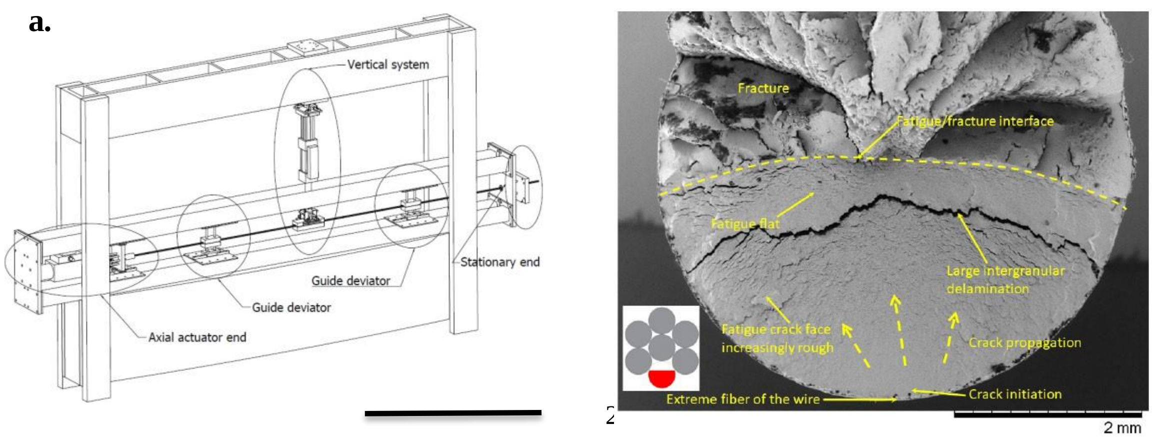


***Figure 1** - Fatigue testing of steel monostrand a.) Test setup for combined axial/bending fatigue, b.) Cross-section of failed wire, showing fatigue initiation from the extreme fibre.*

Understand the creep behavior of temperate species in 4-points bending test

Claude Feldman PAMBOU NZIENGUI[1,2], Chaima JAAFARI[3], Bernard ODOUNGA[1], Nicaise MANFOUMBI BOUSSOUGOU[1], Rostand MOUTOU PITTI[3], Sebastien DURIF[3], Joseph Gril[3]

[1]*Université des Sciences et Techniques de Masuku (USTM), Ecole Polytechnique de Masuku (EPM), URMM, Franceville BP 941, Gabon,* *pclaudefeldman@gmail.com*

[2]*Laboratoire de Recherche et de Valorisation du Matériau Bois (LaReVaBois), BP 3989, ENSET, Libreville, Gabon*

[3]*Université Clermont Auvergne (UCA), Clermont Auvergne INP, Institut Pascal, Clermont Ferrand F-63000, France*

Creep loading *European species* *Crack propagation* *Analytical model*

Abstract In structure, wood is faced to the effects of the loading intensity and environmental changes, which in some cases are at the origin of the ruin of this material. The present paper deals with the proposition of an analytical model of notched beams subjected to a long-term loading (4-points bending) test in outdoor conditions. The proposed model considers the impact of cracks propagations and the intensity of the load applied on the beam. The study is focused on the implementation of an analytical model of the notched beam compliance (J_N) based on the Timoshenko beam theory assumptions which considers the effects of shear. The analytical model proposed also considers the geometry of the beam tested and the environmental effects particularly moisture content (MC) variations in the beam. The validation of the analytical model shows satisfactory results based on the good fit between the experimental curves and the analytical curves. Figure 1 shows the typical beam loaded and considered for the implementation of the analytical model. The specimen is made to allow a linear crack propagation from the notch until its total collapse.

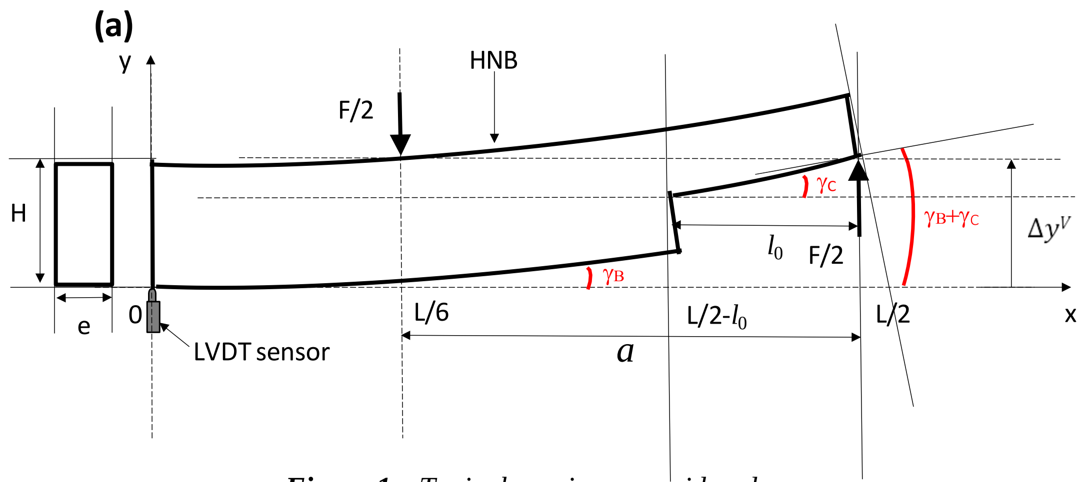


***Figure 1** – Typical specimen considered*

Analytical characterisation in Mode I fracture of adhesively bonded Double Cantilever Beam mixed glue joints

Cédric Horphé NDONG BIDZO[1,5], Claude Feldman PAMBOU NZIENGUI[2,3], Serge EKOMY ANGO[6], Samuel IKOGOU[2], Beat KAISER[5], Rostand MOUTOU PITTI[4,6]
ndonghorphe@gmail.com

[1]*Ecole Nationale des Eaux et Forêts, BP 3960 Libreville Gabon,*

[2]*Université des Sciences et Techniques de Masuku (EPM), URMM, BP 901 Franceville, Gabon,*

[3]*Laboratoire de Recherche et de Valorisation du Matériau Bois (LaReVaBois), BP 3989, ENSET, Libreville, Gabon*

[4]*Université Clermont Auvergne (UCA), Clermont Auvergne INP, Institut Pascal, Clermont Ferrand F-63000, France*

[5]*Ecowood SA, Z.I des Acaés BP 4016 Libreville, Gabon*

[6]*CENAREST, IRT, Libreville, Gabon*

Tropical species *Grid method* *Failures parameters*

Abstract This paper investigates cracking in opening mode 1 of tropical multi species Glued Laminated Timbers (GLT). The main objective of this study is to determine analytically the rate of energy restitution and to compare it with experimental values done in a previous study. Specimens are tested in Double Cantilever Bending (DCB), and crack is initiated on the glue joint to facilitate the delamination under a static loading. Mechanicals parameters were obtained using a full field measurement technique. Three tropical species, with different density, are chosen and glued by pair. The adhesive used is a Phenol Resorcinol Formaldehyde (PRF) associated with a hardener HRP-155. The Compliance-Based Beam Method (CBBM) theory was used for analytical method. An analytical model which considers the elastic and shear strain energy was proposed, the model can predict critical ERR of DCB joint system.

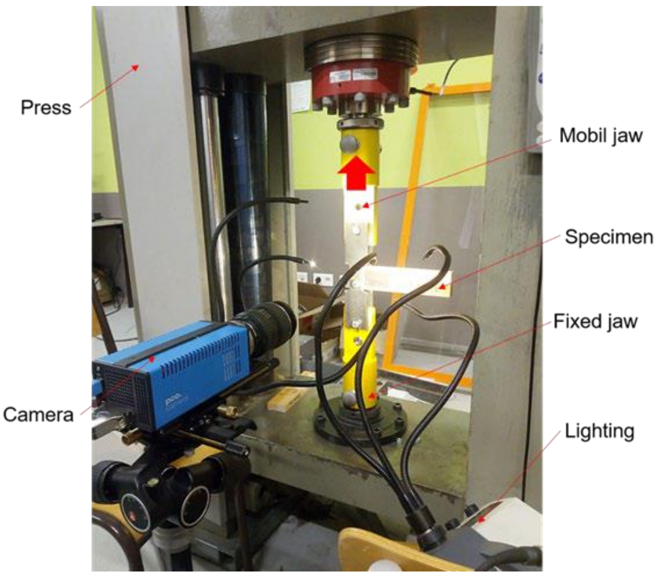


***Figure 1** – Experimental device*

Investigation of the fracture mechanical behavior of amorphous polymers considering crack tip heating

Johannes Kaiser, Christian Bonten
Johannes.Kaiser@ikt.uni-stuttgart.de

Institute of Plastics Engineering/University of Stuttgart, Germany, Pfaffenwaldring 32, 70569 Stuttgart

fracture initiation *crack tip heating* *thermography*

Abstract Due to the steadily growing use of plastics, also for technically demanding applications, the selection of materials and their design are becoming increasingly important in order to exploit the full potential of the material used. An important part of the plastic design is the consideration of the temperature, but the heat development of the component under mechanical load has hardly been taken into account till today. Standard mechanical methods are often unable to accurately describe molecular processes and the failure dynamics that can be derived from them. Fracture mechanics methods in combination with imaging techniques offer the possibility to investigate the local failure much more precisely and represent a useful supplement to the standard testing methods. The unforeseen changes in the individual plastic properties due to the increased internal temperature changes during crack formation and the local softening derived from this can thus be considered in much greater detail. Previous investigations show a high discrepancy of results due to the measurement technique used. These range from a few Kelvin temperature increase up to several hundred Kelvin, but did not allow an exact localization of the temperatures occurring. Thus, it has not yet been possible to clarify whether plastification at the crack tip inhibits or promotes crack growth.

In order to be able to investigate this question, a test setup was implemented that determines basic fracture mechanics parameters and, in combination with a high-resolution thermographic camera, can also provide temperature data with spatial and temporal resolution for each point on the so-called crack resistance curves. Three amorphous plastics were investigated in this study. These include a polystyrene and two polycarbonates with different chain lengths. The J-integral was used to describe the fracture mechanical properties. The J-integral describes the toughness of a material against crack growth. To determine the J-integral, a tensile load is applied to pre-notched test specimens. The crack growth is recorded using digital image correlation. Based on this crack length, the J-integral can be determined using the data from the tensile test. To ensure accurate temperature measurement at the crack tip, the thermographic camera used for the measurement must be calibrated.

In a first series of tests, the test setup was used to determine the temperature change at the crack tip for test speeds between 1 mm/min and 250 mm/min. Due to the different polymer structure and the resulting different forces of attraction between the molecular chains of the polymers investigated, a clear difference in the maximum temperatures occurred. Also the material behavior had a major influence on the shape of the fracture process zone and showed a difference in the temperature data and strain rate recorded with the digital image system.

Modelling fatigue life and hydrogen embrittlement of bcc steel with unified mechanics theory

Hsiao Wei Lee[1], Milos B. Djukic[2], Cemal Basaran[3]

[1]University at Buffalo, Civil, Structural, and Environmental Engineering, Ketter Hall, 206,
Buffalo, NY 14228, NY, USA

hlee53@buffalo.edu

[2]University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade 11120, Serbia. mdjukic@mas.bg.ac.rs

[3]University at Buffalo, Civil, Structural, and Environmental Engineering, Ketter Hall, 243, Buffalo, NY 14228, NY, USA. cjb@buffalo.edu (corresponding author)

Entropy *Unified mechanics theory* *Thermodynamics* *Fatigue*
Steel *Hydrogen embrittlement*

Abstract The fatigue life estimation of metals operating in hydrogen-rich environments such as hydrogen pipelines, hydrogen-burning internal combustion engines, etc. is important. Studies in the past 40 years have shown that the diffusion of hydrogen into steel and other metals causes various chemical reactions, hydrogen-material interactions, and microstructural changes. That leads to hydrogen embrittlement (HE) and other types of hydrogen damage mechanisms including hydrogen environmentally assisted cracking (HEAC). Hydrogen embrittlement mechanisms, such as hydrogen-enhanced localized plasticity (HELP) and hydrogen-enhanced decohesion (HEDE) can have synergetic effects in steel depending on the hydrogen concentration level. At concentrations above and below the critical hydrogen concentration, HEDE and HELP dominate the embrittlement process, respectively. Different HE mechanisms result in distinctly different fracture modes, both ductile and fully brittle. The ultrasonic vibration fatigue life of bcc steel with a ferrite-pearlite microstructure pre-charged with hydrogen at different concentrations is studied. Modeling is based on the unified mechanics theory (UMT), which does not need any empirical dissipation/degradation potential function or an empirical void evolution function. However, the UMT does require analytical derivation of the thermodynamic fundamental equation of the material, which is used to calculate the thermodynamic state index (TSI) of the material. The UMT is ab-initio unification of the second law of thermodynamics and the universal laws of motion of Newton. Dissipation/degradation evolution is governed by Boltzmann's second law of thermodynamics entropy formulation. The original contribution of this study is the derivation of the thermodynamic fundamental equation of pre-hydrogen embrittled bcc steel subjected to ultrasonic very high cycle fatigue and the numerical simulations of fatigue life estimation using the proposed novel model. The synergetic interaction of hydrogen embrittlement mechanisms in steel and other metallic materials, i.e., HELP and HEDE at different hydrogen concentrations (HELP + HEDE model) is also studied, reviewed, and applied. The synergetic effects between ultrasonic vibration fatigue life and synergistically active hydrogen embrittlement mechanisms in low carbon bcc steel (S355J2+N, equivalent to ASTM A656), according to the HELP+HEDE model for HE, is modeled for the first time using UMT and also thoroughly discussed.

Prediction of crack paths for an inclined edge crack including crack-face friction and subjected to mixed mode loading

Sjoerd Hengeveld[1,2], Davide Leonetti[1], Johan Maljaars[1,2] , Bert Snijder[1]

[1]*Structural Engineering and Design, Eindhoven University of Technology, De Zaale 1 ,Eindhoven 5612 AZ, The Netherlands*

[2]*Reliable Structures, TNO, Molengraaffsingel 8, Delft, 2629 JD, The Netherlands*

Crack growth direction   Mixed-mode fatigue crack growth   crack paths

Abstract Accurately describing the fatigue crack growth rate and fatigue crack growth direction is crucial in determining the residual fatigue life of steel structures in general and for railway rails in particular. Railway rails are commonly subjected to complex cycling loading resulting in non-proportional mixed mode fatigue crack growth. The crack growth rate and crack growth direction depend on the crack driving force, which can be estimated using the Finite Element (FE) method. The stress intensity factor (SIF) is often considered as crack driving force and depends on the applied load, the crack length and geometry. Friction between the crack faces potentially reduces the mode-II and mode-III SIFs shielding the crack tip, similar to crack closure in mode-I. Several methods exist to estimate the crack growth direction as a function of the SIFs, such as the maximum tangential stress and the maximum crack growth rate criteria. The application of these criteria in non-proportional mixed-mode loading including friction has not yet been evaluated in literature.

This paper concerns a numerical investigation of crack growth rate and direction for an inclined edge crack subjected to a moving patch load including both normal and tangential stress components, mimicking a crack in a rail. A 2D plane strain FE model is created to calculate the SIFs in Abaqus FEA. A modified version of the standard virtual crack closure technique (VCCT) is implemented to calculate the SIFs using quarter-point elements. Friction between the crack faces is considered using a Coulomb friction model. The crack is incrementally extended in the predicted direction after each passage of the moving load, allowing to estimate the crack growth direction and rate using different criteria. Moreover, a parametric study is conducted to study the effect of the friction coefficient, the tangential stress component, the crack length and the initial crack angle. The results are compared in terms of predicted crack paths and SIF characteristics.

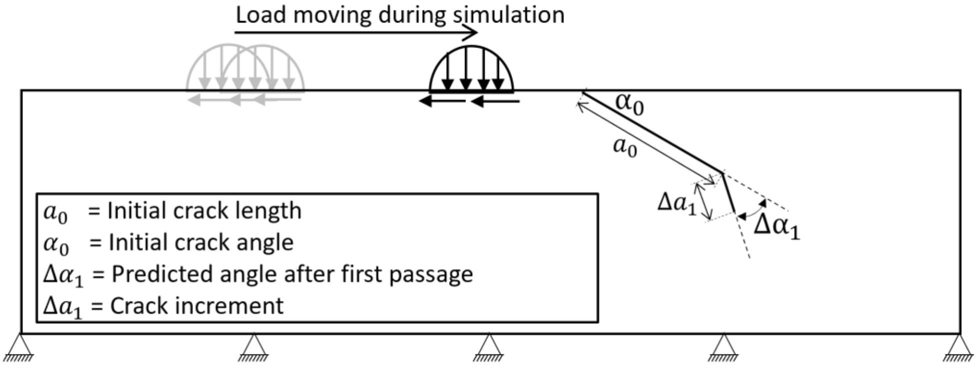


***Figure 1** – Schematization of model with inclined crack*

Effect of heat treatment on the microstructure and fatigue properties of laser beam welded cp-Ti joints

Marcin Wachowski, Robert Kosturek, Krzysztof Grzelak, Lucjan Śnieżek, Ireneusz Szachogłuchowicz

Military University of Technology, Faculty of Mechanical Engineering, 2 gen. S. Kaliskiego st., 00-908 Warsaw, Poland

Laser beam welding *Low cycle fatigue test* *titanium*

Abstract The aim of this research was to investigate the microstructure and mechanical properties of cp-Ti joints obtained in laser beam welding (LBW) with post-weld heat treatments. LBW technology provides a significant benefit for the welding of titanium and its alloys because of high precision and rapid processing capability. The joined workpiece was a 3 mm thick sheet made of commercially pure titanium Grade 1. The laser welding process has been performed by using Fanuc 710i machine with 3kW power and 1,5 m/min welding speed. In the following, the joints were subjected to additional heat treatment: stress relief annealing (550°C/0.5h) or annealing (700°C/2h). To check the influence of the heat treatment of the microstructure and properties of the joint, the welded joints were sectioned perpendicular to the welding direction where metallurgical examinations, hardness measurements and low cycle fatigue test were performed. In order to investigate the joints microstructure, the samples were examined using light microscope (Olympus LEXT OLS 4100) and scanning electron microscope (Jeol JSM-6610). It has been reported that the obtained joints are characterized by presence of three separate areas, i.e. base material (BM), heat affected zone (HAZ) and fusion zone (FZ). The analysis of the microstructure of all samples showed that BM contained fine, uniaxial grains of phase α. The weld showed the presence of very fine martensite α'. The high cooling rate associated with the laser process led to a complete transformation of titanium into a martensitic phase α'in the weld. HAZ contains a mixture of martensite and primary phase α. The highest number of cycles to failure was reported for the sample subjected to the post-weld annealing at 700°C. Additionally, it has been revealed that post-weld heat treatment influences the localization of crack initiation due to recrystallization and dissolution of the martensite phase in the welded zone.

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Seawater degradation: effects on damage properties of polymer-based composite structures

Norman Osa-uwagboe*, Vadim Silberschmidt, and Emrah Demirci

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

n.osa-uwagboe@lboro.ac.uk

Fibre-reinforced plastics *Seawater degradation* *Damage*

Abstract; This paper focuses on the effects of seawater degradation on the energy absorption properties of FRPs sandwich structures to gain more understanding of its damage mechanism. Specimens made of plain-woven carbon fiber-reinforced plastics /Epoxy and glass fiber-reinforced plastics/epoxy as facesheets with polyvinylchloride (PVC) foam core were investigated. The specimens were degraded under 3.5% salinity for 16 weeks and their moisture absorption was evaluated over the period. Quasi-static indentation (QSI) tests were conducted, and the force-displacement and energy- displacement curves were analyzed. X-ray Miro-CT tomography was used to analyze the damage behavior as well as the damaged region of the structure. The result showed a reduction in the energy absorption capabilities of the structure due to decreased interfacial bonds between the core and the face sheets and a variation in damage area, damage depth, and bulging height. Results indicated that continuous exposure to seawater affects the energy absorption/damage resistance properties of the FRP sandwich structures significantly.

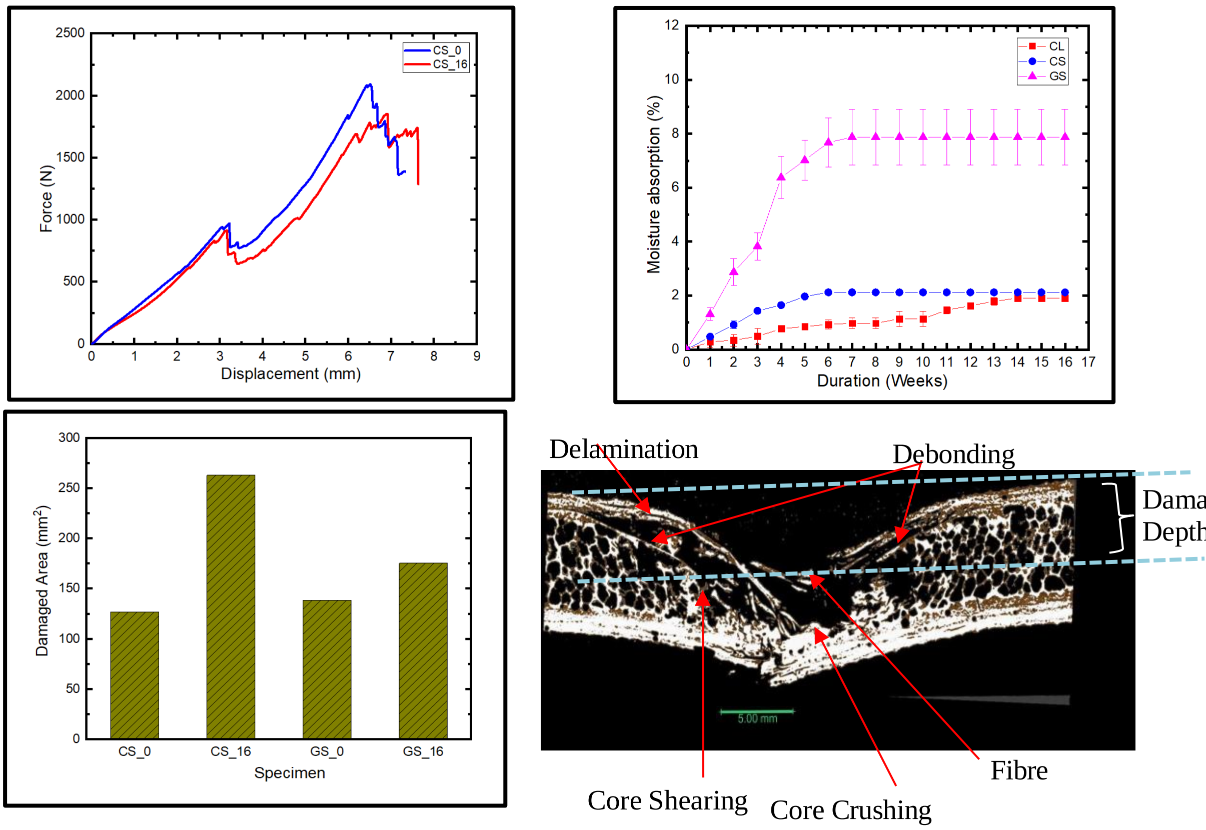


Figure 1 – Damage Analysis on CFRP sandwich panels subjected to seawater degradation

Design of a New Passenger Train Seat Structure using Finite Element Analysis and Design Optimization Algorithms

F. Alves[1], J. Marques[1], J.A. Madeira[2], R. Baptista[2], V. Infante[2]

[1]*IST, 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*

Finite Element Analysis *Design Optimization Process* *Train Seat*

Abstract The transport sector is one of the activities with the greatest environmental impact, with the extraction of large amounts of non-renewable raw materials, high energy consumption, and the consequent high emissions of greenhouse gases. So far, several environmental analyses have been carried out and different ecological design solutions proposed applied to all stages of the life cycle of vehicles. According to the European Commission, rail transport accounts for 11% of freight transport and 8% of passenger transport.

Seat structures present one of the best opportunities for weight reduction using new materials and design techniques; in this study, a new train seat structure was conceived, reducing the overall weight while not compromising overall stiffness. Design optimization techniques were applied to achieve that goal while attempting to restrain production methods to those that would be traditionally employed in the manufacturing of a train seat, along with geometrical constraints imposed by the ergonomics and visual design of the seat. To obtain a lightweight and safe seat structure, different thicknesses of beam profiles and materials were numerically modelled using finite-element analysis, considering the boundary conditions defined in the UIC 566 standard. The Direct MultiSearch (DMS) algorithm was applied in the optimization process since is the first approach to multiobjective, derivative-free, optimization that is non-heuristic and non-scalarized. The optimization tool of the commercial software Siemens NX (SOL200) was used as well to provide a comparison with available commercial software. The following conditions were defined as requirements: a maximum structure mass of 5.5 kg; a maximum displacement (in the headrest area) of 35 mm; and a maximum von Mises stress equal to or lower than 60% of the yield stress of the material (either steel or aluminium).

The proposed new train seat structure, which resulted from the numerical optimization process, presents an aluminum structure frame where a total weight reduction of close to 30% was achieved compared to the reference structure (which weighed 8kg).

Experimental and numerical analysis of FSW process control effects on morphology and strength of dissimilar aluminum to polymer joints

Arménio N. Correia[1], Ricardo Baptista[2], Daniel F.O. Braga[3], Virginia Infante[4]

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

[2]*Escola Superior de Tecnologia de Setúbal, Instituto Politécnico de Setúbal, Estefanilha, 2914-508 Setúbal, Portugal*

[3]*INEGI, Faculdade de Engenharia da Universidade do Porto, Rua Dr. Roberto Frias, 400, Porto, 4200-465, Portugal*

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

Friction Stir Welding *Dissimilar Joints* *Structural Integrity*

Abstract An engineering grade, glass fiber reinforced polymer (GFRP), Noryl™ Resin GFN2, and an aluminum magnesium silicon alloy, AA6082-T6, were joined by Friction Stir Welding (FSW) in overlap configuration. Since the FSW process can be either position or force controlled, a series of experimental analysis were carried out in order to assess the effects of the control method with different sets of parameters on resulting joints' morphology and mechanical performance. The fabricated joints were subjected to quasi-static tensile shear tests and its morphologies were characterized in the cross-sectional and longitudinal directions, both in the macro and microscales. Additionally, the joints' characterization was complemented with numerical analysis using the commercial software Abaqus® with which 2D finite elements models were developed both in plane strain and plane stress conditions. From both experimental and numerical analysis, it was found that the joints fabricated with a force-controlled process exhibited superior mechanical strength when compared with the position controlled ones. This fact can be explained by the resulting morphologies that were found to be significantly different depending not only on process control but also on the amount of tool penetration.

Hydrogen effects in high-strength lath martensite steel bars for structural engineering

Mihaela Iordachescu, Patricia Santos, Andres Valiente

Materials Science Dpt., ETSI Caminos, Universidad Politécnica de Madrid, s.n. Prof. Aranguren St., 28040 Madrid, Spain

mihaela.iordachescu@upm.es

Lath martensite steel *Hydrogen-assisted cracking* *Damage tolerance*

Abstract: The incorporation of sustainability and resilience criteria for design, construction and maintenance in structural engineering requires accurate geometrical configuration and loading control of structural members essential for safety assurance. The high-strength steel bars intended for use in pre- or post-stressed construction meet these criteria, but their brittleness and sensitivity to environmentally assisted cracking currently entail risks for structural integrity. However, high strength steels with lath martensitic microstructure that rises toughness and lowers the transition temperature have been developed in the last decades and bars made from these steels are currently commercialized for use in construction.

The paper addresses the damage tolerance of these bars when simultaneously subjected to tensile loading and hydrogen charge, which is assessed by using a failure assessment diagram (FAD) that allows comparing the experimentally obtained data with respect of the load solution for fully plastic regime. The research is based on slow rate tensile tests made in a standardized thiocyanate solution with previously damaged specimens as well as on the fractographic analysis of the broken samples. This reveals that the steel is singularly sensitive to hydrogen action, which consists of two-phases assisted cracking, namely initiation and propagation (Figure 1). The transition from one phase to another occurs at the end of the small-scale yielding (SSY) regime and the cracking resistance in the initiation phase strongly decreases in the propagation phase. Nevertheless, the embrittlement of the steel by the action of hydrogen remains localized at the crack front and is insufficient to produce brittle fracture before the plastic collapse of the resistant ligament.

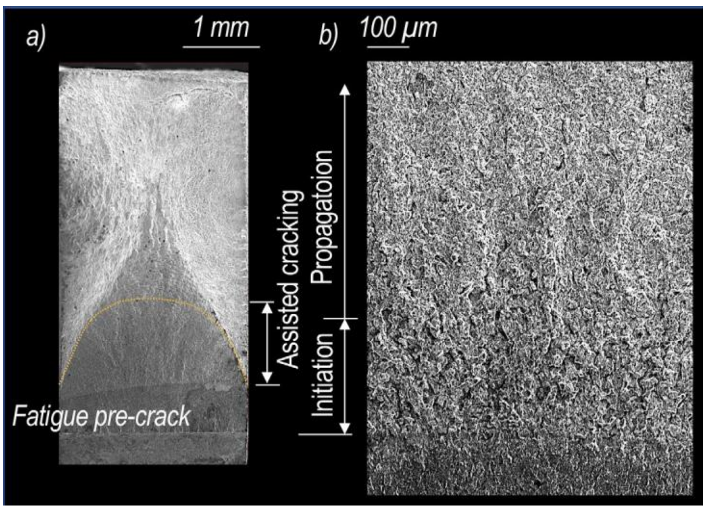


Figure 1. *a) fracture surface of a broken specimen; b) higher magnification detail from the hydrogen-assisted cracking zone*

A Crack Problem in a Complete Contact Configuration

Hyung-Kyu Kim

LWR Fuel Technology Research Division, Korea Atomic energy Research Institute 989-111 Daedeokdaero Yuseong-gu Daejeon 34057, Rep. Korea, hkkim1@kaeri.re.kr

Sharp edge contact *Dislocation density function* *Influence function*

Abstract A crack problem incorporating a contact problem is studied. It is attempted to obtain the stress intensity factors of a crack in a half plane which is in contact with an indenter having a sharp edge. It is assumed that the crack initiates and grows perpendicularly from the sharp edge of the indenter whose angle is 90°, the elastic properties of the contacting bodies (indenter and half plane) are the same and the coefficient of friction is sufficiently high. Thus, an adhered complete contact configuration of a quarter plane and a half plane is formed where a crack is included (Figure 1). Such a problem may be found in many assemblies of mechanical components. A crack problem in fretting fatigue experiments using a bridge type pad can also be an example. To deal with this problem, a distribution of pseudo edge dislocations are used for the traction free conditions of the free boundaries of the contacting bodies as well as the crack. Contact analysis is conducted first. Asymptotic analysis method is adopted with applying the Williams stress potential. This produces an eigenvalue problem from which the singularity order of the stress components are obtained. As a result, dominant terms of the stress components are expressed as $\sigma_{ij}^{ct} = K_I^{ct} r^{\lambda_I - 1} f_{ij}^I(\theta) + K_{II}^{ct} r^{\lambda_{II}-1} f_{ij}^{II}(\theta), (i,j) = (r,\theta)$ where $\lambda_M, f_{ij}^M(\theta), (M = I, II)$ are the eigen-solutions. $K_M^{ct}, (M = I, II)$ are the *contact stress intensity factors* which are obtained from a simple finite element analysis. Before the crack analysis, stresses induced by the dislocation arrays, intentionally distributed along the free boundaries of the quarter and half planes for the traction free condition, are evaluated using the dislocation density function approach. This is one of the key results of this work and has a form of $F_{kij}(\hat{y}) = 1/\left(\hat{y}^{1-\lambda_I} + \hat{y}^p\right) \sum_{q=0}^{m} \left[A_q (\hat{y}/(1+\hat{y}))^q\right], (k = x, y; i, j = x, y)$ where $\hat{y} = y/\eta$ and η being the location of a dislocation on y axis to simulate another traction free condition of a crack in the consecutive analysis. It takes a role of correction functions to the influence functions of an infinite body problem. In the crack analysis, the normal and shear stress components along the crack line are evaluated by adding the stress components evaluated from the pseudo dislocations along the crack and from the prior contact analysis. A numerical technique using the Jacobi-Chebyshev polynomial, often used for a crack problem, is applied. Finally, the *crack stress intensity factors* are obtained such as a form of $K_M^{cr}/\sqrt{\pi c} = A K_M^{ct} c^{\lambda_M - 1} + B K_M^{ct} c^{\lambda_M - 1}, (M = I, II)$ where A, B are the constants and c is the length of a crack.

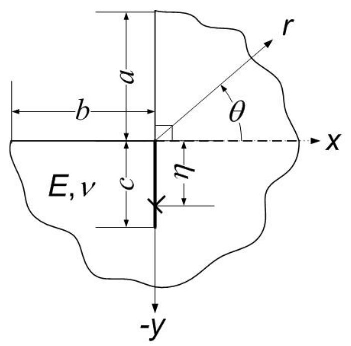


***Figure 1** – Geometrical description of the present problem.*

Applications of additive technologies in the maintenance of machinery and equipment

Miloslav Kepka, Miroslav Zetek, Zdenek Chval, Ivana Zetkova, Yusuf Bakir, Martin Zahalka, Tomas Kalina, Michal Krizek

Regional Technological Institute, Faculty of Mechanical Engineering, University of West Bohemia, Univerzitni 2632/8, 30100 Pilsen, Czech Republic

kepkam@fst.zcu.cz

Powder bed fusion *Multi-jet fusion* *Spare parts*

Abstract the Regional Institute of Technology, a research center of the Faculty of Mechanical Engineering at the University of West Bohemia in Pilsen, has some technologies for additive manufacturing. This is a metal printing technology called powder bed fusion and a technology for printing composite materials and plastics.

The necessary tools for reverse engineering, support calculations, in-service measurements, laboratory tests and material analysis are available.

The contribution will present the potential of additive technologies in the maintenance of machines and equipment. Examples of printed spare parts will be shown: oil vapor breather, gearbox cover, edging machine roll, spacers and more.

Figure 1 – Examples of printed spare parts

Towards detecting the strong vertical shock induced by a shallow earthquake

Koji Uenishi

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

uenishi@k.u-tokyo.ac.jp

Dynamic structural failure *Audible earthquake* *Higher frequency*

Abstract This contribution treats a long standing enigma of the strong vertical shock, often felt near an epicenter on the onset of seismic shaking but not recorded by seismographs. Beginning with the 1995 Hyogo-ken Nanbu (Kobe), Japan, earthquake, not only the verbal evidences by a number of people for various earthquakes at different places but also the unique dynamic failures induced in underground and surface structures do support the idea of the existence of such strong vertical shock generated by relatively shallow earthquakes. However, due to the lack of capability of appropriately detecting higher frequencies at an audible level over 16 Hz, historically it has been difficult for a seismograph to "correctly" record the shock involving vibrations of very high frequencies. The mechanical discussion is mainly for natural earthquakes and earthquake swarms currently being monitored near epicenters in Japan, but it is of importance also in interpreting mining-induced earthquakes and enhancing the dynamic safety of nearby mines and structures in the underground and on the surface.

Figure 1 *– An astonishing earthquake-induced structural failure found on the surface in Kobe in January 1995. The reinforced concrete (RC) buildings near Sannomiya railway station looked completely safe at first sight, but the middle floor was vertically compressed and it totally disappeared (Photograph courtesy of Kobe City).*

Crack initiation and growth in compacted graphite iron: effect of graphite inclusions

Xingling Luo, Konstantinos P. Baxevanakis, Vadim V. Silberschmidt

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

Compacted graphite iron *Cohesive* *Crack initiation*

Abstract Compacted graphite iron (CGI), also known as vermicular graphite iron, is a double-phase engineering material, extensively used in engine cylinders and brake disks, thanks to its good combination of mechanical properties and thermal conductivity. Despite its wide use and considerable past research, the fracture behaviour of CGI at the microscale is not yet fully understood, especially the effect of graphite inclusions. Due to very complex shapes of graphite inclusions randomly embedded in the metallic matrix, building realistic 3D models is time-consuming and computationally expensive. Hence, a novel 2D computational framework capable of predicting crack initiation and growth in CGI is necessary.

In this work, a 2D CZE-based model is developed to predict the crack initiation and propagation in different boundary conditions. Scanning electron microscopy was used to characterise the microstructure of CGI and the resulting scans were analysed using image-processing software. Then, finite-element models of typical microstructures were generated and loaded under tension. The metallic matrix and graphite particles were assumed isotropic and ductile, described by the classical J2 flow theory of plasticity. Cohesive elements were implemented into the models using a Python script and assigned to the ferritic matrix, graphite inclusions, and the graphite-ferrite interface. The morphology, orientations and distance of graphite particles significantly influences the onset of crack and the stiffness of the specimen. Validation of simulations is based on experimental data from our group pervious study. The developed models will contribute to the understanding of CGI's fracture behaviour.

Phase-field modelling of environmentally induced damage

S. Kovacevic*, M. Makuch, E. Martinez-Paneda

Department of Civil and Environmental Engineering, Imperial College, London, SW7 2AZ, UK

s.kovacevic@imperial.ac.uk

Stress corrosion cracking *Hydrogen embrittlement* *Diffuse interface*

Abstract Environmentally assisted damage is the primary cause of the failure of metallic structures and components in various industries. After the rupture of the protective film, several different physicochemical phenomena operate simultaneously and at different length scales. The synergistic effect of mechanical loading and a corrosive environment facilitates the nucleation and growth of cracks. Anodic corrosion reactions amplify local material dissolution at the crack tip, while at the same time, cathodic and hydrolysis reactions generate hydrogen, resulting in the uptake and diffusion of hydrogen within the metal and ultimately leading to embrittlement. Tracking the evolution of the metal-environment interface subjected to the electro-chemo-mechanics effects has been seen as the biggest computational challenge intrinsic to the coupled nature of the problem. The phase-field model has emerged as a powerful tool for dealing with the evolution of interfaces in arbitrary domains under complex physics and handling complex topological changes. Recent development in phase-field modelling of corrosion damage [1] has shown that this paradigm can naturally track the evolution of the metal-environment interface and readily capture pit-to-crack transition and crack propagation without ad hoc criteria. We extend that formulation and develop an electro-chemo-mechanical phase-field framework for predicting localized corrosion in polycrystalline materials. The role of the electrochemical environment and microstructural features of the corroding material, such as grain orientations and grain boundaries, is incorporated into the framework. Several different boundary value problems, considering various microstructure topologies, are generated to examine the effect of grain orientation and grain size on localized and mechanically-assisted corrosion. The main findings will be presented. The presentation will be extended by introducing a phase-field formulation for capturing the synergy of both hydrogen embrittlement and material dissolution mechanisms in driving material degradation [2].

References:

[1] Cui C., Ma R., Martinez-Paneda E. A phase field formulation for dissolution-driven stress corrosion cracking. *Journal of the Mecahnics and Physics of Solids*, Vol. 147 104254, 2021.

[2] Cui C., Ma R., Martinez-Paneda E. A generalised, multi-phase-field theory for dissolutiondriven stress corrosion cracking and hydrogen embrittlement. *Journal of the Mechanics and Physics of Solids*, Vol. 166 104951, 2022.

International Conference on Structural Integrity 2023

Static analysis of a lamp post according to Eurocode EN-40

E.S. Gonçalves[1], J. Gonçalves[2], H. Rosse[3], J. Costa[1], L. Jorge[1], J.A. Gonçalves[1], J.P. Coelho[1], J.E. Ribeiro[1]

[1]Instituto Politécnico de Bragança, 5300-052, Bragança; Portugal

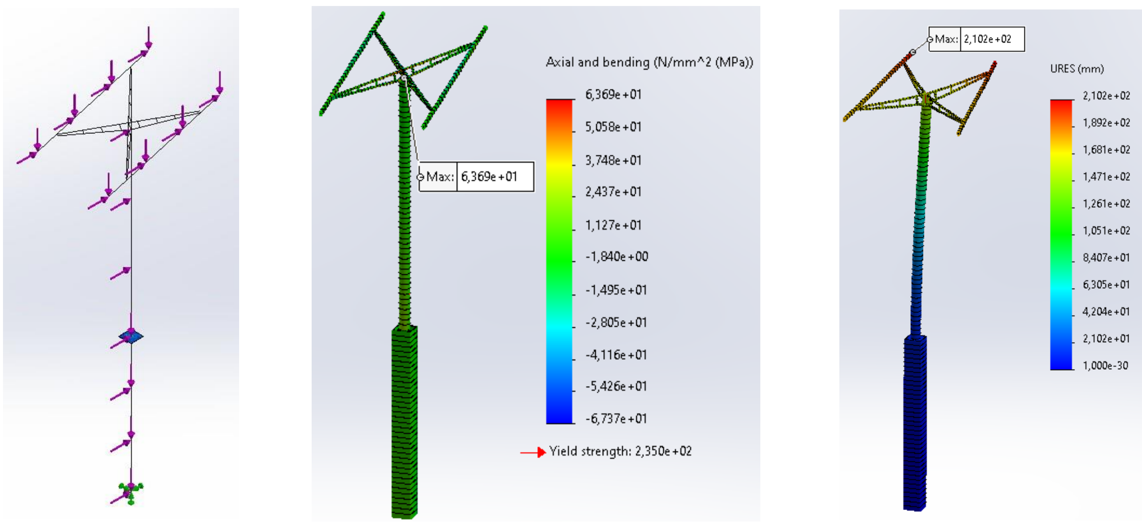
jribeiro@ipb.pt

[2]Valled, 5300-692, Bragança; Portugal;

[3]MORE-Colab, 5300-358, Bragança; Portugal;

Crosswalk *Lamppost* *Static analysis*

Abstract: When people move around a town, at some point in their journey they need to cross the road using a dedicated crosswalk. However, crossing is not always done safely due to weather conditions, lack of visibility by pedestrians, or distraction by motorists. In this sense, to promote safety at the crossing, lamp posts are often installed. In the case of the VALLPASS project, this aims to install two poles in opposite positions to the direction of crossing, with various functionalities and technological innovations, creating a luminous tunnel for the safe passage of pedestrians. To verify the mechanical resistance of the lighting poles, numerical simulations were performed using the finite element method, where the boundary conditions considered the criteria defined by the European standard EN-40 "Lighting Columns". This standard specifies the loads acting on the column, namely the horizontal forces due to the action of wind according to standard NP EN 1991-1-4:2010 and the vertical forces due to the self-weight of the entire structure, as well as the integrated electronic components. The snow action was also considered according to NP EN 1991-1-3:2009, as defined in Figure 1a. Considering a post with a lower square and upper cylindrical section, with a total height of 7 meters and with a support section for photovoltaic panels, the static analysis obtained a combination of maximum axial and bending stresses of 63.69MPa (Figure 1b), a maximum displacement of 21cm (Figure 1c) at the free ends of the photovoltaic panel support section and a factor of safety of 3.4 in the section where the combination of axial bending stresses is more severe, being used approximately 27% of the elastic range of S235JR steel.



a) b) c)

***Figure 1** – Static analysis: a) Boundary conditions; b) Axial and bending stresses; c) displacement*

Thermal analysis for testing underground battery location

E.S. Gonçalves[1], J. Gonçalves[2], H. Rosse[3], J. Costa[1], L. Jorge[1], J.A. Gonçalves[1], J.P. Coelho[1], J.E. Ribeiro[1]

[1]*Instituto Politécnico de Bragança, 5300-052, Bragança; Portugal*

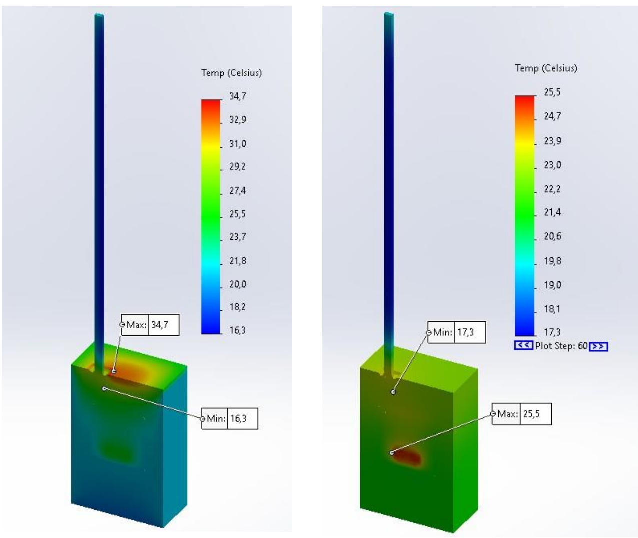
jribeiro@ipb.pt;

[2]*Valled, 5300-692, Bragança; Portugal;*

[3]*MORE-Colab, 5300-358, Bragança; Portugal;*

Ambient temperature *Batteries* *Thermal analysis*

Abstract: The energy storage batteries, employed in solar systems installed on lamp posts, are usually placed in devices such as switchboards fixed at an elevation near the top of the pole. However, this storage solution becomes inefficient, since it is not possible to guarantee the control of the working temperature of the batteries, due to the low thermal insulation capacity of these storage devices. In this sense, an underground compartment consisting of concrete, steel plate and rock wool was created, embedded in the mounting shoe of the lamp post, with the purpose of using geothermal energy to maintain an adequate temperature inside the compartment. To verify the temperature inside the battery storage compartment, a thermal analysis was performed, where heat transfer by conduction, convection and radiation was considered. Analyses were performed in steady state, and later, transient analyses, considering the initial temperatures of the thermal study in the previous steady state. With a storage volume of 1m3 and the base of the compartment at a depth of 2m, it was verified that it is possible to use geothermal energy to cool or heat, depending on the season, a system through geothermal energy. Considering a typical day in July, with an ambient temperature of 35ºC, there is a reduction of approximately 8ºC inside the compartment, compared to the ambient temperature. Figure 1a shows the temperature variation in steady state and Figure 1b shows the temperature variation in transient regime.



a) b)

***Figure 1** - Thermal analysis: a) Stationary regime; b) Transient regime (time=60min)*

Exploiting DIC-based full-field receptances in mapping the defect acceptance for dynamically loaded components

Dr. Alessandro Zanarini

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

Defect acceptance *DIC dynamic testing* *Fatigue spectral methods*

Abstract Defect acceptance can be seen dependable upon the mapping of effective strains, due to dynamic loading of the components as they are mounted. With proper constitutive models and loading spectra, the experiment-based mapping of the equivalent stresses can be achieved. Fatigue spectral methods turn this knowledge into component's life distributions, which lead to the assessment of where the material reaches first the critical conditions for a failure, whereas can highlight areas of underutilization. Therefore, a risk grading mapping for potential defects can be formulated over the area of inquiry in order to discriminate among safe and dangerous locations. By following this experiment-based approach, potential defects in exercise and production might be tolerated in safer locations, under the chosen dynamic task, with great savings in costs and maintenance.

Full-field dynamic testing can nowadays be achieved by means of optical measurements. Among the image-based ones, Hi-Speed DIC has proved to work in many environments, to be able to estimate full-field receptances of real components in their effective assembling and loading conditions also outside a specific laboratory. The quality achieved in the receptance maps helps in numerically derive the strain FRFs on the sensed surface, to achieve, with known excitation, the experiment-based risk mapping of the real mounted component and defect acceptance criteria. Examples with colored noises and a vibrating rectangular plate are highlighted in details, e.g. as in Fig.1 for the DIC-based risk index mapping.

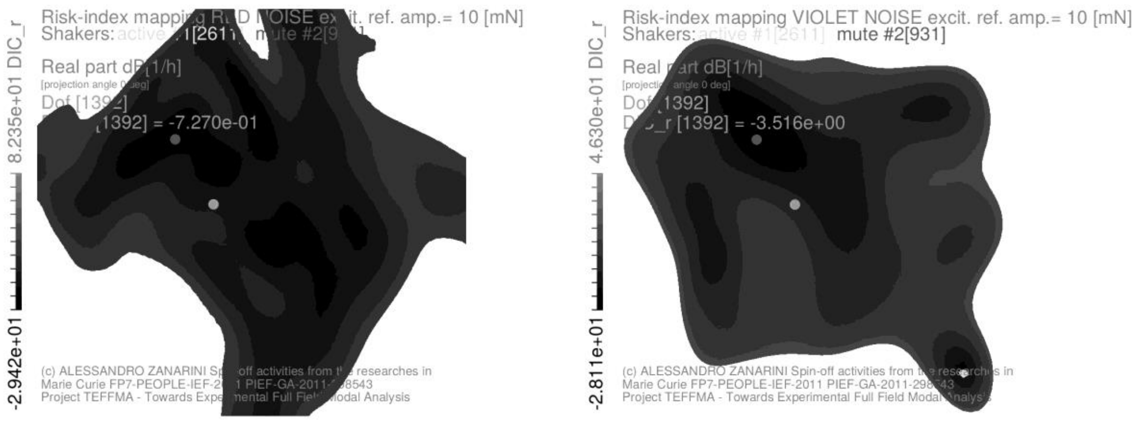


***Figure 1** – Examples of risk mapping from DIC recetances and broad frequency band excitation by red & violet noise spectra, where the defect forbidden areas are whitened.*

On the use of full-field receptances in inverse vibro-acoustics for airborne structural dynamics

Dr. Alessandro Zanarini

[1]*DIN-Dept. Industrial Engineering, Bologna University, Viale Risorgimento 2, I-40136 Bologna, Italy*

a.zanarini@unibo.it

full-field dynamic testing *inverse vibro-acoustics* *airborne loading*

Abstract Dynamic airborne pressure fields may become a concern for the excitation of lightweight structures and components in aerospace and automotive engineering. The distributed dynamic loading may excite excessively the modal base or may shorten the life of the actual realization. The identification of the vibro-acoustic relations becomes therefore of uttermost relevance for the accurate design and manufacturing of relevant components.

Full-field optical techniques can nowadays estimate accurate receptance maps to describe the frequency domain relation between excitation forces and displacement maps on lightweight components, where the inertia-related distortions of traditional transducers are not allowed. The same receptances proved to work in the Rayleigh's integral approximation of the sound propagated in the free-field acoustic domain by the characterized surface. The same background is here followed in early attempts of inverse vibro-acoustics, with the aim to identify, once the airborne pressure field is known in its spectrum, the broad frequency band force that is transmitted to the excitation points used in the direct FRF problem. This identification may permit the airborne structural dynamics' characterization of the components under test for further dynamic displacement and strain distribution studies. Details and considerations on the inverse formulation of the problem, together with examples coming from a real thin plate tested, are provided in this work, as exemplified in Fig.1 with an experimental full-field receptance- based vibro-acoustic FRF map.

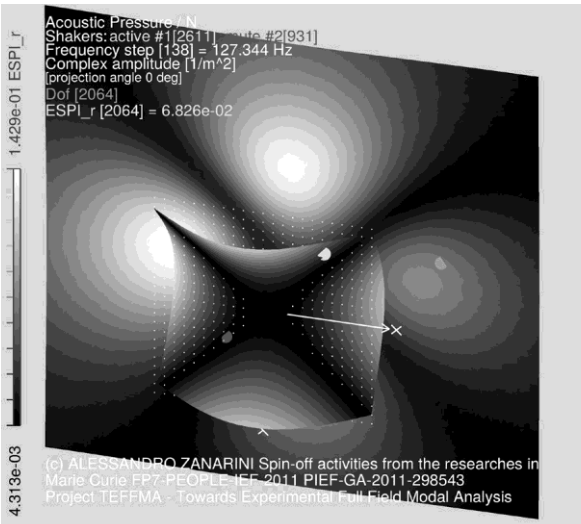


Figure 1 *– Example of vibro-acoustic FRFs, mapping the relations from a thin vibrating plate and the acoustic domain at a specific frequency*

Hydrogen embrittlement behavior of iron-based superalloy A286

Akihiko Fukunaga

Department of Applied Chemistry, Waseda University, Building 121, 513 Wasedatsurumaki- cho, Shinjuku-ku, Tokyo 162-0041, Japan

Hydrogen embrittlement *Slow strain rate tensile test* *Relative reduction of area*

Abstract One comparative value used to evaluate the hydrogen compatibility of metallic materials is the relative reduction of area (RRA) by a slow strain rate tensile (SSRT) test in the NASA database and in Japan. The RRA values obtained from this fracture test represent the behavior after plastic deformation. On the other hand, metallic materials used in high-pressure gas facilities such as hydrogen refueling stations are used in the elastic deformation region below the allowable stress. Therefore, it is necessary to clarify whether these values are due to the effect of hydrogen during elastic deformation or during plastic deformation where cracks are formed on the surface. In this study, during the SSRT test of iron-based superalloy A286, the atmosphere was switched from 70 MPa hydrogen gas to air at some nominal strains. As shown in Figure 1, it was found that the RRA value once decreased when exposed to the hydrogen environment, even if only in the elastic deformation region. Thereafter, the RRA recovers near the yield point, and in the plastic deformation region, the RRA value decreases slowly. This rapid decrease in RRA in the elastic region indicates that the lattice spacing widens, which increases the inter lattice diffusion of hydrogen and the amount of dissolved hydrogen θ_L. In the plastic deformation region, on the other hand, defects such as dislocations begin to move, increasing the defect density and increasing the hydrogen trap θ_B, but decreasing hydrogen diffusion and decreasing the amount of dissolved hydrogen θ_L. As a result, as shown in Equation 1, the amount of trapped hydrogen at the crack tip θ_t once decreases and then θ_t increases. These differences in the mechanisms can be linked to the differences in the hydrogen embrittlement mechanism. That is the difference between the direct weakening of the bonding strength of the matrix atoms (lattice decohesion) and the hydrogen-enhanced localized plasticity (HELP) mechanism, in which hydrogen promotes dislocation motion during plastic deformation. The results of this study indicate that the dominant hydrogen embrittlement mechanism of metric material may differ depending on the test conditions, i.e., material service environment. The results of fracture surface observation and stress cycle of A286 in the elastic region are also reported.

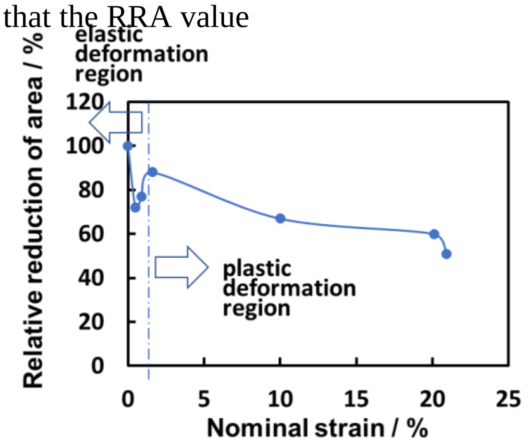


Figure 1- *Relationship between nominal strain of SSRT test whose environment was switched from 70 MPa H_2 to air and RRA at strain rate of 7.5×10^{-6} s^{-1} at 150 ℃ for A286 [1].*

$$\theta_t = \theta_L + \theta_B \qquad \text{Eq. 1}$$

θ_t : Total amount of hydrogen at the crack tip.
θ_L : Amount of dissolved hydrogen in the lattice.
θ_B : Amount of trapped hydrogen in the defect.

Reference: [1] Fukunaga A. Effect of high-pressure hydrogen environment in elastic and plastic deformation regions on slow strain rare tensile tests for iron based superalloy A286. Int J hydrogen Energy, February 13th 2023 online available, https://doi.org/10.1016/j-ijhydene,2023.01.266

Characteristics of local plasticity and boundary character in hydrogen-assisted intergranular and intergranular-like fracture paths

M. Koyama[1], T. Chen[1,2], T. Chiba[3], K. Takai[4]

[1]*Institute for Materials Research, Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai, 980- 8577, Japan*

[2]*Graduate School of Engineering, Tohoku University, 6-6 Aramaki Aza Aoba, Aoba-ku, Sendai, Miyagi, 980-8579, Japan.*

[3]*Graduate School of Science and Technology, Sophia University, Tokyo 102-8554, Japan.*

[4]*Department of Engineering and Applied Science, Sophia University, Tokyo 102-8554, Japan.*

Hydrogen embrittlement *Intergranular fracture* *Martensitic steel*

Abstract Mesoscopic characterization of crack growth in hydrogen-assisted intergranular and intergranular-like fractures was carried out using electron back-scatter diffraction-based crystallographic analyses. To obtain specimens that showed IG and IG-like fracture surfaces, hydrogen charging was conducted before and during tensile tests at a current density of 100 A/m^2 in an aqueous solution of 0.1 N NaOH with and without 5 g/L NH_4SCN. Hydrogen charging prior to the tensile tests was performed at 30 ˚C for 96 hours. When intergranular-like fracture occurred with the solution without NH_4SCN, the fracture surface showed plasticity- related traces. Correspondingly, the plasticity evolution around the cracks was significant compared with that for intergranular fracture that occurred with the hydrogen charging in the solution with NH_4SCN. The plasticity evolution stem from two phenomena. First, the intergranular-like fracture occurred at a larger macroscopic strain than that for intergranular fracture due to the smaller introduced hydrogen content. Second, crack blunting occurred significantly in the intergranular-like fracture. In particular, the second factor is important to understand the intrinsic role of plasticity in the hydrogen-assisted intergranular-like fracture. Based on analyses with misorientation and grain orientation spread values, high-angle grain boundaries ($\theta>15$) were preferentially cracked and associated local plasticity evolution was also significant compared with that for low-angle grain boundary ($\theta \leqq 15$).

Multiscale Modeling of Hydrogen Clustering and Bubbling in BCC Metals

Jun Song

Department of Mining and Materials, McGill University, 3610 University, Montreal, QC H3A 0C5, Canada. Email: jun.song2@mcgill.ca

Hydrogen embrittlement *Hydrogen bubbling* *Multiscale modeling*

Abstract Hydrogen clustering and bubbling, often induced by interactions between hydrogen and nanovoids and dislocations, is one important type of hydrogen damages in structural metals. Focusing on the BCC metal group, we systematically investigated these interactions using computational simulations. For nanovoids, we elucidated the complete process of hydrogen trapping therein, explicitly demonstrating sequential adsorption of hydrogen adatoms on dedicated geometric interstitial sites of nanovoids with distinct energy levels, with interaction between hydrogen adatoms dominated by pairwise power law repulsion. Based on the results, a predictive model has been established for quantitative determination of configurations and energetics of hydrogen adatoms in nanovoids. This model was then further combined with equation of states of hydrogen gas to predict the conditions of hydrogen bubble formation in nanovoids. Furthermore, multiscale simulations based on our predictive model were then performed, yielding good agreement with recent thermal desorption experiments. Meanwhile, for hydrogen at dislocations, we showed that hydrogen clustering can be strongly facilitated by anisotropic stress field along particular crystalline directions and demonstrated that platelet-shaped hydrogen cluster formation can be thermodynamically enabled around certain dislocations. Such hydrogen clustering can further promote the formation of dislocation junctions which are otherwise unstable in absence of hydrogen. These hydrogen-enabled dislocation junctions can stay stable under loading, subsequently promote vacancy loop formation and growth. The above findings provide critical mechanistic pieces to advance our understanding of hydrogen induced damages in metals.

Finite element simulation of hydrogen diffusion in girth welds with realistic defects

Yuanxing Ning[1,2], Mingliang Liu[1,2], Cuiwei Li[1,2], Yuxing Li[1,2], Cailing Wang[1,2]

[1]*College of Pipeline and Civil Engineering in China University of Petroleum (East China), Qingdao 266580, China*

[2]*Shandong Key Laboratory of Oil-Gas Storage and Transportation Safety in China University of Petroleum (East China), Qingdao 266580, China*

Girth weld joint *Defects* *Hydrogen diffusion*

Abstract The use of long-distance pipelines for large-scale hydrogen transportation is one of the most economical and effective approaches, but during service, hydrogen embrittlement may be induced and lead to pipeline failure. Welded joints, as a critical component for stability and sustainable of the pipeline operation, require special consideration. In the practical welding process, it is inevitable to produce various welding defects or flaws. Meanwhile, serious stress concentration is present at the welded joints, which is prone to hydrogen enrichment and hence hydrogen cracking, posing a severe hazard to pipeline safety and restricting the development of hydrogen energy. Therefore, the influence of various welding flaws on the hydrogen diffusion behavior needs further investigation. The thermal-mechanical coupling method was used to simulate the welding temperature field and residual stress field. Subsequently, hydrogen diffusion simulations were investigated considering the microstructure heterogeneity of the welded joint and the presence of residual stresses at the weld seam. The influence of porosity and inclusion on the hydrogen diffusion characteristics in the weld was analyzed. The results show that when the inclusions are distributed in the stress concentration region and parallel to the hydrogen diffusion orientation, the inclusions/matrix is prone to hydrogen partial gathering. The dynamic process of hydrogen diffusion was considered the interaction between the hydrogen pressure in the cavity and the residual stress field. The hydrogen pressure and stress intensity factor in the porosity increase exponentially with time. The research results could provide essential references for investigating the hydrogen segregation behavior at the girth welds and the prevention of hydrogen damnification.

Influence of Mo content on susceptibility of medium carbon martensitic steels to hydrogen embrittlement

Magdalena Eškinja[1], Gerald Winter[2], Jürgen Klarner[2], Holger Schnideritsch, Gregor Mori[1], Masoud Moshtaghi[1]

[1]*Montanuniversität Leoben, Chair of General and Analytical Chemistry, Franz-Josef-Straße 18, 8700, Leoben, Austria*

[2] *voestalpine Tubulars GmbH &Co KG, Alpinestrasse 17, 8652, Kindberg-Aumuehl, Austria*

Hydrogen embrittlement *Mo carbides* *Martensitic steels*

High-strength martensitic steels are used in various industrial applications owing to good balance of mechanical properties. Nevertheless, exposure of high-strength steels to hydrogen containing environment can have detrimental influence on their properties as a consequence of elevated susceptibility to hydrogen embrittlement (HE). In previous studies, the effect of Mo content on resistance of martensitic steels to sulphide stress cracking was reported. During the sulphide stress cracking, formation of sulphide layer on material surface can govern hydrogen induced crack propagation. However, in case of sulphide-free conditions, there is limited understanding about the role of Mo in the commercially available martensitic steels and its effect on hydrogen embrittlement.

This research elucidates correlation between the content of Mo carbide and hydrogen uptake of two high-strength Cr-Mo martensitic steels with different chemical composition and heat treatment. Hydrogen trapping behaviour and permeation were investigated by means of electrochemical permeation test and thermal desorption spectroscopy. Electrochemically charged Cr-Mo steels were subjected to slow strain rate tests to elucidate mechanical performance. The carbide distribution and microstructure of Cr-Mo steels were observed using scanning electron microscopy, electron backscatter diffraction and x-ray diffraction.

The results showed the level of reversibility of trapped hydrogen in the microstructure of investigated Cr-Mo steels. Thermal desorption analysis indicated two low temperature peaks with similar activation energies in case of both alloys. Hydrogen related to these peaks referred to as diffusible hydrogen was responsible for the deterioration of mechanical properties. Electrochemical charging showed higher uptake of hydrogen for alloy with higher content of Mo. Higher content of Mo promoted better mechanical performance of this alloy and had influence on susceptibility to HE.

Development of rapid evaluation and analysis system for bearing capacity of highway bridges based on WEB

Jianyong Song[1], An Zhao[2], Shoushan Cheng[2]

[1]*Research Institute of Highway Ministry of Transport, Beijing, China, Haidian District Xitucheng Road No.8, 279101052@qq.com*

[2]*Research Institute of Highway Ministry of Transport, Beijing, China*

Highway Bridge Bearing capacity evaluation WEB remote computing

Abstract Most of the conventional bridge bearing capacity calculation methods are based on bridge structure design calculation finite element software. Manual or semi-manual algorithms are used to evaluate and analyze the bearing capacity of bridges. There are problems such as large data processing workload, tedious modeling process, inability to automatically calculate the comprehensive modification coefficient and extract the bearing capacity evaluation results. In this paper, a set of automatic, integrated and refined cloud system for rapid calculation and analysis of bearing capacity of highway bridges is developed. The system can quickly establish a spatial finite element model and carry out refined finite element calculation and analysis. According to the field test data, the comprehensive modification coefficient and bearing capacity are automatically calculated and compared. Based on the WEB network platform, it can realize authorization, login, project and bridge task creation, remote finite element calculation, key data statistics and analysis, report automatic output and other functions. The test results show that the system realizes the network, automation and intelligence of the bearing capacity evaluation of highway bridges, and improves the work efficiency and quality.

Fatigue analysis of AlSi10Mg recycled powder for additive manufacturing

Martin Matušů[1], Jakub Rosenthal[2], Jan Papuga[1], Jan Šimota[1], Ludmila Růžičková[1], Libor Beránek[1]

[1]Faculty of Mechanical Engineering, Czech Technical University in Prague. Technická 4, Praha 6, Czech Republic, martin.matusu@fs.cvut.cz

[2]Department of Mechanical and Environmental Engineering, OTH Amberg-Weiden, Kaiser-Wilhelm-Ring 23, Amberg 92224, Germany

High Cycle Fatigue *Additive manufacturing* *Fatigue strength*

Abstract The present study focuses on the high cycle fatigue domain (HCF) of additively manufactured (AM) material AlSi10Mg under cyclic dynamic loading conditions. The specimens are produced from powder using Selective Laser Melting (SLM) technology. The main objective of this work is to analyse the fatigue strength with respect to individual subsequently additively manufactured platforms and to investigate the repeatability of printing using this technology and appropriate heat treatments. The effect of printing powder recycling is questioned.

In SLM procedure, the printing material is distributed in the chamber and then heated to the melting point with a laser. This not only affects the particle of the printed structure, but also the surrounding areas. After sieving and mixing with fresh powder, the used rest around the printed part is recycled to print another batch. The specimens are hourglass shaped to assess fatigue strength. They are left as-printed with a transition radius of R = 60 mm, a diameter of the critical cross-section of 9 mm and with M18x1 heads as interface to the test machine. Two different heat treatment setups were applied. One of which post-treats the samples at 240°C for 6 hours, the second pair of series is heated to 200°C for two hours and then air cooled to ambient temperature. The tensile and roughness parameters of the printed specimens are evaluated. Temperature monitoring during the experiment is parallelly used to describe the temperature rise during dynamic cyclic loading in order to estimate the fatigue life behaviour in a cost-effective manner.

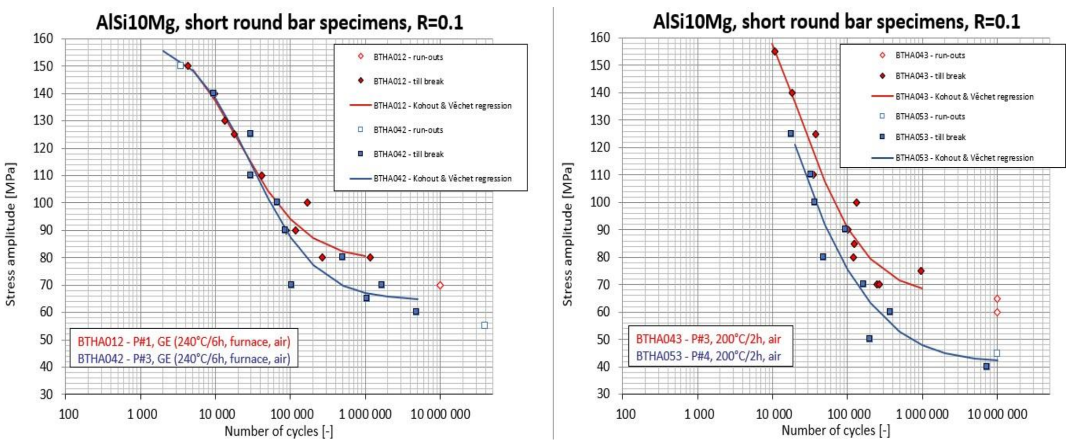


***Figure 1** – Fatigue curve of AM manufactured AlSi10Mg of three different batches and two heat treatment strategies.*

Investigation of the hybrid beam behaviour during three-point bending test

Jaroslav Václavík, Jan Chvojan

Research and Testing Institute Plzen, Dynamic Testing Laboratory, Tylova 1581/46, 30100 Plzen, Czech Republic, chvojan@vzuplzen.cz

Hybrid beam *CFRP* *Bus structure*

Abstract The hybrid beam for bus structure parts is the combination of CFRP plate and hollow profile made from stainless steel. Special intention is focused to lower the bus structure mass and increase stiffness resistance to crash and fatigue damage.

The paper presents the requirements for the hybrid structure and gives results, performed during 3-point bending tests of hollow profiles manufactured from ferritic stainless steel 1.4003. The profiles were filled with two types of foam and CFRP plate SIKA CarboDur® S512 was glued from the bottom of the profile using the adhesive SikaPower® 1277. The measurement of force and beams displacement was supplemented by measurements of strains in several places.

The results of the tests of single and double beems are discussed. When the profile is filled with foam, a plastic joint is formed at an 20% higher load force and approximately the same increase in deflection of the sample was found. When reinforcing the profile only with a CFRP strip on the bottom side, there was no significant increase in strength. It is interesting that the results are the same for both foams, even though the tensile strength of the polyurethane foam was measured to be approximately 2x higher than that of the epoxy foam. At the of the CFRP plates there was measured the stress near the maaterial yield point.

Presented tests are the starting point for the reinforcement of the selected hollow beams for the whole of the bus.

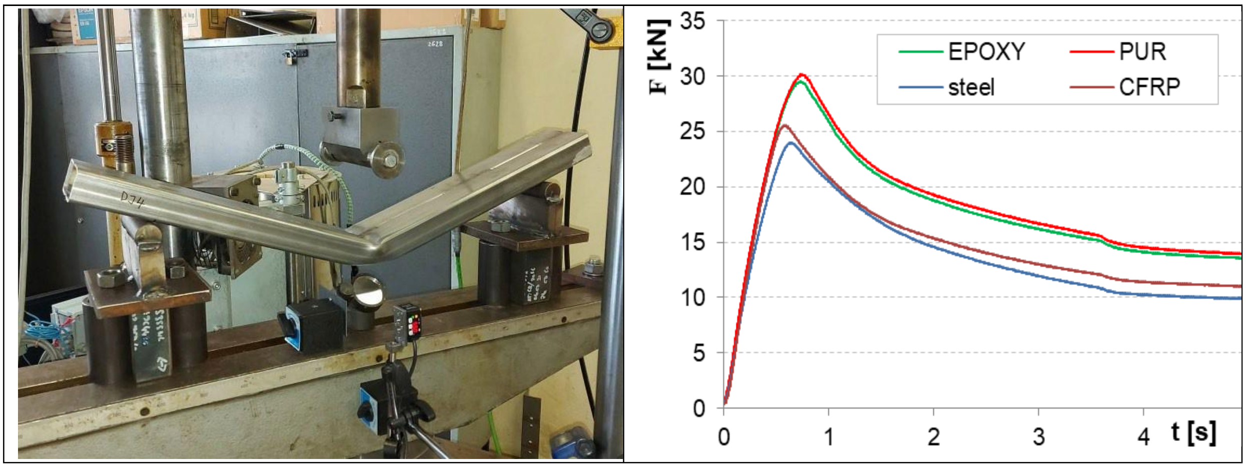


***Figure 1** – Set-up of the 3-point bending test and comparison of the force distribution for steel profile, steel with glued CFRP plate and steel filled with PUR and EPOXY foams*

The article has originated in the framework of M-ERA.NET call 2019 and was supported with Technological Agency of Czech Republic under the No. TH71020003.

Damage analysis of the prestressing strand-wires from a 40 years old urban viaduct

Maricely de Abreu, Mihaela Iordachescu, Andrés Valiente

Materials Science Dpt, E.T.S.I. Caminos, Canales y Puertos, Universidad Politécnica de Madrid. Calle profesor Aranguren s/n, Ciudad Universitaria, 28040-Madrid, Spain

m.deabreu@upm.es

Fracture *Damage tolerance* *Damage mechanisms*

Abstract

This study aims to determine the failure cause of the prestressing steel strand-wires of an urban viaduct after 40 years of service. Recently, the viaduct, a post-tensioned reinforced concrete structure had experienced an increasing tendency to crack, despite various repairs. In the latest inspection, the extensive concrete damage allowed to detect the severe deterioration of the steel-sheaths used to protect the strands from the environmental action. The research is intended to analyse the damage and its root causes in these currently exposed strand-wires. For this, the employed methodology is based on microstructural and mechanical characterization of the steel wires by tensile testing samples in distinct damage condition and the comparative fractographic analysis of the wires broken in service with the laboratory ruptured ones. Figure 1 illustrates the representative damage in the service-broken wires produced by generalized corrosion which in some cases propitiates the initiation and propagation of environmentally assisted cracks.

The research results proved to be satisfactory with respect to the quality of the steel wires, their damage and rupture being due to the concurrence of construction deficiencies and accidental environmental actions over the 40 years of service.

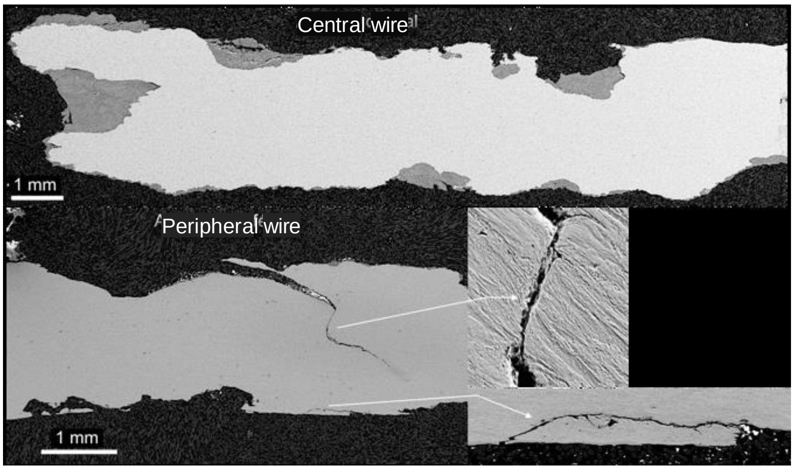


***Figure 1** – Corrosion damage and assisted cracking of wires during service.*

Role of prior austenite grain structure in hydrogen diffusion, trapping and embrittlement mechanisms in as-quenched martensitic steels

Renata Latypova[1], Eric Fangnon[2], Olli Nousiainen[1], Sakari Pallaspuro[1], Jukka Kömi[1]

[1]Materials and Mechanical Engineering, Centre for Advanced Steels Research, University of Oulu, Finland, renata.latypova@oulu.fi

[2] Materials to Products, Department of Mechanical Engineering, School of Engineering, Aalto University, 02150 Espoo, Finland

Hydrogen embrittelement *PAG structure* *Martensite*

Abstract Ambition to utilise hydrogen as a green energy has led to increase in research of potential materials that can ensure a safe infrastructure for the transportation and storage of hydrogen. Ultrahigh-strength steels are prospective materials for this, but their utilisation requires thorough investigations, such as microstructural optimization to mitigate the risk of hydrogen embrittlement (HE).

This study investigates the effects of prior austenite grain (PAG) structure on hydrogen embrittlement (HE) susceptibility of 500 HBW direct-quenched (DQ) steel with auto-tempered lath-martensitic microstructure. Three materials are tested: a direct-quenched steel (DQ), and the same austenitized at 860 °C (A860) and 960 °C (A960) for 25 min, followed by quenching. DQ and A860 have different PAG morphologies, elongated vs. equiaxed, but similar 10 µm average PAG size, and A960 has a fourfold PAG size compared to A860 and the same equiaxed PAG morphology.

Constant load (CL) tests with notched tensile specimens under continuous hydrogen charging in 3% NaCl + 0.3 % NH_4SCN and -1.2V_{SCE} applied potential were conducted to determine time-to-fracture under variable load levels. After the CL tests, hydrogen contents of the specimens were measured with TDS, and the fracture surfaces were analysed with FESEM. Electrochemical hydrogen permeation tests were conducted with the same hydrogen charging conditions as in CL tests to assess hydrogen diffusion properties, and to evaluate the density of reversible traps.

CL tensile tests show that the original DQ material with elongated PAG structure has the best resistance to HE with a quasi-cleavage cracking mechanism. A860 and A960 with equiaxed PAG structures are more susceptible to HE, showing partly intergranular crack propagation. Hydrogen diffusion is the slowest in DQ with a slight increase for A860 and A960. H diffusion is not dominated by the PAG structures, and the differences are caused by differing microstructural substructures. Different levels of HE susceptibility are linked to changes in crack propagation mechanisms caused by the geometrical shape of the PAG structures. The effect of different HE mechanisms and hydrogen trapping properties are evaluated and discussed.

Fracture toughness of polyurethane materials: experimental and numerical investigation on the size effect

Daniela Scorza[1], Andrea Carpinteri[1], Liviu Marsavina[2], Camilla Ronchei[1], Sabrina Vantadori[1], Andrea Zanichelli[1]

[1]*Department of Engineering and Architecture – University of Parma, Parco Area delle Scienze 181/A, 43124 Parma, Italy – daniela.scorza@unipr.it*

[2]*Department of Mechanics and Strength of Materials – Politehnica University of Timisoara, Blvd. Mihai Viteazu 1, 300222 Timisoara, Romania*

Fracture toughness *Two Parameter model* *Size effect*

Abstract Polyurethane (PUR) materials are polymers composed of a chain of organic units joined by urethane links. High density PURs (with a density greater than 200 kg/m^3) present a porous solid structure, and their main applications are fixtures and gauges, master and copy models, hard parts for electronic instruments, and so on [1]. The mechanical properties of these materials are directly related to the mechanical properties of the base materials composing the foam, the geometry of the cellular structure, and the relative density achieved through the manufacturing process. Such PURs have a ductile behaviour in compression, being able to absorb a considerable amount of energy, whereas they show a linear elastic behaviour up to fracture with a brittle failure when subjected to tensile loads [1]. As a consequence, it is of practical interest to investigate the fracture behavior of such materials especially when micro-structural defects, like cracks, filled cells or missing walls holes induced by manufacturing process, are present.

The present research work deals with the evaluation of the Mode I fracture toughness of a particular PUR foam with nominal density equal to about 700kg/m^3, whose commercial name is Necuron® 651, by performing three-point bending tests under crack mouth opening displacement control on single-edge notched specimens. Fracture toughness is herein determined by applying the Two-Parameter Model (TPM) [2,3]. Particular attention is paid to the size effect by examining three different beam sizes. Moreover, such experimental results are numerically simulated by employing a micromechanical numerical model [4], and the independence of the PUR foam fracture toughness from the specimen size is also numerically proved. Finally, the obtained Mode I fracture toughness value is compared with that reported in the literature for the same material [1].

Bibliography

[1] Voiconi T., Negru R., Linul E., Marsavina L., Filipescu H. The notch effect on fracture of polyurethane materials, Frattura ed Integrità Strutturale, 30 (2014) 101-108.

[2] Jenq Y., Shah S.P. Two Parameter Fracture Model for Concrete, Journal of Engineering Mechanics, 111 (1985) 1227-1241.

[3] Carpinteri A., Fortese G., Ronchei C., Scorza D., Vantadori S. Mode I fracture toughness of fibre reinforced concrete. Theoretical and Applied Fracture Mechanics, 91(2017) 66-75.

[4] Scorza D. Mechanical Modelling of Short-Fibre-Reinforced Materials under Static or Cyclic Loading, PhD Thesis (2015), ISBN: 978-88-31482-00-4.

Advances in aluminium alloys performances applied to the next generation of aircraft wing

Erembert Nizery, Jean-Christophe Ehrström, Marion Bellavoine

Constellium C-TEC, CS10027, 38341 Voreppe cedex, France
erembert.nizery@constellium.com

Aluminium-Copper-Lithium *Metallic wing* *Spectrum fatigue*

Abstract In the context of rising environmental concerns while aircraft production rates remain high, there is a need to further improve the performance of aerostructures (weight, recyclability), and in particular of the wing. The current aircraft wing structures consist of aluminium alloys (A320 and B737 single-aisle) or composite materials (long range aircraft with slower production rates). For the next generation, aluminium wing structures are well positioned: end-of-life recycling is strongly in favour of aluminium, and the lightweighting potential is comparable to the values claimed by competitor materials. The technical and cost competitiveness of the aluminium solution relies on advanced joining techniques and improved alloys with enhanced properties.

On the material side, the lower wing skins are particularly important for the overall wing performance, since they account for the larger weight share. Damage tolerance is a main design driver for lower wing skins, so any alloy improvement in crack propagation resistance can convert into weight savings or increased inspection intervals. AW236, the new lower wing AlCu-Li Airware® solution (TRL 6 maturity) is a key enabler of the next generation metallic wing, with -5% in density and +35% in spectrum fatigue lifetime (Fatigue Crack Growth Rate under a sequence of loads representative of a lower wing loading) compared to advanced conventional 2xxx solutions. Advanced metallic materials solutions (upper wing and stringer alloys, Fiber Metal Laminates) are also developed for future improvement steps.

In this study, the new lower wing Al-Cu-Li plate product is characterized in static, toughness, crack propagation and corrosion. In particular, the performance under a commercial lower wing spectrum is shown and compared to reference aluminium alloys. An estimation of weight savings in the wing structure is presented for this new product, as well as for the alternative next generation FML solution.

Finite element analysis of unnotched and notched functionally graded steel specimens

Ela Marković[1*], Robert Basan[1], Jelena Srnec Novak[1], Andrej Žerovnik[2]

[1]University of Rijeka, Faculty of Engineering, Vukovarska 58, 51000 Rijeka, Croatia

*[2]University of Ljubljana, Faculty of Mechanical Engineering, Aškerčeva c. 6, 1000 Ljubljana, Slovenia *emarkovic@riteh.hr*

Functionally graded materials *Unnotched and notched specimen* *Finite element analysis*

Abstract Number of engineering components, such as gears, shafts and bearings, frequently experience high and usually very localized, static and dynamic loads and stresses. In order to increase the load-carrying capacity and durability of such components, various types of heat treatments may be applied. In particular, surface heat treatments are used to selectively enhance the load-bearing capacity of the most heavily stressed regions of the component. As a consequence, the resulting material exhibits a surface layer that is considerably harder and stronger than the material at the core. Such materials, possessing gradually varying material properties, are known as functionally graded materials (FGMs) and with them, the aim is to improve the structural integrity of components in an optimal, targeted manner [1].

In this study, a finite element analysis of the stress-strain response of unnotched and notched specimens made from homogeneous and functionally graded low-alloy steel 42CrMo4 subjected to static loading is performed. In order to properly capture stress-strain response, particularly in the vicinity of the notches, a multilinear material model was used in the analysis. For the characterization of gradual variation of elasto-plastic material properties in FGMs, a number of models related to different heat treatments and materials are available in the literature. In this study, a model of hardness distribution in surface hardened 42CrMo4 steel proposed in [2] was utilized. For the definition of FGM 42CrMo4 steel nonlinear behavior, a functional relationship between the individual monotonic Ramberg-Osgood parameters and the hardness was established using experimental material data gathered from existing literature. Results of the mechanical response of specimens with homogeneous material properties and FGMs were presented in this study, highlighting significant differences. Experimental validation of the model is planned in further studies, with potential expansion to include cyclic loading conditions.

References

[1] Abali, B. E. et al. (2012). Numerical modeling of functionally graded materials using a variational formulation, Contin. Mech. Thermodyn., 24(4), 377–390.

[2] Hertter, T. (2003). Rechnerischer Festigkeitsnachweis der Ermüdungstragfähigkeit vergüteter und einsatzgehärteter Stirnräder, Ph.D. Thesis, Technische Universität München, Munich, Germany.

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Hydrogen-assisted fatigue crack propagation in ferritic iron: An overview of macroscale behavior and microscale mechanisms

Yuhei Ogawa[1], Osamu Takakuwa[2]

[1]*National Institute for Materials Science, 1-2-1, Sengen, Tsukuba, Ibaraki, 305-0047, Japan, yuhei.ogawa.bz@gmail.com*

[2]*Department of Mechanical Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka, 819-0395, Japan, takakuwa.osamu.995@m.kyushu-u.ac.jp*

BCC iron *Fatigue crack growth* *Pressurized hydrogen gas*

Abstract: Hydrogen-assisted fatigue crack growth (HAFCG) in steels is an obstruction for reliable design of high-pressure vessels or pipelines used for storage and transportation of pressurized gaseous hydrogen. Plenty of researches have been carried out to elucidate the rationales of HAFCG on ferritic steels, although none of the proposed models can independently work to make sense overall crack growth acceleration characteristics and its dependences on mechanistic as well as environmental variables. A pure iron was selected in our studies as a model system of ferrite, with the aim of circumventing microstructural complexity and simplifying the interpretation of fracture mechanisms inside the crack tip fracture process zone. Fatigue crack growth (FCG) tests were performed in 0.2-90 MPa hydrogen gas with the load ratio, $R = 0.1$, frequency, $f = 1$ Hz and stress intensity factor range, ΔK = 10-20 MPa·m$^{1/2}$, followed by post-mortem analyses of crack-wake deformation substructures *via* electron backscattered diffraction (EBSD), electron channeling contrast imaging (ECCI) and transmission electron microscopy (TEM).

The FCG rate in hydrogen exhibited two stage behavior in the examined ΔK range. That is, the relatively lower ΔK regime where FCG rate was almost equivalent with that in laboratory air (Stage I), and the higher ΔK with substantial acceleration of FCG up to 30 times (Stage II). The predominant fracture modes were intergranular (IG) fracture for the former, and transgranular quasi-cleavage (QC) for the latter. A combined work of multiple electron microscopy techniques revealed a well-evolved dislocation cell or sub-grain structures immediately beneath the IG fracture surface in Stage I, generating small-sized voids along the peripheral un-cracked grain boundaries (GBs) in which the IG fracture may commences in virtue of the linkage of these GB micro-voids. On the other hand, the QC feature was characterized by weakly-evolved scattered dislocations with the fracture path parallel to {001} crystallographic planes. Implications were thus made that the important process for the IG fracture is successive nucleation of GB damages owing to hydrogen-dislocation-GBs interactions, while the dislocations pinning by hydrogen and resultant suppression of plastic relaxation at the crack tip zone triggers microscopic cleavage and thereby resulted in FCG acceleration in Stage II.

Fatigue crack growth rate at the interface of steel and structural adhesive in DCB specimens with thick bondline

Rahul Iyer Kumar, Wim De Waele

Soete Laboratory, Department of Electromechanical, Systems and Metal Engineering, Technologiepark-Zwijnaarde 46, 9052 Gent, Belgium.

Rahul.IyerKumar@UGent.be; Wim.DeWaele@UGent.be

Fatigue crack growth rate *Thick bondline* *Interface characterization*

Abstract: The marine industry has the ambition to replace the primary metal superstructures of ships with superstructures made entirely of composite sandwich panels. The use of these lightweight materials would lead to reduced fuel consumption, lower CO_2 emissions and faster ships. Despite these advantages, composites and adhesive joints are limited to secondary structures in the marine industry due to the lack of knowledge on their long-term fatigue strength in the challenging marine environment. Ships are often built in shipyards which are open to the elements which leads to concerns about the presence of manufacturing flaws, and the reliability and repeatability of the final bonded joint. Additionally, the manufacturing tolerances in shipyards are in the millimetre range. Because of these reasons, it is critical to evaluate the flaw tolerance of joints with thick adhesive bondline under cyclic loading and exposure to a marine environment.

The current research focuses on characterizing the adhesively bonded joint at the steel-adhesive interface. The fatigue behaviour in terms of crack propagation and the influence of ageing hereon are evaluated under mode-I loading conditions by subjecting double cantilever beam (DCB) specimens to cyclic loads. The specimen consists of two rectangular steel plates bonded together by Methyl-Methacrylate (MMA) adhesive with a nominal thickness of 8 mm. A non-adhering Teflon tape film was placed at the interface between the adhesive and one of the steel plates to obtain a discontinuity in the bond line which represented an initial crack of length a_0 = 50mm as shown in Figure 1. The influence of ageing is evaluated by subjecting the DCB specimens to a salt-spray chamber for six weeks to mimic the corrosive marine environment. Photographs are taken at regular intervals during fatigue testing to determine the crack length which is needed to quantify the crack propagation rate and to calculate the strain energy release rate (ΔG_I) according to the Penado-Kanninen model.

The results of the experiments show that for the aged specimens, initially, the crack grew at a faster rate than that of the unaged specimens. This may be due to the corrosion at the interface near the crack tip resulting from the ageing process. On the contrary, as the test progressed the aged sample showed greater resistance to crack propagation, which is hypothesized to be influenced by post-curing in the salt-spray chamber.

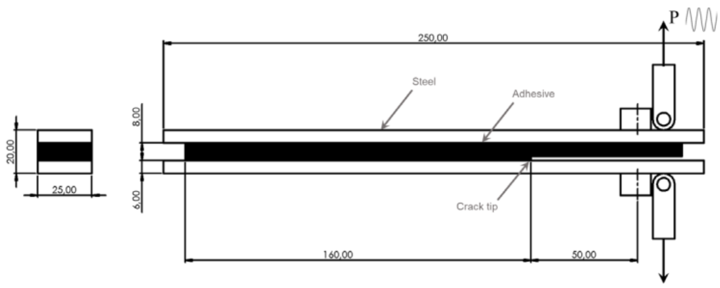

***Figure 1**: Schematic representation of the double cantilever beam specimen*

Hydrogen trapping at micro/nano-sized secondary hardening precipitates

Stefanie Pichler, Gregor Mori, Mahdieh Safyari, Masoud Moshtaghi

Chair of General and Analytical Chemistry, Montanuniversitaet Leoben,
Franz-Josef-Strasse 18, 8700 Leoben, Austria
stefanie.pichler@unileoben.ac.at

Secondary hardening Hydrogen trapping Hydrogen embrittlement precipitates

Abstract Martensitic stainless steels, which are used for different industrial applications are well known for their outstanding mechanical properties and their good corrosion and wear resistance. In the studies related to the mentioned properties, special attention is paid to the formed precipitates, which should be studied in terms of their hydrogen trapping behaviour. However, there is limited understanding about their hydrogen trapping behaviour.

As part of this study, the hydrogen trapping behaviour of martensitic stainless steels and the different trap sites in the material are investigated, especially the role of secondary hardening precipitates, that are formed during tempering - as trap sites. The material is subjected to various heat treatments and subsequently the effects of the microstructure on the trapping behaviour are examined by using thermal desorption spectroscopy. Size, proportion and distribution of the precipitates affect their hydrogen trapping behaviour. A high number of finely distributed precipitates in the material acting as hydrogen traps, will affect the hydrogen embrittlement behaviour of the investigated alloy. Furthermore, hydrogen mapping and high-resolution microstructural characterizations are conducted to gain an in-depth view on hydrogen trapping of the microstructure in this material class.

Damage evolution investigation of two hydrogen-charged pipeline steels using X-ray micro-CT

Robin Depraetere[1], Wim De Waele[1], Margo Cauwels[2], Tom Depover[2], Kim Verbeken[2], Stijn Hertelé[1]

[1]Ghent University, Department of Electromechanical, Systems and Metal Engineering, Technologiepark-Zwijnaarde 46, 9052 Zwijnaarde, Belgium, robidpra.Depraetere@ugent.be

[2]Ghent University, Department of Materials, Textiles and Chemical Engineering, Technologiepark-Zwijnaarde 46, 9052 Zwijnaarde, Belgium

X-ray micro-CT *Fracture* *Hydrogen embrittlement*

Abstract In the light of the energy transition, part of the current natural gas pipeline grid will be converted to hydrogen gas pipelines. One of the challenges of this conversion is the well-acknowledged reduction in mechanical properties of steel in the presence of hydrogen, commonly known as “hydrogen embrittlement”. The steels in-use are of variable characteristics (strength grade, rolling process), resulting in different plasticity and fracture behaviours. The present work investigates the effect of hydrogen on the fracture behaviour of two pipeline steels with different microstructural characteristics. A relatively older grade API 5L X56 steel produced by normalized rolling is compared with a relatively newer grade API 5L X70 steel produced by thermomechanically controlled processing (TMCP). Tensile tests were performed on smooth and notched round bar specimens that were hydrogen pre-charged electrochemically (ex-situ), and compared to tests on uncharged specimens as a reference. The fractured specimens were scanned using High Resolution X-ray Computed Tomography to visualize and quantify the damage underneath the fracture surface. Statistics regarding the void size distribution and void shapes are provided. The fracture process in the absence of hydrogen is significantly different for the two steels which is attributed to their differences in microstructure. The presence of hydrogen appears to accelerate the fracture processes in both steels. Significant hydrogen enhanced lateral void growth is observed for the API 5L X70 steel, while the void shapes of the API 5L X56 steel are only slightly affected. Based on these observations, the possibly active HE mechanisms are discussed for the two investigated pipeline steels.

Hydrogen-accelerated/decelerated fatigue crack propagation in Ni-based superalloy 718

Osamu Takakuwa[1], Yuhei Ogawa[2]

[1]*Department of Mechanical Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka, 819-0395, Japan, takakuwa.osamu.995@m.kyushu-u.ac.jp*

[2]*National Institute for Materials Science, 1-2-1, Sengen, Tsukuba, Ibaraki, 305-0047, Japan, yuhei.ogawa.bz@gmail.com*

Ni-based superalloy *Fatigue crack growth* *Crack closure*

Abstract Ni-based superalloy 718 (Alloy718) has superior mechanical properties: high-temperature performance with excellent strength-ductility balance, utilized with the view to having better durability even in severe environments, e.g., hydrogenating environment, such as oil well pipes, rocket engines, etc. Alloy718 has high susceptibility to hydrogen embrittlement (HE) even with the aforementioned superior properties. For the practical usages of Alloy718 in the severe hydrogenating environment, HE events, especially in the fatigue process, should be elucidated to devise a fabrication process to reduce the susceptibility to HE. Alloy718 has ordered coherent precipitates (γ'' (Ni_3Nb) and γ' ($Ni_3(Al, Ti)$)), and a semi-coherent δ (Ni_3Nb) nucleated along grain boundaries (GB), achieving fine-grained microstructure as the δ phase works as an obstacle against grain growth during hot working and solution treatment. Grains grow much more prominent when the processes are carried out beyond the temperature range of the δ phase nucleation. The metallurgical state of the fine-grained microstructure accompanied by δ phase and the coarse-grained microstructure without δ phase are called "δ-FG" and "CG", respectively, in the present study.

Thermal H-gas charging under pressure of 100MPa at 543K for 200 ~ 300h was performed prior to the fatigue crack growth (FCG) tests, which introduced hydrogen content of 90 ~ 100 wt.ppm. Then, some FCG tests were carried out according to investigate extensive FCG properties where stress intensity factor range, ΔK, ranging from its threshold level: ΔK-decreasing test for $\Delta K < 20$ MPa m$^{1/2}$ and ΔK-increasing test for $\Delta K > 20$ MPa m$^{1/2}$. The ΔK-increasing test controlled a load range, ΔP, kept constant that ΔK increased spontaneously as the crack grew. The ΔK-decreasing test controlled, ΔP, decreased as the crack grew with a decreasing rate of 2 MPa m$^{1/2}$/mm.

The FCG acceleration/deceleration events induced by the presence of H in δ-FG and CG, can be divided by ΔK levels: at $\Delta K < 15$ MPa m$^{1/2}$, no acceleration of the FCG was detected for both δ-FG and CG, but rather a deceleration was observed in CG. The crack propagated with transgranular aspects along mainly {111} slip plane (SPs) or annealing twin boundaries (ATBs). At $\Delta K > 15$ MPa m$^{1/2}$, the autocatalytic acceleration occurred in δ-FG. In this case, the cracks preferentially propagated along the δ-decorated GBs. In contrast to δ-FG, CG did not exhibited the FCG acceleration as well as $\Delta K < 15$ MPa m$^{1/2}$. The crack growth path was not affected by ΔK levels and was either the {111} SPs or ATBs, responsible for the crack deflection at all ΔK levels. Hence, it is presumed that the crack deflection invoked the intense roughness-induced crack closure (RICC), which directly reduced the effective stress intensity factor range, ΔK_{eff}, resulting in the FCG deceleration in CG with the presence of H.

Study of hydrogen trapping at carbides after gaseous charging at elevated temperatures and its impact on mechanical properties

Liese Vandewalle, Tom Depover, Kim Verbeken

Ghent University; Department of Materials, Textiles and Chemical Engineering; Sustainable Materials Science, Tech Lane Ghent Science Park 46, B-9000 Ghent, Belgium

Liese.Vandewalle@UGent.be

Hydrogen trapping *Thermal desorption spectroscopy* *Gaseous charging*

Abstract The introduction of hydrogen in the steel may occur during service, typically at temperatures close to room temperature, but also various production steps, at elevated temperatures, may lead to considerable hydrogen uptake. Introducing carbides in a steel microstructure has been proposed as an interesting strategy for improving the resistance against hydrogen embrittlement while maintaining a sufficiently high strength level.

In this study, the hydrogen absorption and trapping in carbide containing steels from a very low hydrogen partial pressure atmosphere at elevated temperatures is evaluated and compared to the case of electrochemically introduced hydrogen. Generic Fe-C-X steels (with X=V or Ti), varying in carbon content, are studied. The steels are subjected to a quench and temper treatment, where tempering is performed in a dilute hydrogen gas atmosphere for various times. Detailed microstructural analysis via SEM and TEM together with characterization via thermal desorption spectroscopy (TDS) and hot extraction are performed to analyze the hydrogen trapping ability of the different types of carbides. Additionally, tensile tests are performed to evaluate the effect on the mechanical properties.

Significantly different behavior is observed after gaseous hydrogenation. The Ti-alloyed steels show significant hydrogen uptake at elevated temperatures. TDS analysis revealed strong trapping at the bulk carbon-vacancies inside the (undissolved) TiC. On the other hand, no hydrogen introduction is observed in the Fe-C-V steel containing only precipitated carbides. Lowering the austenitization temperature of the Fe-C-V steels to a temperature where undissolved carbides remain present, resulted in a limited introduction of weakly trapped hydrogen. This is in strong contrast to the hydrogen trapping behavior after electrochemical charging. Additionally, no significant embrittlement could be observed after purely gaseous charging in contrast to the electrochemical charging.

Crack Detection and Crack Length Measurement in Round Specimen using Multiple Potential Drop Measurements

Jürgen Bär

Universität der Bundeswehr München, Institute of Materials Science, D-85577 Neubiberg, Germany,

juergen.baer@unibw.de

Fatigue *Crack detection* *Potential Drop measurement*

Abstract The early detection of cracks in fatigue experiments on specimens with round cross-sections is often difficult to perform. Due to the unknown location of the crack initiation site on the circumference of the specimen displacement measurements or potential drop measurements do not provide satisfactory results. Previous investigations [1-2] have shown that cracks can be detected and localized early using a multiple potential probe and a simple geometrical model in which the measured potential drop values are treated as vectors.

In this work, the possibilities for determining the crack size and crack geometry that result from this method are examined in more detail. The experimental verification was undertaken by fatigue experiments on a high alloyed steel. The crack size and shape were marked on the fracture surface with overloads introduced in defined intervals. The initiation of cracks at defined positions was forced by introducing notches with an engraving laser.

The crack length is determined from the length of the normal vector. For the calculation of the crack length different mathematical solutions were compared. The widely used Johnson equation [3] shows a good match especially for longer cracks, in case of short cracks larger deviations are observed. For different length to depth-ratios of the cracks, however, differences in the relationship between the length of the normal vector and the crack length take place.

[1] 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.

[2] Nahbein, M.; Bär, J.; 2022. Determination of Cracks using Multiple DC Potential Drop Measurements – Experimental Verification of an Advanced Model, Procedia Structural Integrity 42 (2022) 433-440; DOI: 10.1016/j.prostr.2022.12.055

[3] Johnson, H. H.; 1965. Calibrating the Electric Potential Method for Studying Slow Crack Growth, Materials Research and Standards 5, No. 9, 442-445.

Fatigue Crack Growth Study on the Critical Location of the Portuguese Air Force Epsilon TB-30 Aircraft

T. Barros[1], V. Infante[2], P. Gamboa[3], L. Alexandre[4], A. Moura[5]

[1]Academia da Força Aérea, Granja do Marquês, Pêro Pinheiro, 2715-021, Portugal

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

[3]Centre for Mechanical and Aerospace Science and Technologies (C-MAST-UBI), Universidade da Beira Interior, Covilhã, 6201-001, Portugal

[4]NOVA LINCS, Universidade da Beira Interior, Covilhã, 6201-001, Portugal

[5]Stratosphere S.A., Avepark – Science and Technology Park, Guimarães, 4805-017, Portugal

Fatigue Crack Growth *Experimental tests* *Computational simulations*

Epsilon TB-30 *Portuguese Air Force* *Flight loads*

Abstract The initiation and propagation of fatigue cracks in aircraft structures are caused by cyclic stresses that are inherent to the flight condition. As military aircraft perform demanding maneuvers with a wide range of load factor levels, the growth of these damages is of particular importance and shall be duly monitored to prevent an unexpected failure of the component. In order to monitor the operation of the Portuguese Air Force Epsilon TB-30 fleet that performs basic and elementary piloting instruction, two systems were installed in these aircraft, allowing the recording of load factor data in the aircraft center of gravity and strain data in two critical locations.

This study aims to evaluate and compare the growth of fatigue cracks caused by different flight regimes that comprise the different pilot instruction modulus. This comparison was performed through experimental tests and computational simulations that included the application of real flight load sequences to a 2024-T351 aluminum specimen that is representative of one the aircraft critical locations, in which an initial semi-circular notch was inserted. Results from these tests and simulations provided knowledge about the component behavior regarding the fatigue of materials and may be used by the Portuguese Air Force to adjust the aircraft inspections according to the operation regime.

Application of Artificial Neural Networks to Aircraft Mission Classification

T. Barros[1], L. Alexandre[2], V. Infante[3], P. Gamboa[4], A. Moura[5]

[1]*Academia da Força Aérea, Granja do Marquês, Pêro Pinheiro, 2715-021, Portugal*

[2]*NOVA LINCS, Universidade da Beira Interior, Covilhã, 6201-001, Portugal*

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

[4]*Centre for Mechanical and Aerospace Science and Technologies (C-MAST-UBI), Universidade da Beira Interior, Covilhã, 6201-001, Portugal*

[5]*Stratosphere S.A., Avepark – Science and Technology Park, Guimarães, 4805-017, Portugal*

Fatigue of Materials *Artificial Neural Networks* *Crack Growth*

Epsilon TB-30 *Mission Classification* *Structural Health Monitoring*

Abstract Military aircraft perform a wide range of missions that include demanding maneuvers at high load factor levels, inducing stresses in the aircraft structure. Fatigue of materials that is caused by the variable amplitude loading in flight may lead to the initiation and propagation of cracks and consequently to components' failures. The need to monitor the severity of the Portuguese Air Force Epsilon TB-30 led to the installation of structural health monitoring systems in this fleet. The recording of large amount of load factor and strain data allowed the application of Artificial Neural Networks to classify the missions carried out by this fleet, considering the behavior of the structure to flight loads and fatigue. Based on fatigue crack growth simulations that comprised the application of flight load factor spectra to one of the aircraft critical locations, a mission dataset was developed, assigning a fatigue classification to each mission. Results show that this methodology may be used to classify the Epsilon TB-30 mission with an Accuracy and F1 score of approximately 90%.

Study of Fatigue Crack Propagation in Modified CT Specimens using Artificial Neural Networks

B. Santos[1], T. Barros[1], V. Infante[2], R. Baptista[3]

[1]*Academia da Força Aérea, Granja do Marquês, Pêro Pinheiro, 2715-021, Portugal*

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

[3]*CDP2T, Escola Superior de Tecnologia de Setúbal, Instituto Politécnico de Setúbal, 2910-761 Setúbal, Portugal*

Modified CT specimens *Stop Drill Hole* *Fatigue crack propagation*

Crack-growth arrest *Artificial Neural Networks* *Variable amplitude fatigue*

Abstract The focus of this study is to investigate fatigue crack propagation in modified Compact Tension (CT) specimens employing a combination of finite element method (FEM) simulations, experimental tests, and artificial neural networks (ANNs). This research aims to assess the potential of ANNs in accurately predicting the mechanism of fatigue crack growth in engineering materials under flight loads with variable amplitude loading. The CT specimens are modified using Stop Drill Hole (SDH) technique with different hole diameters and centre coordinates.

Initially, a FEM simulation is performed to determine the fatigue crack growth path for each configuration and generate relevant data.

Afterwards, experimental tests are conducted to validate FEM results. The fatigue crack growth path is monitored and recorded. The experimental results are then compared to numerical data.

The final stage of the study involves the use of machine learning techniques, particularly ANNs, to predict fatigue crack growth. The ANN model is trained using data obtain at the previous stages of the study. The predicted results are then compared to the experimental data, and the behaviour and accuracy of the ANN model is measured. After that, the trained model is then used to predict the fatigue crack growth path for a new set of data.

Determining the Length of Short Surface Cracks with DC Potential Drop Measurements

Naveen Kumar Kanna, Jürgen Bär

Universität der Bundeswehr München, Institute of Materials Science, D-85577 Neubiberg, Germany,

naveen.kanna@unibw.de

Fatigue *Crack length measurement* *DC Potential Drop*

Abstract The DC Potential drop measurement technique is often used to measure the crack length in fatigue tests. The resolution of this method advances with the crack length. In consequence the determination of the length of short fatigue cracks is not very precise, especially when the Johnson-equation [1] is used to calculate the crack length from the measured potential drop.

In this work the propagation of short fatigue cracks emanating from the surface in a low alloyed steel is investiagted. To get a defined crack initiation site a small notch is prepared using a laser engraving system on the surface of the specimen. The crack length is measured with a DC potential drop method by copper wires laser spot welded onto the surface at a distance of 1 mm below and above the laser notch. To mark the size of the half elliptical cracks on the fracture surface, overloads were introduced in fixed intervals. The individual cracked area as well as the crack depth and length on the surface were measured using an image analysis program. In this experimental work beside the Johnson equation and a polynomal approach a simple approach based on a root function suggested by Tiedemann [2] was used:

$$a = q \cdot \left(\frac{U}{U_0} - 1\right)^r + a_{notch}$$

whereby the fitting parameter q is related to the slope and the parameter r with the degree of curvature of the fitting curve.

The Tiedemann equation showed the best agreement with the measured data for both short and long cracks, thus providing a simple way to determine the length of semi-elliptical fatigue cracks on a surface acquired from potential data.

[1] Johnson, H. H.; 1965. Calibrating the Electric Potential Method for Studying Slow Crack Growth, Materials Research and Standards 5, No. 9, 442-445.

[2] Tiedemann, D.; 2016. Zweidimensionale Ausbreitung kurzer Risse unter Berücksichtigung bruchmechanischer und kontinuumsmechanischer Aspekte. PhD.-Thesis, Universität der Bundeswehr München.

Joint Efficiency of Friction Stir Welded Additively Manufactured Thermoplastic Components

Pedro Rendas[1], Lígia Figueiredo[2], Pedro Melo[1], Bruno Soares[1,3], Catarina Vidal[1,3,*]

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

[2]Bioceramed - Cerâmicos para Aplicações Médicas S.A, São Julião do Tojal, 2660-360, Portugal

[3]Laboratório Associado de Sistemas Inteligentes, LASI, 4800-058, Guimarães, Portugal

c.vidal@fct.unl.pt

Friction Stir Welding *Thermoplastics* *Additive Manufacturing*

Abstract The use of thermoplastic materials with material extrusion (ME) additive manufacturing (AM) techniques like Fused Deposition Modelling (FDM) are becoming increasingly popular for high-performance applications. Additive manufacturing's ability to produce complex geometries coupled with the high strength-to-weight ratio of some thermoplastics has increased the potential of additively manufactured thermoplastic components in demanding fields such as aerospace and medicine. However, the dimensional limitations of AM equipment and the components anisotropy resulting from AM deposition may require joining procedures to combine different components. Considering this, the use of conventional thermoplastic welding techniques can result in lower joint performance associated with the void defects typical of FDM deposition. Here, Friction-based welding techniques such as stationary shoulder friction stir welding (SS-FSW) have the potential to produce strong weld regions and increase the joint performance by disrupting polymeric chain alignments created by AM deposition. The use of assisted heating in SS-FSW helps to overcome the low thermal conductivity of thermoplastics and control cooling rates, reducing warping defects and promoting crystalline formation in semi-crystalline thermoplastics. This work investigates the effects of process parameters on the joint efficiency of SS-FSW thermoplastic joints by performing butt welds on additively manufactured Polylactic Acid (PLA) plates. Joint performance is accessed through uniaxial testing of tensile specimens cut perpendicularly to the weld direction. Results indicate that the presence of void defects on the retreating side can be reduced through the use of assisted heating, leading to an increase in joint efficiency.

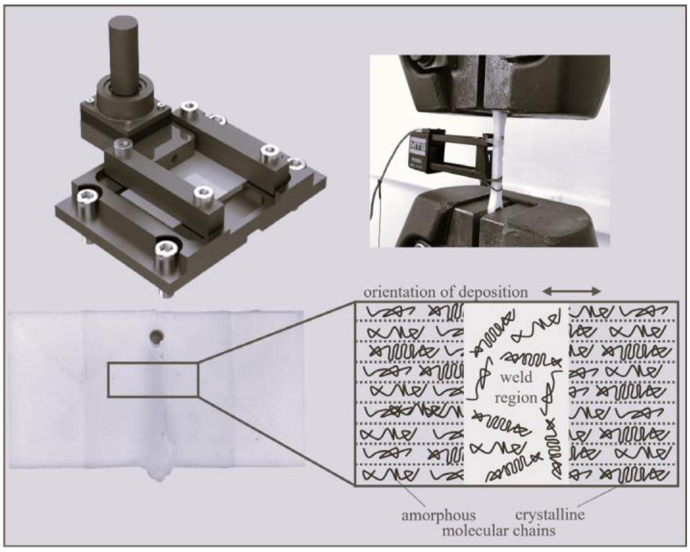

Figure 1 *– SS-FSW of additively manufactured PLA plates*

Self-sensing metallic material based on piezoelectric ceramic microparticles envisaging structural health monitoring applications

Pedro M. Ferreira[1], Miguel A. Machado[1, 2], Marta S. Carvalho[1, 2], Catarina Vidal[1, 2, *]

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

[2]*Laboratório Associado de Sistemas Inteligentes, LASI, 4800-058 Guimarães, Portugal*

c.vidal@fct.unl.pt

Self-sensing material | *Piezoelectric microparticles* | *Structural Health Monitoring (SHM)*

Abstract Predictive maintenance through a condition-based continuous monitoring perspective is a predominant matter in Structural Health Monitoring (SHM). In metallic structures, this can be achieved by using embedded sensors (ESs) or through surface sensors (SSs). These last are exposed to external environmental conditions that can be quite severe, damaging sensors and compromising their functionality. For this reason, there has been an increasing interest in researching ESs and their inherent manufacturing processes by the scientific community. These sensors use smart materials to convert external *stimuli*, such as stress, strain, or temperature, into electrical output signals.

In the last few years, much effort has been dedicated to assess the possibility of incorporating these materials in metallic components. However, conventional manufacturing processes are often associated with high processing temperatures due to the fusion of the base material. For this reason, solid-state processing techniques have been studied to allow the incorporation of piezoelectric ceramic particles in metallic materials.

This work presents a self-sensing material fabricated by Friction Stir Processing (FSP). The use of this solid-state technology made possible the piezoelectric functionalization of aluminum-based parts by incorporating piezoelectric ceramic microparticles into different aluminium alloys. The effects of different piezoelectric ceramic particles on the electromechanical properties were evaluated in terms of the electrical response and mechanical strength. The self-sensing materials revealed an average electrical sensitivity of about 10.5×10^{-2} mV/ ε. Microhardness measurements and uniaxial tensile tests showed that the inclusion of these particles into aluminium-based parts affect the material's properties, namely increase the mechanical strength and decrease the electrical conductivity, when compared to metallic parts without particles. Moreover, the polarization process revealed to be fundamental for improving the materials' self-sensing capability.

Evaluation of the tensile properties of X65 pipeline steel in compressed gaseous hydrogen using hollow specimens

Alessandro Campari[1], Florian Konert[2], Jonathan Nietzke[2], Oded Sobol[2], Nicola Paltrinieri[1], Antonio Alvaro[3]

[1] Norwegian University of Science and Technology (NTNU), Department of Mechanical and Industrial Engineering, Richard Birkeland vei 2b, 7034 Trondheim, Norway

[2] Bundesanstalt für Materialforschung und -prüfung (BAM), Department of Component Safety, Unter Den Eichen 87, 12205 Berlin, Germany

[3] SINTEF, SINTEF Industry, Richard Birkeland vei 2b, 7034 Trondheim, Norway

Hydrogen embrittlement *In-situ tensile test* *Hollow specimens*

Abstract Hydrogen has great potential into the decarbonization process of the energy and transport sectors, thus helping to mitigate the urgent issue of global warming. It can be sustainably produced through water electrolysis with potentially zero emissions, and efficiently used in fuel cell systems. Despite its environmental advantages, hydrogen is an extremely flammable substance and its interaction with most metallic materials could result in their mechanical properties degradation to an extent that could make them inherently unsafe. Extensive material testing under realistic operating conditions is required to determine the criteria under which hydrogen-induced damage is to be expected. In-situ slow strain rate tensile (SSRT) test is an option that allow the quantification of the behavior of metals in hydrogenated environments. The standardized procedure for testing in-situ the pressurized gaseous hydrogen effect on metals consists of the utilization of an autoclave as a containment volume. Testing inside an autoclave is difficult, expensive, and time-consuming, and requires specialized equipment and trained personnel. A relatively recent method to circumvent these issues and provide affordable and reliable test results consists in using hollow specimens as the gas containment volume, thus applying the hydrogen pressure inside rather than outside the specimen. This experimental setup allows us to minimize the volume of hydrogen and perform the tests safely and effectively. This study focuses on the evaluation of tensile properties of X65 vintage pipeline steel tested in a high-pressure hydrogen environment using hollow specimens. A constant nominal strain rate of $1 \cdot 10^{-6}$ s^{-1} is applied. Tests are performed at several pressure levels (from 6 to 20 MPa) to evaluate the effect on the reduced area at fracture (RA). In this way, this study provides insights on the applicability of novel, reliable, and safer testing method which can be used to assess HE, particularly in relation with hydrogen-induced loss of ductility in metallic material.

Fatigue crack closure of nuclear steels: effect of load ratios

Théotime Asselin[1,2], Gilbert Hénaff[1], Olivier Ancelet[2], Guillaume Benoit[1], Florence Hamon[1]

[1]*INSTITUT Pprime, Département Physique et Mécanique des Matériaux, Téléport 2, 1 avenue Clément Ader, 86961 Futurocsope Chasseneuil Cedex, France*

theotime.asselin@framatome.com

[2]*Framatome, 1 pl. Jean Millier, 92400 Courbevoie, France*

Fatigue *Crack closure* *DIC*

Abstract During their life, nuclear reactor components are subjected to a primary stress-controlled loading (155 bar pressure), to which a secondary strain-controlled loading is added. The secondary loading can originate from the thermal transients caused by shutdowns and restarts of the nuclear units and may lead to the initiation of a fatigue crack. It is therefore necessary for the manufacturer and the operator to correctly understand fatigue crack initiation and growth in order to improve the design rules. Part of the research conducted by Framatome is then focused on the comprehension of fatigue crack growth and crack closure effects under specific loadings.

A cylindrical specimen containing an initial spherical surface defect is introduced, on which a paint speckle is applied on the surface near the defect. Potential drop method is employed to characterize the crack initiation and growth, and DIC is used to compute the displacements fields around the crack tip.

Tests were performed on two different steel grades (304L stainless steel and French Reactor Pressure Vessel steel 18MnD5) at positive and negative load ratios and crack closure measurements were performed, allowing to consider the effective stress intensity factor as a possible fatigue crack growth driving force.

Study of Relevance of Alloying Elements in Estimating Cyclic Yield Stress and Ramberg-Osgood Parameters of Steels

Tea Marohnić*, Ela Marković, Robert Basan

University of Rijeka, Faculty of Engineering, Vukovarska 58, 51000 Rijeka, Croatia

tmarohnic@riteh.hr

cyclic parameters *statistical analysis* *alloying elements*

Abstract In order to reduce the number of needed experiments, efforts are being made ever since the mid-20th century to estimate parameters of complex nonlinear cyclic and fatigue behavior of materials from readily available properties such as yield stress, tensile strength, hardness, etc. Approaches vary from analytical that are still being developed and used due to their simplicity and practicality, as did Derrick and Fatemi, 2022 for additively manufactured metals, to those based on machine learning techniques that provide a possibility to better describe relationships between tensile properties and cyclic and fatigue behavior of materials. Regardless of the approach, but especially important when it comes to machine learning algorithms, is to achieve the proper balance of the number of learning examples (datasets), input and output variables. Thus, a new approach to the estimation of cyclic and fatigue behavior related parameters of unalloyed, low-alloyed and high-alloyed steels was developed and proposed in Marohnić, 2016, 2017. As an integral part, and prior to modelling of the aforementioned relationships using artificial neural networks, it includes a detailed statistical analysis for identification of monotonic properties relevant for the estimation of each particular cyclic and fatigue parameter and each steel subgroup. This ensures that only input variables that significantly contribute to the estimations are used, and reduces the dimensionality. Chemical composition, along with heat treatment, predominantly dictates the material's microstructure, and consequently, mechanical properties and behavior, and is more commonly available than microstructure or specifics of the heat treatment. With the assumption that the most relevant alloying elements, when combined with previously determined relevant monotonic properties could improve the estimations, statistical analysis of relevance of alloying elements for estimation of parameters and cyclic and fatigue behavior of steels is performed in this study.

References

Derrick, C., Fatemi, A. (2022). Correlations of fatigue strength of additively manufactured metals with hardness and defect size. *Int J Fatigue*, 106920. https://doi.org/https://doi.org/10.1016/j.ijfatigue.2022.106920

Marohnić, T., Basan, R. (2016). Study of Monotonic Properties' Relevance for Estimation of Cyclic Yield Stress and Ramberg-Osgood Parameters of Steels. *J Mater Eng Perform 25*(11). https://doi.org/10.1007/s11665-016-2311-1

Marohnić, T., Basan, R. (2018). Estimation of cyclic behavior of unalloyed, low-alloy and high-alloy steels based on relevant monotonic properties using artificial neural networks. *Materwiss Werksttech*, *49*(3). https://doi.org/10.1002/mawe.201700192

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Comparison of hydrogen embrittlement susceptibility of martensitic stainless steel subjected to conventional and cryogenic heat treatment

Mirjam Bajt Leban[1], Bojan Zajec[1], Bojan Podgornik[2], Tadeja Kosec[1]

[1]Slovenian National Building and Civil Engineering Institute, Dimičeva 12, 1000 Ljubljana, Slovenia

mirjam.leban@zag.si

[2]Institute of Metals and Technology

Martensitic stainless steel *Cryogenic heat treatment* *Hydrogen embrittlement*

Cryogenic heat treatment is often used in combination with other heat treatments such as quenching and tempering to achieve specific properties in the steel. The process is commonly used in the automotive, aerospace, and tool manufacturing industries, where high-performance materials are required.

Within this research, susceptibility to hydrogen embrittlement (HE) of X17CrNi16-2 martensitic stainless steel conventionally and cryogenic heat treated was evaluated and compared. Following sets of specimens were prepared for this study: 1) austenitization at 1050 ^oC followed by quenching and post tempering at 480 ^oC and 2) austenitization at 980 ^oC followed by quenching and post tempering at 600 ^oC. One part of each specimens' set was after reaching room temperature during quenching exposed to cryogenic treatment in liquid nitrogen for 24 hours. Extensive microstructural study of this steel prior to hydrogen charging is presented elsewhere[1]. Slow strain rate test (SSRT) with the strain rate 10^{-6} /s was conducted during electrochemical hydrogen charging in aqueous solution of 0.732 g NaOH/L and 4.77 g $Na_2B_4O_7$□$10H_2O$ at charging current density of 0.1 mA/cm^2.

The results of SSRT clearly shows decrease of mechanical properties when specimens were undergoing hydrogen charging. In addition, chosen heat treatment austenatization/ tempering temperature also shows significant impact on HE susceptibility. No clear impact of cryogenic treatment on HE susceptibility was observed from the data gained during this investigation.

1. Jovičević-Klug, P., Jovičević-Klug, M., Sever, T., Feizpour, D. & Podgornik, B. Impact of steel type, composition and heat treatment parameters on effectiveness of deep cryogenic treatment. *Journal of Materials Research and Technology* **14**, 1007–1020 (2021).

Fatigue fracture in advanced ultrahigh-strength steels tested under gaseous hydrogen charging

Supriya Nandy[1], Sakari Pallaspuro[2], Pekka Moilanen[1], Renata Latypova[2], Janne Pakarinen[1], Jukka Kömi[2], Elina Huttunen-Saarivirta[1]

[1]VTT Technical Research Centre of Finland Ltd, Kemistintie 3, Espoo 02044, Finland

supriya.nandy@vtt.fi

[2]Materials and Mechanical Engineering, Centre for Advanced Steels Research, University of Oulu, Finland

Advanced high-strength steels *Gaseous hydrogen charging* *Fatigue*

Abstract. Third-generation advanced high-strength steels are a modern group of structural materials that have excellent mechanical properties, typically originating from bcc+fcc multiphase microstructures. These are being adopted in industry to respond to ever-increasing strength requirements, and to enable reduced material thicknesses in load-bearing structures. However, a weak point of high-strength steels is their susceptibility to hydrogen embrittlement (HE). Therefore, it is vital to understand the mechanisms by which hydrogen impairs their performance. In particular, understanding the behaviour under dynamic loading situations that occur due to repeated charging-discharging cycles, i.e., fatigue, becomes imperative.

In this work, we investigate the fatigue behaviour of 1.3 – 1.4 GPa yield strength steels as tested under gaseous hydrogen charging. With an aim to understand the role of residual austenite in HE, a lath-martensitic and a martensitic-austenitic steel were chosen. The selected steels were subjected to room-temperature fatigue testing with R = -1 in air (133 Hz) and at 100 bar gaseous H environment (16 h pre-charging) using an in-house HyBello test machine (0.03 Hz). Results show that the investigated steels exhibit dramatically reduced fatigue life and endurance limit in a high-pressure H_2 environment. Fatigue life is most impacted at a lower load range compared to that at a higher load range. The S-N curves of these steels exhibit bi-linear slopes, suggesting a change in fatigue crack initiation micromechanism. Fractographic evidence indicates striking differences in failure mechanisms when subjected to H_2. The uncharged fracture surface exhibits clear fatigue striations in contrast to the H-charged specimens. The absence of striations designates that stage-II stable crack growth does not occur in presence of hydrogen. Contrary to tests in the air, H-charged specimens have extensive micro-void coalescence at the last stage of fatigue. Thus, hydrogen shortens the fatigue life of these steels remarkably, mainly by the faster stable crack growth rate, as addressed via microstructural characterisation.

Evaluating hydrogen embrittlement susceptibility of a duplex stainless steel

L.B. Peral[1,2], A. Díaz[1], C. Rodríguez[2], J.M. Alegre[1], I.I. Cuesta[1]

[1]*Structural Integrity Research Group (GIE). University of Burgos. Spain*

[2]*SIMUMECAMAT Research Group. University of Oviedo. Spain*

2205 Duplex Stainless Steel *In-situ tests* *Aging treatment*

Abstract Duplex stainless steel (2205 DSS) has been widely used in petrochemical industry and marine environments because of their outstanding strength, weldability, and corrosion resistance in chlorine environments. However, 2205 DSS is sensitive to hydrogen embrittlement what has limited its use to work in hydrogen environments at high pressure.

In this study, hydrogen embrittlement susceptibility of a 2205 DSS, with different microstructures, has been evaluated by means of in-situ tests in a high pressure hydrogen reactor, able to work up to 300 bar. Hydrogen embrittlement susceptibility has been studied by slow strain rate tensile tests (SSRT) according to ASTM G142. Smooth and notched specimens have been employed. Hydrogen damage is discussed through the microstructural features analysis and the operative hydrogen embrittlement mechanisms. In addition, these mechanisms and the observed embrittlement are numerically captured in a coupled model for hydrogen-assisted cracking that combines hydrogen transport and phase field damage.

Material characteristics relevant for resistance to fatigue crack propagation in structural steels

Tomáš Vojtek[1], Radek Kubíček[1,2], Pavel Pokorný[1], Pavel Hutař[1]

[1]*Institute of Physics of Materials, Czech Academy of Sciences, Žižkova 22, 616 62 Brno, Czech Republic*

[2]*Faculty of Mechanical Engineering, Brno University of Technology, Technická 2, 616 69 Brno, Czech Republic*

Fatigue threshold *Oxide-induced crack closure* *Cyclic softening*

Abstract Our research focuses on structural integrity of engineering components with the emphasis on fatigue fracture. Material characteristics obtained under monotonic loading may not necessarily be relevant for studying of behaviour under cyclic loading. In particular, properties such as those from a tensile test or the fracture toughness are often thought to be the most important ones, however, this may not be true especially for high cycle fatigue, where the zone of plastic deformation has microscopic dimensions. Resistance to fatigue crack propagation is given by the threshold stress intensity factor range ΔK_{th}. Our work focuses on identification of the constituents of ΔK_{th}, their separation and description of the related mechanisms and factors that may influence them.

The true (intrinsic) material resistance to fatigue crack propagation is the effective threshold $\Delta K_{eff,th}$, which is surprisingly well predictable for most metals owing to the simple equation $3/4 \cdot Eb^{0.5}$. Note that the only elastic modulus E and the Burgers vector b is included, which means that there is no dependency of the intrinsic resistance to fatigue crack growth on the yield stress or on the tensile strength. For steels, this value is about 2.5 $MPa \cdot m^{0.5}$. Therefore, extrinsic mechanisms such as crack closure are responsible for most of the threshold value as well as for differences between materials. The most widely used models of plasticity-induced crack closure predict constant values independently of material. The reason is that they consider only monotonic material properties for simulations of cyclic plasticity. Cyclic softening and hardening should also be taken into account to correctly asses the ratio between monotonic and plastic zone sizes. In the near-threshold regime, only a small portion of the positive part of the cycle is effective. For example, if ΔK_{th} is equal to 16 $MPa \cdot m^{0.5}$ at $R = -1$, the effective threshold forms only about 16% of this value. When only the positive part of the cycle is considered, the crack closure mechanisms are responsible for 2/3 of the resistance.

Since the residual fatigue life of components depends significantly on the accurate value of ΔK_{th}, our work has been focused on resolving questions such as the scatter of the experimentally obtained ΔK_{th} under various testing conditions and identification of the most important influencing factors. In structural steels, oxide-induced crack closure was identified as the cause of relatively high measured thresholds and their large variation observed under different conditions. Experimental techniques often overestimate the threshold due to loading history effects, which poses a problem for reliable and conservative damage-tolerance design. Our work helps to solve this situation by application of a technique reducing some of the effects (air humidity) and it helps to decide which of the influencing factors can be expected to be active in applications and which not.

Application features of distributed fiber-optic sensors based on Rayleigh scattering for gradient strain field measurement

Serovaev G.S., Matveenko V.P., Kosheleva N.A.

Perm Federal Research Center of the Ural Branch of the Russian Academy of Sciences, 614990, Perm, 13a, Lenina street

serovaev@icmm.ru

Distributed fiber-optic sensors *Rayleigh scattering* *Gradient strain field*

Abstract Monitoring the strain of various parts of a controlled structure is an important task for Structural Health Monitoring systems. Fiber-optic sensors, specifically point sensors using fiber Bragg gratings and distributed sensors using Raman, Brillouin, or Rayleigh scattering, are effective solutions for measuring strain and temperature. Distributed fiber-optic sensors are able to measure strain throughout the entire optical fiber length, while point sensors only detect changes in specific regions. Among distributed sensors, the Rayleigh backscattering method provides the best spatial resolution for measuring strain and temperature using a single-mode optical fiber.

This study presents results on measuring strain in uniform and gradient strain fields using distributed sensors based on Rayleigh backscattering and compares the results with point sensors based on fiber Bragg gratings. The study also shows how the length of a scattering profile fragment (gauge length) affects the accuracy of measuring non-uniform strain distribution. The experiments were conducted using surface-mounted fiber-optic sensors and sensors embedded in the material during manufacturing. The study focuses on polymer composite and thermoplastic materials used in additive manufacturing by fused deposition modeling. Obtained results demonstrate a satisfactory agreement between the values of strain obtained using point and distributed fiber-optic sensors.

The study was prepared in the framework of the program for the creation and development of the world-class scientific center «Supersonic» for 2020-2025 with the financial support of the Ministry of Education and Science of the Russian Federation (Agreement No. 075-15-2022-329 of April 21, 2022).

High temperature properties of Fe-10Al-4Cr-4Y_2O_3 nanocomposite

Petr Dymáček[1], Milan Jarý[1], Natália Luptáková[1], Štěpán Gamanov[1], Lenka Kunčická[1,2] Radim Kocich[1,2], Bohuslav Mašek[3], Jiří Svoboda[1]

[1]Institute of Physics of Materials CAS, Žižkova 22, 61662 Brno, Czech Republic
pdymacek@ipm.cz

[2] Faculty of Materials Science and Technology, VŠB – Technical University of Ostrava, 70800 Ostrava, Czech Republic

[3]Faculty of Electrical Engineering, University of West Bohemia, Univerzitní 8, 306 14 Plzeň, Czech Republic

ODS alloy *Nanocomposite* *Creep*

Abstract The creep and oxidation resistant Fe-based nanocomposites with high volume fraction of dispersed oxide precipitates have been investigated. The chemical composition Fe-10Al-4Cr-4Y_2O_3 seems as most suitable after several rounds of optimization. This alloy is called FeAlOY. Two principal ways of consolidation (i) hot rolling and (ii) hot rotary swaging (RS) are applied and its influence on microstructure and mechanical properties is systematically evaluated. The tensile properties in wide range of temperatures (RT-1300 °C) are compared with previous generation of ODS alloys that can be found in the open literature (see Fig. 1). Short term creep tests in tension and compression show promising results in the temperature range of 1100-1300 °C. Potential applications of the FeAlOY can be the pull rods of high temperature testing machines, gas turbine blades or furnace fan vanes. The necessary effort must be now focused on expanding the production from laboratory samples to larger industrial pieces.

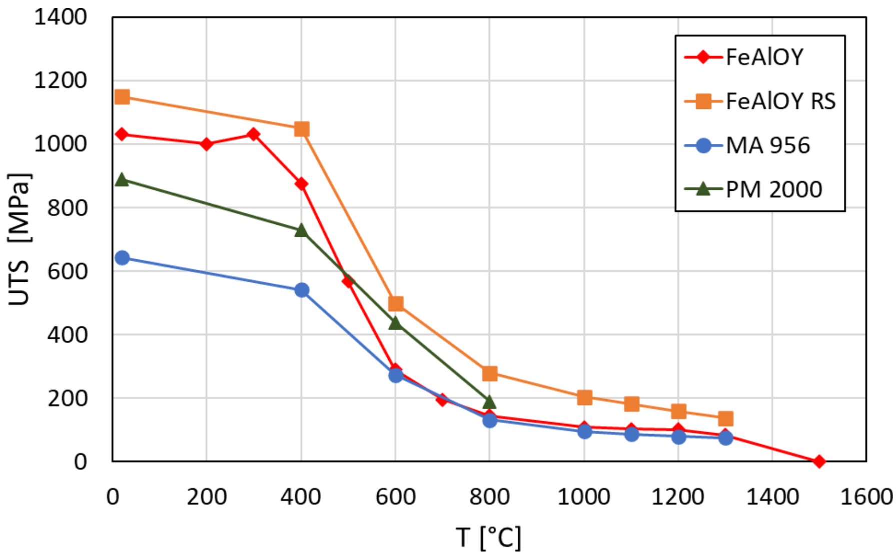


***Figure 1** – comparison of tensile strength of ODS alloys*

Predicting pure and mixed mode plastic zones using finite elements and artificial neural networks analysis

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

[1]*CDP2T, 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*

Finite Element Analysis *Artificial Neural Networks* *Plastic Zones*

Abstract Although in many applications' material behavior can be considered as linear elastic, some structural integrity approaches require material to be considered as elastic-plastic. In fracture mechanics when a crack front is considered, the materials' elastic-plastic properties lead to the formation of a plastic zone around the crack front. The size and shape of this zone depends on the material behavior, yield criterion considered and nominal loading conditions. This problem is especially complex under mixed mode conditions if non-proportional loading is present, where the shape and size of the plastic zone evolves during the loading cycle. Several approaches to the problem can be used. Analytical models, consider the theoretical stress distribution around the crack front and a yielding criterion to determine the shape and size of the plastic zone. These approaches are normally based on fracture mechanics parameters such as the stress intensity factor. Numeral methods such as the finite element method, allow for a more accurate plastic zone determination based on specimen geometry and material model. Finally, artificial neural networks can learn from both numerical and experimental results to predict accurate plastic zones bases on different input parameters.

In this study both analytical and numerical input data is used to train an artificial neural network that can predict the shape and size of a plastic zone around a crack front on a CTS specimen under non-proportional mixed loading. The von Mises yield criterion was considered, allowing for the plastic zone contour determination. Then, on a more complex analysis, the network was trained to also determine the stress distribution around the crack front, based on the obtained numerical results. The results show that it is possible to train an artificial neural network to predict the size and shape of the plastic zone and the influence of the training data type and size and the influence of the different network parameters was analyzed. Achieving a fully trained network will reduce the computational cost for solving these problems in the future

Surface severe plastic deformation for improved fatigue properties and applications in the hydrogen sector

Thierry Grosdidier[1, 2], Marc Novelli[1, 2]

[1] Université de Lorraine, Laboratoire d'Etude des Microstructures et de Mécanique des Matériaux (LEM3 UMR 7239), 7 rue Félix Savart, BP 15082, Metz F-57073, France

[2] Université de Lorraine, Laboratory of Excellence on Design of Alloy Metals for low-mass Structures (DAMAS), Metz F-57045, France

severe plastic deformation *gradient structure* *hydrogen storage* *hydrogen embrittlement*

Abstract Various techniques enabling surface severe plastic deformation (SSPD) have been developed or optimized over the past years. This manuscript presents recent developments in the SSPD field that take advantages of having a deformed gradient surface with higher strength and improved "reactivity". After a short recall on some of the SSPD techniques, the importance of controlling the processing parameters (including temperature) to produce the adequate surface and subsurface modified microstructure is underline [1]. Then, after a short recall of the effect of these hardened gradient surfaces on mechanical properties and fatigue (see for example [2]), the interest of having an improved surface reactivity produced by SSPD is illustrated for different challenges in the hydrogen sector including solid state hydrogen storage and hydrogen embrittlement [3-5].

[1] T Grosdidier, M Novelli, Recent developments in the application of surface mechanical attrition treatments for improved gradient structures: processing parameters and surface reactivity, Materials Transactions 60 (2019), 1344-1355.

[2] Pierre Maurel, Laurent Weiss, Thierry Grosdidier, Philippe Bocher, How does surface integrity of nanostructured surfaces induced by severe plastic deformation influence fatigue behaviors of Al alloys with enhanced precipitation? International Journal of Fatigue, 140 (2020) 105792.

[3] K. Edalati, E. Akiba, W. J. Botta, Y. Estrin, R. Floriano, D. Fruchart, T. Grosdidier, Z.J. Horita, J. Huot, H.W. Li, H.J. Lin, Á. Révész and M. J. Zehetbauer, Impact of Severe Plastic Deformation on Kinetics and Thermodynamics of Hydrogen Storage in Magnesium and Its Alloys, J. Mater. Sci. Technol. 146, (2023), 221-239.

[4] K. Edalati, M. Novelli, S. Itano, H.W. Li, E. Akiba, Z. Horita, T. Grosdidier, Effect of gradient-structure versus uniform nanostructure on hydrogen storage of Ti-V-Cr alloys: Investigation using ultrasonic SMAT and HPT processes, J. Alloys Compd. 737 (2018) 337–346.

[5] M Novelli, K Edalati, S Itano, HW Li, E Akiba, Z Horita, T Grosdidier, Microstructural details of hydrogen diffusion and storage in Ti–V–Cr alloys activated through surface and bulk severe plastic deformation, International Journal of Hydrogen Energy 45 (2020), 5326-5336.

Advanced Acoustic Emission Signal Processing Techniques for Structural Health Monitoring

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

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

claudia.barile@poliba.it

Acoustic Emission *Structural Health Monitoring* *Empirical Mode Decomposition*

Abstract The innovation in material science and the introduction of new structural materials in the commercial and industrial market is forcing researchers to look for modern, sophisticated and advanced structural monitoring tool. Acoustic emission technique is one of the most widely used Structural Health Monitoring (SHM) tool. Despite its remarkable advantages over all other passive Non-Destructive Evaluation (NDE) tools, its applicability is constantly questioned. This can be attributed to the complex time-frequency characteristics of acoustic waves, especially when used in highly noisy environments or highly inhomogeneous structures. In this study, an advanced signal processing technique is used to analyse the acoustic signals generated by different failure modes of composite specimens.

Carbon fibre reinforced polymer (CFRP) composite specimens are tested in a short beam shear configuration. The acoustic emission signals generated by the specimens under load are recorded using a piezoelectric sensor. These recorded signals are analysed using an advanced signal processing approach based on Empirical Mode Decomposition (EMD). A cross-correlation based approach is used to analyse the Intrinsic Mode Functions (IMFs) of the decomposed signals to improve their signal-to-noise ratio. A method based on the arrival time and Pearson's moment correlation coefficient of the signal IMFs is used to discriminate the P-waves and S-waves of these acoustic signals. The time-frequency characteristics of the P-waves and S-waves of the stress waves are used to study the failure modes in the composite specimens.

Advances in Quantitative Hydrogen Embrittlement Assessment

Joshua Jackson[1,2], Craig Tod[2], Milos B. Djukic[3], Bryan Fahimi[4]

[1]*Applied Fracture Mechanics and US Corrosion Services, 8307 Kempwood Dr., Houston, TX 77055 USA*

josh@appliedfracturemechanics.com

[2]*Applied Fracture Mechanics, 8307 Kempwood Dr., Houston, TX 77055 USA,* *craig@appliedfracturemechanics.com*

[3]*University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade 11120, Serbia.* *mdjukic@mas.bg.ac.rs*

[4]*SLB - OneSubSea, Beltway 8., Houston, TX 77055 USA,* *bfahimi@onesubsea.com*

Accelerated Hydrogen Embrittlement | *Design-Based Fracture Mechanics* | *Quantitative Environmental Cracking Analyses*

Abstract Metallic materials are subject to a wide range of environmentally assisted cracking (EAC) mechanisms. Hydrogen embrittlement (HE), stress corrosion cracking (SCC), and corrosion fatigue (CF) are a few common issues seen in many industries [1]. Traditional testing methods for these mechanisms are time-consuming and expensive, limiting their possible use in design, production, R&D, and failure analysis. Environmentally assisted cracking (EAC) has traditionally been very hard to prevent because (1) there are many variables that can contribute to its occurrence and (2) testing is slow and therefore usually infrequent. Accelerated HE and SCC susceptibility testing offers the potential for more widespread and frequent inspection that can help prevent failures, increase efficiency, and reduce costs due to scrap, storage, and recalls. Quantitative environmental corrosion testing data can be used to predict and thus prevent failures from common EAC and corrosion mechanisms like SCC and HE. Accelerated testing now makes it possible to design in a manner that prevents premature corrosion or cracking by avoiding susceptible materials. In many cases, routine testing using these methods is possible within a reasonable time and cost as a quality control tool.

Accelerated methods to rapidly determine the loading threshold where environmental cracking occurs have been demonstrated for several common corrosion mechanisms. But how should the data be applied? For engineering purposes, accelerated testing methods are described which allow for the rapid qualification of materials by a quantitative technique based on fracture mechanics. Measurements from these tests provide useful data that can be used for the comparison of materials or coatings, engineering calculations, research, and failure analysis. Fracture mechanics provides the basis for turning accelerated corrosion testing data into usable engineering decisions and powerful predictive prevention tools.

Quantitative testing of environmental cracking susceptibility using step loading is a proven accelerated technique for determining the threshold stress where corrosion mechanisms like HE or SCC occur. From there, fracture mechanics analysis provides the basis for analytical evaluation that can drive engineering decisions and analysis. Calculated values like the damage tolerance index (DTI) can be applied in practical ways, such as determining the maximum safe size for bolts of a specific material or setting the maximum allowable load for a given application.

[1] M. Wasim, M.B. Djukic, External corrosion of oil and gas pipelines: A review of failure mechanisms and predictive preventions, International Journal of Natural Gas Science and Engineering 100 (2022), p. 104467. https://doi.org/10.1016/j.jngse.2022.104467

Hydrogen embrittlement determination of L485MB pipeline steel and its heat affected zone via notched tensile tests

Laura De Pue[1], R. Jubica[2], Lisa Claeys[2], Somsubhro Chaudhuri[1], Tom Depover[2], Wim De Waele[1], Kim Verbeken[2], Stijn Hertelé[1]

[1]*Ghent University, Department of Electromechanical, Systems and Metal Engineering, Soete Laboratory, Tech Lane 46, 9052 Zwijnaarde, Belgium*

laura.depue@ugent.be

[2]*Ghent University, Department of Materials, Textiles and Chemical Engineering, Sustainable Materials Science, Belgium*

Hydrogen Embrittlement *Heat Affected Zone* *Notched Tensile Test*

Abstract Within the global energy transition, a hydrogen pipeline grid will be deployed over Europe. To realize these plans in a reasonable time frame, it is envisaged that around 60% of this grid will consist of retrofitted natural gas pipelines. A known phenomenon in many metals is hydrogen embrittlement (HE), when ductility and fracture toughness are reduced in hydrogen environments. One of the more critical zones for HE in pipelines are the heat affected zones (HAZ) since they may have a lower fracture toughness compared to the pipeline steel (base metal). Additionally, imperfections as in lack of fusion between weld and base metal are situated in that region. This work compares the HE of the HAZ of a girth welded ISO3183 L485MB pipeline steel to that of the base metal, via notched tensile tests. 10mm round bars with two types of notches – having a radius 6 mm and 2 mm – are tested see Figure 1. Both geometries have the same net section diameter of 6mm. The effect of hydrogen is studied by electrochemically pre-charging the specimens for 18 hours in 0.5M H_2SO_4 containing 1g/l thiourea at a current density of 0.8mA/cm². To compare the results, hydrogen embrittlement indices (EI) are calculated based on the area reduction obtained by image analysis at total elongation. The increased stress triaxiality resulted in a higher average EI for the configuration having the sharpest notch. The investigated HAZ showed about 30percentage points increased embrittlement as compared to the base metal for both geometries and hence was more sensitive to hydrogen embrittlement, for the material tested in this paper.

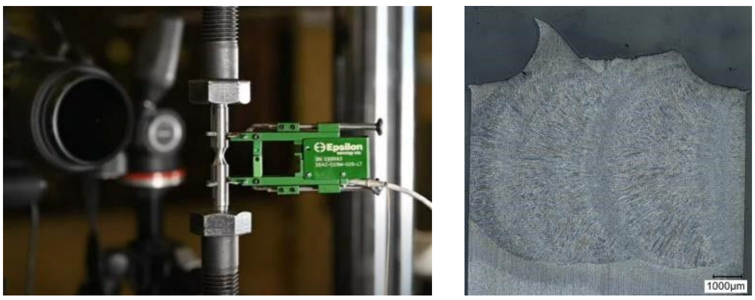


Figure 1 *– Test set-up of notched tensile test (left) and a broken test specimen (right)*

Hydrogen-assisted degradation of an X70 pipeline steel evaluated by single edge notched tension testing

Margo Cauwels[1], Robin Depraetere[2], Wim De Waele[2], Stijn Hertelé[2], Tom Depover[1], Kim Verbeken[1]

[1]*Ghent University, Department of Materials, Textiles and Chemical Engineering, Sustainable Materials Science, Technologiepark 46, B-9052 Zwijnaarde, Belgium*

Margo.Cauwels@UGent.be

[2]*Ghent University, Department of Electromechanical, Systems and Metal Engineering, Soete Laboratory, Technologiepark 46, B-9052, Belgium*

Hydrogen embrittlement *Pipeline steels* *SENT*

Abstract It is well known that the presence of hydrogen in steel structures can cause a degradation in their mechanical properties, such as fracture toughness. This phenomenon, commonly called hydrogen embrittlement (HE), poses a potentially serious challenge for structural steels subjected to cathodic protection or pipelines transporting high-pressure hydrogen gas. The repurposing of natural gas pipelines for hydrogen gas transport has gathered much interest in the past few years, and it is evident that these pipeline steels should be qualified for hydrogen service. Fracture toughness is an important property for these steels. The single edge notched tension (SENT) test can be used to quantify the fracture toughness of a steel and this test has been shown to induce a constraint level comparable to that of a pipe with through-thickness or surface cracks. LS-oriented SENT specimens, extracted from an API 5L X70 pipe, are hydrogen pre-charged in an aqueous 0.1M NaOH solution under a current density of 0.8 mA/cm^2 for 48h to obtain saturation and subsequently tested either ex-situ or with concurrent hydrogen charging (in-situ). For the latter case, a significant shift in fracture mode takes place, with most of the crack growth appearing to occur through quasi-cleavage. For the former, only limited quasi-cleavage is found. Furthermore, cracking along the microstructural banding proved to show a significant influence on the cracking behavior during the test, complicating the test result interpretation for qualifying hydrogen gas pipelines.

Dynamic transient analysis of the reactor Core Barrel during LB LOCA

Yaroslav Dubyk[1], Oleksii Ishchenko[1,2], Vladislav Filonov[1,2]

[1]IPP-CENTRE LLC, Budindustrii 5B str, Kyiv, Ukraine

dubyk-yr@ipp-centre.com.ua

[2]NTUU "KPI" 37, Peremohy av, Kyiv, Ukraine.

Water Hammer *Shell dynamics* *Failure assessment diagram*

Abstract The article deals with the influence of the water hammer event resulting from the rupture of the main circulation pipeline, for the Core Barrel of VVER-1000 reactor. The assumption of a double-ended pipe break in the main coolant loop piping of a nuclear power reactor followed by blowdown (a rapid loss of coolant through the break) has been considered as the worst possible loss-of-coolant accident (Large Break LOCA).Such event is called a design basis accident or DBA and should be analyzed for the reactor's safe long-time operation. Research in this area has been conducted since the 80s of the XX century and one of the most difficult issues is the calculation of thermohydraulic parameters during a LB LOCA in the reactor, which determines the dynamic loads. To overcome this issue in previous authors' works a special CFD model was developed to obtain loads during hot leg break and cold leg break. Nevertheless, an important point remains CFD results transfer for mechanical analysis, especially since it might be an issue for shell which have both surfaces loaded. In the present work the calculations are performed using two models: the first one is an analytical shell model, the second one is 3D FE model of the Core Barrel. As the first step, both models are compared using a free vibration analysis (see Fig.1). Next, pressure loading in time is applied for both models to get a dynamic response and resulting stresses. Finally structural integrity analysis is performed using failure assessment diagram (FAD). As a result comparison between the speed, accuracy and computational cost of two different models (approaches) is performed to provide an insight of the perspective use of analytical shell models compared to well-known FE computational tools.

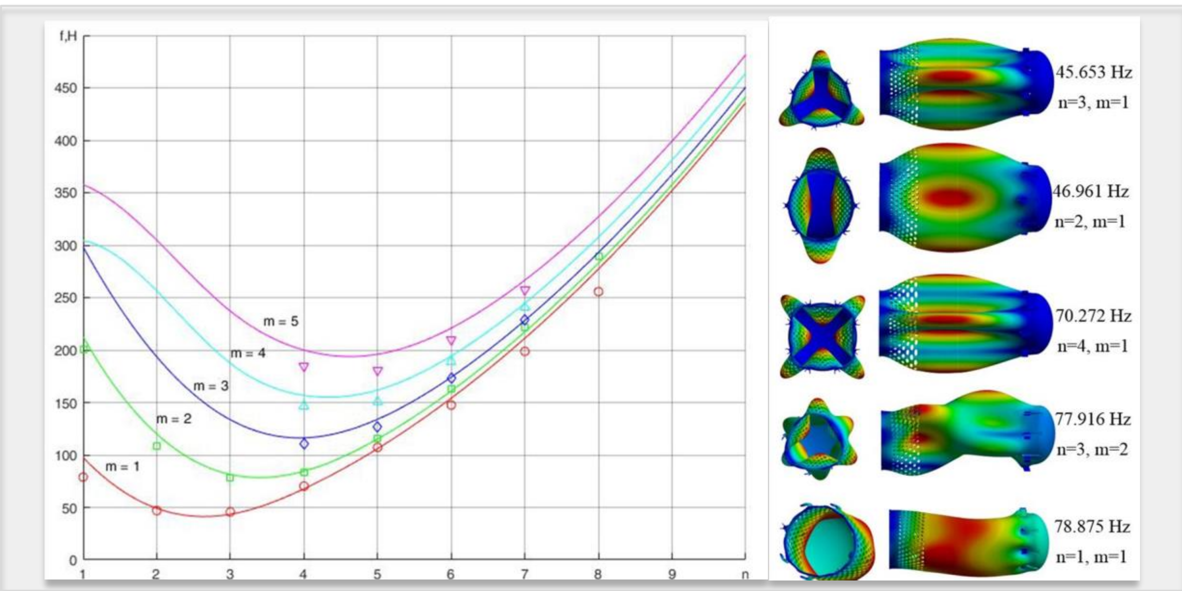


Figure 1 - Comparison of the calculated natural frequencies: markers - ANSYS (○) m=1, (□) m=2, (◊) m = 3, (△) m = 4, (▽) m = 5; continuous lines – analytical solution(a); The first natural frequencies and forms of frequency CB (ANSYS) (b)

Hydrogen interaction with an equiatomic CoCrFeMnNi high entropy alloy

Lisa Claeys[1], Hauke Springer[2,3], Mohammadhossein Barati Rizi[1], Kim Verbeken[1], Tom Depover[1]

[1]*Ghent University, Department of Materials, Textiles and Chemical Engineering, Research group Sustainable Materials Science, Technologiepark 46, 9052 Zwijnaarde, Belgium*

Lisa.Claeys@UGent.be

[2]*Department of Microstructure Physics and Alloy Design, Max-Planck-Institut für Eisenforschung, Düsseldorf, Germany*

[3]*Institut für Bildsame Formgebung, RWTH Aachen University, Aachen, Germany*

High entropy alloy *Hydrogen diffusivity* *Deformation mechanism*

Abstract High entropy alloys (HEA) recently emerged as a promising group of materials. They consist of multiple principle elements and, rather unexpectedly, several of them solidify into a single phase structure. Moreover, the multi-element nature often gives rise to extraordinary properties, such as high strength/hardness, outstanding wear resistance, excellent ductility or corrosion resistance, etc. In the pioneering work on HEA compositions, the Cantor alloy is presented, named after the publishing author. It is an equiatomic combination of cobalt, chromium, iron, manganese and nickel with a face centered cubic (FCC) crystal structure. Due to the extraordinary mechanical behavior of the Cantor alloy, the field of hydrogen embrittlement was drawn towards this material, which lead to the observation that the alloy was only mildly susceptible to hydrogen-assisted degradation. Since this could be a major opportunity for the creation of more hydrogen-resistant materials, more fundamental understanding on the hydrogen interaction with the Cantor alloy is required.

In this work, the equiatomic CoCrFeMnNi Cantor alloy is subjected to a series of microstructural, hydrogen and mechanical characterization techniques. The material has a recrystallized FCC structure with chromium oxide and manganese sulphide inclusions. Moreover, Cr-rich precipitates are found that were formed during hot rolling and/or post-rolling heat treatment. The hydrogen diffusivity is measured via different experimental approaches, i.e. thermal as well as electrochemical extraction methods. It is found that on average, hydrogen diffusion is faster in the Cantor alloy compared to FCC steels. Possibly, the multi-element nature with varying atom sizes results in a more favorable interstitial hydrogen diffusion path. Secondly, deformation mechanisms are characterized via electron backscatter diffraction measurements in the absence and presence of hydrogen after slow strain rate tensile testing. The material is prone to twin formation and hydrogen is found to increase the twin fraction. The fracture surfaces are analyzed with scanning electron microscopy. Hydrogen clearly alters the overall fracture type which is characterized more in depth with electron backscatter diffraction on cross-sections of the tensile tested specimens.

Increasing the resistance to hydrogen embrittlement of martensitic medium carbon steels

Margot Pinson, Kim Verbeken, Tom Depover

Ghent University; Department of Materials, Textiles and Chemical Engineering; Sustainable Materials Science, Tech Lane Ghent Science Park 46, B-9000 Ghent, Belgium

Tom.Depover@UGent.be

Hydrogen embrittlement *Steels with martensitic microstructure* *Thermal desorption spectroscopy* *mechanisms*

Abstract High strength martensitic steels are used for a multitude of industrial applications due to their high hardness. However, their high strength levels are generally linked with an inherently brittle character which is the main limitation for these type of steels. Moreover, it is widely accepted that the presence of hydrogen is steel microstructures leads to a degradation of their mechanical properties. The question raises how these already brittle microstructures interact with hydrogen.

In study, the hydrogen embrittlement behaviour of a generic Fe-0.4C steel is studied in order to get fundamental insights on the interaction between hydrogen and steels with a martensitic structure. A combined analysis of the hydrogen trapping behaviour by thermal desorption spectroscopy and the hydrogen embrittlement degree by in-situ bending tests indicates that the hydrogen assisted degradation is dominated by hydrogen trapped at the high angle grain boundaries, e.g. the martensitic block and packet boundaries. Moreover, the martensitic matrix does not have the ability to arrest the hydrogen assisted cracks.

Therefore, this research suggests two different ways to increase the hydrogen embrittlement resistance of martensitic medium carbon steels. On the one hand, hydrogen trapping carbides can be introduced to avoid the hydrogen accumulation at these high angle grain boundaries, as such successfully affecting the crack propagation pathway. Cementite or nano-sized Ti- or V-based carbides act as an effective hydrogen trap and, as such, retards the hydrogen accumulation at the high angle grain boundaries. However, it is also observed that hydrogen assisted cracks may initiate at the precipitate/matrix interface, so a careful design is recommended. On the other hand, a ferritic microfilm on the prior austenitic boundaries can be introduced by the addition of aluminium in the alloy composition, which redirects the crack propagation path along the ferrite/martensite interface since the interface suffers preferentially from hydrogen enhanced decohesion compared to the quasi-cleavage fracture obtained without the presence of this ductile microfilm. Both materials engineering concepts result in improved mechanical behaviour (both in air an in hydrogen) and can be obtained by adding a limited amount of alloying elements and by applying straightforward heat treatments.

The effect of austenitizing temperature on the hydrogen embrittlement of API 5L X100 pipeline steel

Reza Khatib Zadeh Davani[1,*], Ehsan Entezari[1], Sandeep Yadav[1], Jhon Freddy Aceros Cabezas[2], Jerzy Szpunar[1]

*[1]Department of Mechanical Engineering, University of Saskatchewan, 57 Campus Dr, Saskatoon, SK, S7N 5A9, Canada. * Corresponding email*

rek144@usask.ca

[2]Metallurgical Engineering and Materials Science Department, Universidad Industrial de Santander, Bucaramanga, Colombia.

Hydrogen Embrittlement *Pipeline steel* *EBSD and XRD*

Abstract

In this study, different heat treatments including one-step austenitizing at 880°C, 830°C, and 780°C for 90 min, followed by oil quenching to room temperature and tempering at 600°C for 30 min, and finally, oil quenching to room temperature, were used to investigate the hydrogen embrittlement of heat-treated specimens made of API 5L X100 steel. The tensile test was used to assess the hydrogen embrittlement susceptibility. Specimens' microstructure was assessed using a scanning electron microscope SEM, X-Ray Diffraction (XRD) and Electron Backscatter Diffraction (EBSD. The specimens' macro- and micro-texture was assessed. By X-ray diffraction and EBSD. Energy Dispersive Spectroscopy (EDS) was used to further examine the specimens' fracture surface and hydrogen-induced cracking (HIC).

All the examined specimens contain polygonal ferrite, quasi-polygonal ferrite, blocky austenite/martensite, and bainitic ferrite. Moreover, the as-received specimen also shown the highest hydrogen embrittlement index, while having the highest ultimate tensile strength (UTS) both before and after the hydrogen charging. This is consistent with the hardness findings, which shown that the as-received specimen had the highest microhardness value. The results also point out that the X100 pipeline steel's hydrogen embrittlement can be reduced by the used heat treatment. According to the macro-texture and micro-texture studies, the grain orientation intensity after one treatment steel deviated towards {111} and {110}, whereas after another treatment the {100} grain orientation perpendicular to ND was observed. The specimens also have different levels of deformed grains and different Kernel Average Misorientation (KAM) values. The findings of the fractography observations revealed that the fracture surface of the tensile test specimens contained dimples and cleavage at MnS and Al_2O_3 inclusions, which are significant for initiation of the HIC.

Crack growth resistance of actual pipe welds exposed to hydrogen and natural gas mixture and pure hydrogen under high pressure

Guillaume Benoit[1], Denis Bertheau[1], Gilbert Henaff[1], Laurent Alvarez[2]

[1] *Institut Pprime UPR3346 Chasseneuil Futuroscope, France*

[2] *TEREGA Pau - France*

Welded structure *Static and cyclic loading* *Hydrogen embrittlement*

Abstract

In a context of reducing greenhouse gas emissions, the development of the hydrogen strategy seems to be chosen in many industrial sectors. The use of hydrogen as an energy carrier implies the transport of large quantities of hydrogen gas over long distances. The option of using the existing natural gas (NG) network is studied since several years. It raises the issue of sensitivity to hydrogen embrittlement of existing structures. First of all, it is plan to use a mixture of natural gas and hydrogen while guaranteeing safe operating conditions. Then dedicated pipelines to the transport of pure H2 will be developed. In this regards, the present study focused on pipelines girth weld was undertaken to get a first assessment of the impact of the hydrogen gas content in natural gas on the crack growth. In this purpose, tensile, fracture toughness and fatigue crack propagation tests were carried out at RT on a servo-hydraulic machine equipped with a pressure vessel. Behavior in NG, NG + H2 blend and pure H2 has been studied under a pressure of 8.5 MPa. Tensile and CT specimens were extracted from different actual circular welds (pipes with an external diameter from 350 to 900 mm, respectively with thickness from 7 to 13 mm) representative of those present in the network. Gage length of tensile specimens and crack planes of CT specimens are located within the weld joint (Figure 1). Three couple of steel grades associated with a welding process were studied, namely two carbon steel pipes, a vintage pipe (X60) and a modern pipe in L415 (X60), welded using a manual cellulosic electrode welding process (SMAW), and finally a modern pipe in L485 steel (X70) welded by mechanized welding process (GMAW). No huge impact on tensile properties has been observed whereas significant differences on surface reduction areas where observed with hydrogenated environments. The fracture toughness results indicate no significant effect of hydrogen on the K values, while the plastic opening, CTOD and experimental equivalent values to the J-integral are affected at different degrees. Furthermore, fatigue crack growth rates are enhanced by more than an order of magnitude in the 25% H2-NG blend in the high ΔK region compared to NG. Additional analyses, in particular based on microfractographic observations, are presented to interpret these results.

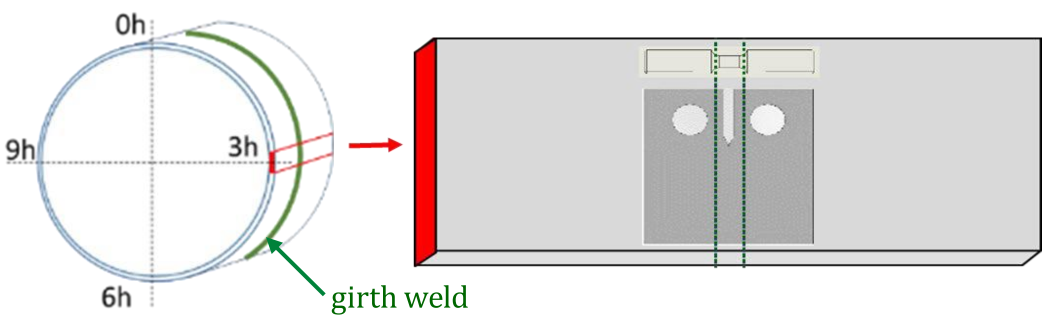


***Figure 1** – Specimens extraction*

Application of TCD approach to fatigue life prediction of notched high strength steel specimens

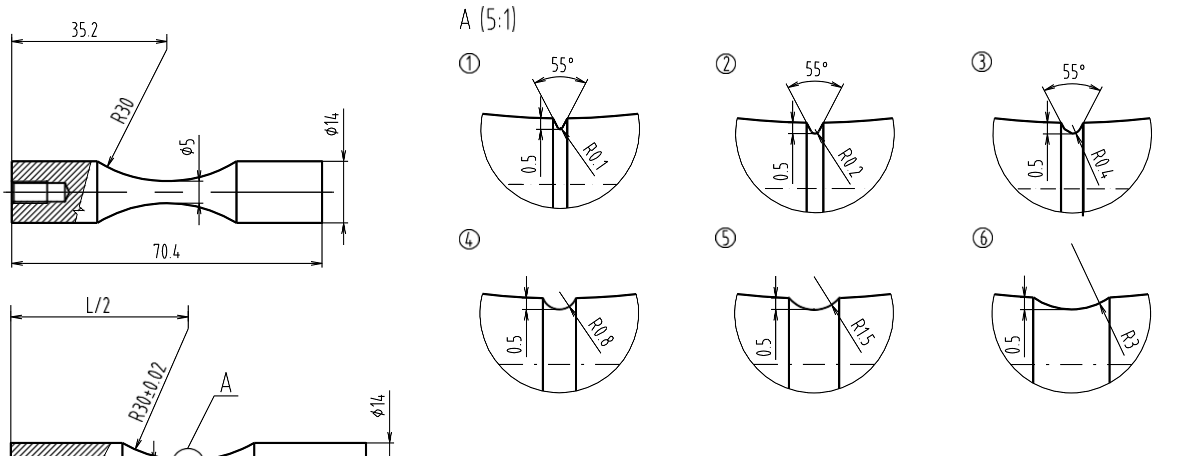
Kamila Kozáková[1,2], Jan Klusák[2], Stanislav Seitl[2]

[1]*Faculty of Mechanical Engineering, Brno University of Technology, Technická 2896/2, 616 69 Brno, Czech Republic*

[2]*Institute of Physics of Materials, Czech Academy of Sciences, Žižkova 22, 616 00 Brno, Czech Republic*

High strength steel *Notched specimens* *Gigacycle fatigue*

Abstract In this research, fatigue data of smooth and notched specimens made of S960 high strength steel are evaluated. The approach of the theory of critical distances (TCD) [1, 2], using axial stress distributions and experimental data, is applied for determination of the length parameter, which can be used for fatigue lifetime predictions. The length parameter depends on number of cycles to failure. Seven sets of test samples including smooth specimens and the samples with different notch radii (see Fig. 1) were tested in the areas of high cycle and very high cycle fatigue. The fatigue tests were performed using an ultrasonic fatigue testing machine working at 20 kHz test frequency. All fatigue tests were carried out under uniaxial symmetric tension/compression loading ($RR = -1$) at room temperature.



specimen no.	1	2	3	4	5	6
notch radius *R* [mm]	0.1	0.2	0.4	0.8	1.5	3
length of specimen *L* [mm]	80.5	80.4	80.3	80.0	79.7	79.1

Figure 1: Smooth and notched specimens, S960

Acknowledgement The research was supported by the Czech Science Foundation, project No. 21-14886S.

[1] TAYLOR, David. The theory of critical distances. Engineering Fracture Mechanics, 2008, 75.7: 1696-1705.
[2] SUSMEL, Luca. The theory of critical distances: a review of its applications in fatigue. Engineering Fracture Mechanics, 2008, 75.7: 1706-1724

Verifying of the different lattice structure on the material stability produced by additive manufacturing made from Inconel 718

Miroslav Zetek[1], Josef Volák[2], Ludmila Kučerová[2], Miloslav Bílý[3], Ivana Zetková[2] Yusuf Bakir[2], Miloslav Kepka[2]

[1]*University of West Bohemia, Univerzitni 8, 301 00 Pilsen, Czech Republic,* mzetek@fst.zcu.cz

[2]*University of West Bohemia*

[3]*Skoda Doosan Power*

Inconel 718 *Lattice structure* *Mechanical properties*

Abstract Main aim of the research work is complex view on the mechanical properties of the Inconel 718 when different lattice structure was used. Three different lattice structures (Gyroid, BCC and Honey cube) were implemented into the testing samples with different size of the internal hole. For the mechanical property's evaluation, the tensile tests and fatigue tests were used in room and high temperature. Very important was identified the influence of the possible internal material defects on the boundary of the lattice structure connection and internal hole surface. For it the IR NDT method was used. This made it possible to analysis the initial place of crack spread by advanced material analyzes. Finally, the major results of the work are S-N curve of the hollow samples filled with lattice structure compared with the normal type samples (full material) in room and high temperature include fracture mechanics.

Improving of mechanical properties of printed maraging steel

Ivana Zetková [1], Miroslav Zetek[1], Miloslav Kepka Jr.[1], Petr Bohdan[1], Karel Trojan[2], Nikolaj Ganev[2], Jiří Čapek[2], Ludmila Kučerová[1], Miloslav Kepka[1]

[1]*University of West Bohemia, Faculty of Mechanical Engineering, Regional Technological Institute, Univerzitni 22, 306 14 Pilsen*

zetkova@rti.zcu.cz

[2]*Czech Technical University in Prague*

Maraging steel *Residual stress* *Fatigue life*

Abstract The contribution deals with improving of residual stress in printed maraging steel X3NiCoMoTi18-9-5 by process parameters change. The printed series of samples were produced using DMLS (Direct Metal Laser Sintering) technology on the device EOS M290.

In general, printed components arise the undesirable tensile residual stress which cause deformations and cracks. There were tested different parameter sets for stress reducing. Drilling method and rentgen thermography were use for residual stress evaluation. The optimized parameter set was compared with standard parameter set from the view of fatigue life testing, material analysis and surface quality. Concretely, the fatigue strength values at different numbers of cycles were compared and the S-N curves were calculated. Material analysis were focused on the changes in the structure and phase distribution. Surface quality was evaluated through profile and surface roughness measurement.

Modeling Ageing and Fatigue for Structural Integrity Calculations of Large-Scale Pressure Systems

Fekete, Tamás

Centre for Energy Research, H-1121 Budapest, Konkoly-Thege M. str. 29-33., Hungary

fekete.tamas@ek-cer.hu

Structural Integrity *Methodology* *Fatigue*

Abstract For Large-Scale Pressure Systems (*LSPS*s), the aim of Structural Integrity (*SI*) is to ensure safety of the system throughout its lifetime. The effectiveness of *SI* is crucially dependent on the predictive capabilities of the theory applied in *SI* Calculations (*SIC*s). Nowadays, *SIC*s of *LSPS*s are largely based on the suggestions of standards and guidelines, whose principles were laid down more than a hundred years ago, at the end of the 19th century, at the maturity level of engineering mechanics at that time. A number of research efforts are currently on-going to overcome the known limitations of *LSPS SIC* methodologies, but the results of *R&D* activities have not yet been consolidated into a coherent system.

The present research aims to develop a robust, generalized methodology for *SIC*s of *LSPS*s that: (1) integrates recent knowledge from various disciplines of science and engineering relevant to the topic; (2) is based on philosophically sound hypotheses; (3) fits into a theoretical framework built in accordance with the hypotheses; (4) allows deriving innovative models and computational procedures for future engineering applications.

SI is a complex transdisciplinary concept, whose conceptual framework can be divided into four levels: (1) Philosophy level; (2) Science level; (3) Engineering level; (4) Practice level. The four levels of *SI* form an entangled system, which means that the levels –although they may seem independent at first glance– are not independent but interrelated; no single level gives a complete picture of *SI*. However, by combining the cross-relationships between the knowledge developed at each level in a logical and purposeful way, the knowledge of the subject area is multiplied and becomes more coherent. Eg., philosophical considerations can help in the development and choice of the scientific basis of the problem; philosophy can help in the clear formulation of the problems and the elaboration of relevant basic hypotheses. Using philosophical considerations, it was found that *LSPS*s can be modelled as *complex non-equilibrium systems*. A fundamental characteristic of non-equilibrium systems is that their internal –meso- and micro-– structures exhibit irreversible time evolutions, even if their macroscopic characteristics appear to change little or not at all. Such mechanisms manifest themselves in the ageing of structural materials. Therefore, a unified physical theory was sought to describe fracture mechanics and ageing in a unified framework. *Generalized Thermomechanics* (*GT*), based on modern Non-Equilibrium Thermodynamics (*NET*) is capable of providing such a unified description; therefore, *GT* seems to be the best choice as a theoretical framework for *SI*. Using *NET*, different ageing mechanisms, *including fatigue*, can be described in a unified conceptual framework, and theoretical models taking into account the simultaneous effects of several ageing mechanisms can be formulated. This is the framework within which the concept of structural health and its meaning can be conceptualised.

The presentation shows arguments that justify describing fatigue analysis and other ageing mechanisms within the unified theoretical framework.

Effect of Nickel on the hydrogen embrittlement, diffusion, and trapping properties of ferritic-martensitic dual-phase low alloy steel in tempered condition

Esteban Rodoni[1], Tom Depover[1,2], Kim Verbeken[2], Mariano Iannuzzi[1]

[1] Curtin Corrosion Centre, Curtin University, Building 614 De Laeter Way, Bentley, Perth, WA, 6102, Australia

Esteban.rodoni@curtin.edu.au

[2]Department of Materials, Textiles and Chemical Engineering, Research group Sustainable Materials Science, Ghent University, Technologiepark 46, Ghent, 9052, Belgium

Hydrogen embrittlement *Hydrogen transport* *Low alloy steels*

Abstract Hydrogen embrittlement (HE) is one of the main threats to pipelines that transport hydrogen. In a perceived effort to reduce HE risks, ASME B31.12 regulates materials used for hydrogen pipelines with restrictions similar to those imposed by ISO 15156-2 for sour oil and gas (O&G) service. Both standards restrict the maximum nickel content in low alloy steels (LAS), i.e., 0.5-wt% for hydrogen transport and 1-wt% for O&G. Since Ni additions to LAS improve technological and mechanical properties, these restrictions exclude many steels with superior performance from use under H-bearing environment.

This work quantifies the influence of Ni on hydrogen diffusion and trapping and HE resistance using research-grade dual-phase (DP) ferritic-martensitic LASs. Ni additions decreased the hydrogen apparent diffusion coefficient and increased the hydrogen trapping as measured by hydrogen permeation test and thermal desorption spectroscopy, respectively.

Further testing with slow strain rate test indicated that Ni had no detrimental effect on the HE resistance.

Definition of a test-independent hydrogen embrittlement index for advanced high-strength steels

Giuseppe Macoretta, Carlo Maria Belardini, Marco Beghini, Bernardo Disma Monelli, Renzo Valentini

Department of Civil and Industrial Engineering, University of Pisa, Pisa, Italy

giuseppe.macoretta@unipi.it

AHSS *Hydrogen embrittlement* *Sheet metal*

Abstract. Advanced High Strength Steels (AHSS) are extensively utilized in the automotive industry due to their high strength and ductility characteristics. Among these, Martensitic Steels (MS-AHSS) are employed to manufacture structural components that play a critical role in impact safety. Nevertheless, the microstructure of MS-AHSS makes it prone to Hydrogen (H) embrittlement, which occurs due to the H absorbed during production processes or in service.

In the present work, an MS-AHSS was studied through slow strain rate tensile tests on smooth and notched specimens, which were electrochemically H pre-charged. After each test, the average H concentration was measured by the hot extraction method at a constant temperature. Fractographic analyses were carried out to identify the damage mechanism in the fracture onset region.

Using the finite element method, each test was reproduced employing an H-dependent material model, which included a stress-strain elastoplastic law, a damage model, and a fracture criterion. The model was calibrated with data from the smooth specimens and then used to predict the response of the notched ones. It allowed capturing the whole experimental mechanical response up to failure.

The work made it possible to identify the maximum strain at failure as a test-independent material property suitable for the definition of the H embrittlement index.

A Comparison Study on Environmental Effects of Natural and Synthetic Fiber Reinforced Polymer Composite (NFRPC) for their Potential Application

Dillip Kumar Bisoyi[1] and Chinmayee Dash[2]

[1]Department of Physics and Astronomy, National Institute of Technology Rourkela, Rourkela-769008, India.

dkbisoyi@nitrkl.ac.in)

[2] Department of Physics and Astronomy, National Institute of Technology Rourkela, Rourkela-769008, India

Biodegradability *NFRPC* *Potential Applications*

Abstract Easy access with biodegradability and sustainability features, natural fiber have attracted in scientific and industrial sectors. It is also been utilized as the alternative for synthetic or engineering fiber. Composite materials prepared from natural fiber have high strength to weight ratio, high stiffness, good corrosion resistance etc. Nevertheless, carbon fiber, which is a synthetic fibre, shows superior properties in comparison to natural one, however, natural fiber reinforced polymer composite (NFRPC) shows some unique properties in wide range of applications. The protocol followed are for Nano order structure involved in natural fibre are evaluated using techniques like SAXS, XRD, FTIR & FESEM etc., NFRPC are fabricated by hand layup method. Based on this concept, a review is prepared on the difference between natural and synthetic fiber reinforced composites for various potential applications. It will also address the various aspects of both composites including cost, processing and environmental impacts with respect to our findings.

Experimental investigation of modulation transfer technique for damage detection of structures

Andrzej Klepka, Jakub Górski, Kajetan Dziedziecch

AGH University of Science and Technology, Department of Robotics and Mechatronics

klepka@agh.edu.pl

Modulation transfer *Non-linear acoustics* *Damage detection*

Abstract Non-linear acoustics is one of the methods for identifying structural damage. Due to the high sensitivity, techniques based on non-linear damage-induced effects can be used to detect and locate structural discontinuities even at the early stage of damage. Many techniques use non-linear acoustics. One of them is the modulation transfer method. It assumes the transfer of modulation of an amplitude-modulated acoustic wave to another unmodulated wave in the presence of damage. The article focuses on damage detection issues using the technique mentioned above. Experimental results will be presented to confirm the possibility of identifying damage based on the modulation intensity index. The tests were carried out on the damaged structure with fatigue crack. Two excitation sources were used: an amplitude-modulated wave (pumping wave) and a mono-harmonic excitation (probing wave). The structure response was acquired using non-contact measurement methods - a laser vibrometer.

Investigating correlation of collected coordinate measurement data and the grid size in the residual stresses computed by the contour method

Mahjoubeh Sistaninia[1], Hans-Peter Gänser[1], Jürgen Maierhofer[1], Thomas Antretter[2]

[1]*Materials Center Leoben Forschung GmbH, Leoben, Austria*

mahjoubeh.sistaninia@mcl.at

[2]*Chair of Mechanics, Montanuniversistät Leoben, Leoben, Austria*

Contour method *Richardson extrapolation* *Mesh size*

Abstract The contour method, first proposed by Prime [1], is categorized as a destructive method to estimate the residual stresses in a specimen. It involves the following steps: First the specimen is cut into two parts using EDM (Electro Discharge Machining), then the surface geometries of these two cut pieces are measured in a grid using a coordinate measuring machine (CMM). Finally, these coordinates are applied on the surface of a geometry model of the specimen in a FE (Finite Element) software, and the stresses needed to push and pull these surface deflections back to zero are calculated using simulation. In this way, the residual stress field across the complete surface of the specimen is obtained [2].

A critical, nevertheless frequently disregarded step in this method, is the compatibility of the mesh size of the FE model with the grid size of the CMM data. This research shows that, if the mesh size is not properly selected, the calculated residual stresses will differ markedly from the real values. Since finding the true value of the stresses in a real specimen is not easy, and furthermore due to various uncertainty and noise effects in practice, here a FE model with a small mesh size containing well-defined residual stresses is used to mimic the behavior of the real specimen and CMM, and the deflections and residual stresses generated from this model are considered as the reference data (ground truth). In the next step, the effects of mapping the deflections from this reference model to different mesh sizes is investigated and the resulting residual stresses are compared with the ground truth.

For industrial application, the optimal mesh is not simply the one with the smallest possible grid size, since there is always a competition between the resource usage (CPU time, memory) and the accuracy of the results. Therefore, in this paper the optimal mesh is found employing Richardson extrapolation [3] for grid convergence and via this method a proper mesh, in terms of grid size and CPU-time can be achieved.

References

[1] M.B. Prime, Cross-sectional mapping of residual stresses by measuring the surface contour after a cut, J. Eng. Mater. Technol., 2001, 123, 162-168.

[2] A. Achouri, F. Hosseinzadeh, P.J. Bouchard, S. Paddea, O. Muransky, The incremental contour method using asymmetric stiffness cuts, Materials & Design, 2021, 197.

[3] P. Roache, Verification and validation in computational science and engineering, Albuquerque: Hermosa Publishers, 1998.

Very high cycle fatigue behavior of high strength steels subjected to high frequency loading

Jan Klusák[1], Kamila Kozáková[1,2], Stanislav Seitl[1]

[1] *Institute of Physics of Materials, Czech Academy of Sciences, Žižkova 22, 616 00 Brno, Czech Republic*

[2] *Faculty of Mechanical Engineering, Brno University of Technology, Technická 2896/2, 616 69 Brno, Czech Republic*

High strength steels *Ultrasonic fatigue loading* *Gigacycle fatigue*

Abstract The paper deals with the study of the fatigue properties of high-strength structural steels S960 and S690. Fatigue life is measured in the very high cycle region using an ultrasonic testing device at a test frequency of 20 kHz. All fatigue tests were performed under uniaxial fully reversed tension/compression loading (R = -1) at room temperature. The fatigue lifetimes of both steels are compared and related to the microstructure of the materials. Fracture surfaces are analyzed by scanning electron microscopy. Fatigue data measured in the experimental program serve as inputs for the design and lifetime analyzes of engineering components, and structures.

Acknowledgement The research is supported by the Czech Science Foundation, through the project Influence of material properties of high strength steels on durability of engineering structures and bridges, project No. 21-14886S.

Performance of a polymeric coating material applied to a concrete structure affected by internal expansive chemical reactions

João Custódio[1], Helena Silva[2], Maria Paula Rodrigues[2], Susana Cabral-Fonseca[2], António Bettencourt Ribeiro[2], Filipa Morais[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]*Norscut – Concessão de Auto-Estradas, S.A., Rua Filipe Folque, 10J, 1.º Dto., 1050-113 Lisboa, Portugal*

Polymeric surface protection systems   *Internal expansive chemical reactions*   *Concrete structures rehabilitation*

Abstract Currently, there is a significant number of large concrete structures with deterioration problems related to internal expansive chemical reactions (IECR), in Portugal and worldwide. The structures affected by this pathology are very important in economic and strategic terms, since it is usually encountered in large dams, bridges and viaducts. This kind of degradation is related to the formation of expansive products inside the concrete causing its premature deterioration as a result of expansion and cracking, which in turn accelerates the ingress of moisture and other aggressive agents into the concrete, leading to further degradation of the structure. Thus, IECR can decrease the structure's service life and, ultimately, lead to its decommissioning or demolition. Two main separate material-based mechanisms have been identified to cause the concrete swelling: Alkali-Silica Reaction (ASR) and Internal Sulfate Reaction (ISR, heat-induced internal sulphate reaction, also referred in the literature as delayed ettringite formation, DEF). A common requirement for their occurrence is the presence of sufficient moisture content inside concrete. By controlling the humidity level inside concrete, coatings applied on the concrete surface can contribute to mitigate ASR or ISR by acting as a barrier against ingress of water and allowing the drying of concrete, as long as they have adequate characteristics of permeability to water vapour. This paper presents the general criteria that should be used for the selection of polymeric coating materials for the protection of concrete structures affected by expansive reactions, in order to contribute to increase their durability and the service life. Besides, a case study is presented concerning the performance evaluation of a coating material, selected taking into account the abovementioned criteria and that was applied on a concrete viaduct affected by IECR, in terms of its effectiveness on controlling humidity inside concrete.

Multiaxial fatigue of selected additively manufactured metals

Vladimír Chmelko, Matúš Margetin

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 *Multiaxial fatigue* *Cyclic properties*

Abstract Many hypotheses have been proposed to evaluate the fatigue strength and fatigue life of multiaxially cyclically stressed components. Additive manufacturing of metallic materials brings new specificities in fatigue life assessment, e.g. material build-up direction, internal defects, ... 3 materials produced additively - MS1, 316L, AlSi10Mg - were investigated. For each material, cyclic properties in alternating tension-compression and alternating torsion were obtained. In the next step, experimental fatigue life values were obtained for selected combinations of cyclic tension-twist. These results allow the application of known hypotheses for multiaxial fatigue and the assessment of their suitability or conditions of their application to this kind of materials.

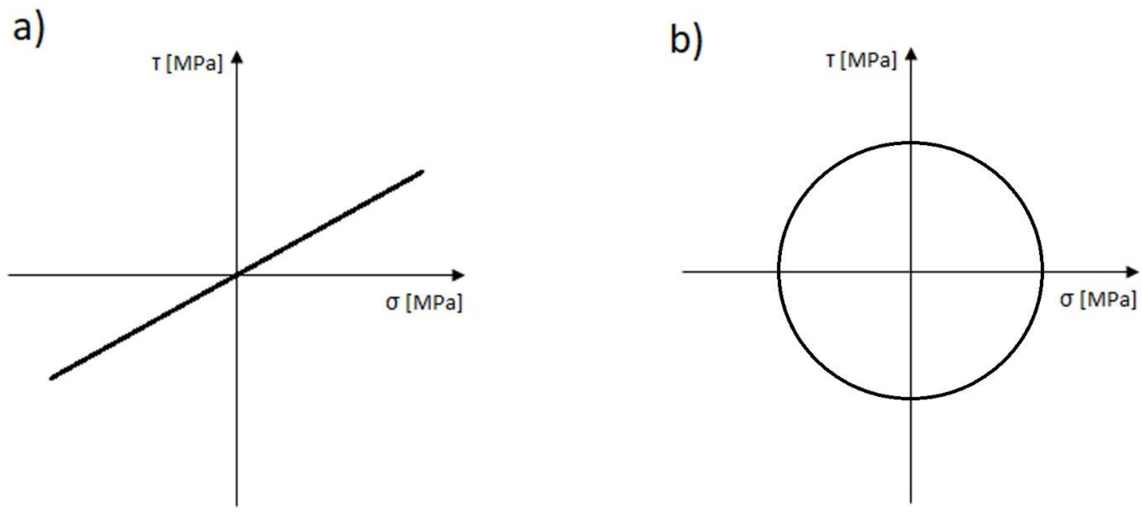


Figure 1 *Load paths for proportional loading by tension and torsion combinations of the materials investigated*

First-principles study on the hydrogen absorption energy in Fe-Cr-Ni austenitic systems: Effect of Cr and Ni content

Junichiro Moriyama[1], Osamu Takakuwa[2], Masatake Yamaguchi[3,4,5], Yuhei Ogawa[6], Kaneaki Tsuzaki[5,6,7]

[1]Graduate School of Mechanical Engineering, Kyushu University, 744 Motooka Nishi-Ku, Fukuoka 819-0395, Japan

moriyama.junitiro.953@s.kyushu-u.ac.jp

[2]Department of Mechanical Engineering, Kyushu University

[3]Center for Computational Science and e-Systems, Japan Atomic Energy agency

[4]Department of Materials Science and Engineering, the University of Tokyo

[5]Elements Strategy Institutive for Structural Materials, Kyoto University

[6]National Institute for Materials Science

[7]Professor emeritus, Kyushu University

Austenitic alloy *Hydrogen absorption energy* *Hydrogen occupancy*

Abstract A recent study demonstrated that solute hydrogen (H) increases strength and improves ductility in some Fe-Cr-Ni-based austenitic alloys with high phase stability of austenite, which is opposite to hydrogen embrittlement. The more solute H content, the more effective the improvement of the strength-ductility balance. The amount of solute H depends on Cr and Ni content; Fe-Cr-Ni-based austenitic alloys with high Cr content and Cr / Ni ratio retained more solute H, enhancing the positive impacts on the strength-ductility balance. However, the quantitative understanding of the contribution of Cr and Ni to the solute H content in the Fe-Cr-Ni-based austenitic alloys still lacks for utilizing H as a beneficial alloying element. In the present study, we evaluated the contributions of Cr and Ni to the solute H content based on the calculation of the hydrogen absorption energy (H-absorption energy), which is the energy required to solidify H in Fe-Cr-Ni system at interstitial positions in the vicinity of Cr or Ni atoms using DFT calculations.

The results demonstrated that both Cr and Ni substitutions reduce the H-absorption energy at its adjacent octahedral site, and Cr worked more effectively than Ni. We divided the H-absorption energy into a part of the mechanical effect from the movement of atoms invoked by solute H and a part of the chemical effect stemming from the change in the electron density condition. Then, it was unveiled that the reduction in the H-absorption energy is predominantly ascribed to the decrement in the latter. H-occupancies of Fe-Cr-Ni-based austenitic practical alloys were calculated by the H-absorption energy. It was well-consistent with the experimental results under the wide range of Cr and Ni content. According to the calculation results, we proposed Cr equivalent for identifying the hydrogen solubility with various Fe-Cr-Ni-based austenitic alloys with any Cr and Ni content.

Effect of CFRP Wraps on the Compressive Strength of Normal and Structural Lightweight Concrete

Rami A. Hawileh, Hind Alharmoodi, Abdallah Hajjaj, Abdulaziz Aljarwan, Jamal Abdalla

Department of Civil Engineering, American University of Sharjah, Sharjah, United Arab Emirates

rhaweeleh@aus.edu

Fibre Reinforced Polymers *Lightweight Concrete* *Concrete*

Abstract Concrete is one of the most prominent building materials in the construction industry. Further, lightweight concrete has recently emerged, contributing to the sustainable values of modern construction. Many researchers have worked on enhancing the concrete's compressive strength by incorporating cementitious materials or by externally bonding fibre reinforced polymer (FRP) composites via epoxy adhesives. Such FRP materials are very promising due to their lightweight and high tensile strength along with high corrosion, impact, and fatigue resistance. This paper aims to investigate the use carbon fibre reinforced polymer (CFRP) wraps in enhancing concrete's compressive properties. The study will be conducted on strengthened and control normal-weight and structural lightweight concrete standard cylinders. The specimens will be tested under compression till failure. The initial test results indicated that wrapping structural lightweight concrete cylinders with 1 layer of CFRP laminates yielded a 44% increase in compressive strength. Further increase is expected with 2 layers of CFRP sheets. In addition, the percent increase between normal weight and structural lightweight concrete will be compared and justified. It is expected that lightweight concrete will experience larger increase in compressive strength since it has initially relatively lower compressive capacity than that normal weight concrete.

Effect of increasing the number of anchors on the flexural performance of FRP-strengthened RC beams

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

rhaweeleh@aus.edu

Fibre Reinforced Polymers *Strengthening* *Anchorage*

Abstract Fiber-reinforced polymers (FRP) have been extensively used in the external strengthening and retrofitting of existing reinforced concrete (RC) structures. Beams strengthened with FRP sheets exhibit improved performance in terms of flexural capacity. However, the ductility of the beams is sacrificed due to the brittle failure of externally bonded FRP sheets in the form of FRP debonding or concrete cover delamination. Spike anchorage systems are developed to prevent or mitigate debonding of FRP sheets in externally strengthened RC beams. This study aims to investigate the effect of increasing the number of FRP spike anchors at the laminate's ends on the flexural behaviour of strengthened and anchored RC beams. Three concrete beams having a length, depth, and width of 2000, 250, 200 mm, respectively, were tested under four-point bending test. The first beam was strengthened and unanchored, and the other two beams were strengthened and anchored with one or two 14-mm diameter FRP anchors on each side, respectively. Results showed an increase in the strain utilization of 11% for the beam anchored with two anchors on each side. The ratios of the maximum strain to the debonding strain calculated for each beam were 1.08, 1.43, 1.64 for the control unanchored, anchored with two anchors, and anchored with four anchors, respectively. Thus, it can be concluded that anchoring FRP sheets with two anchors at the laminate's ends if feasible is more effective than one anchor in delaying debonding failure, and thus would lead to a better enhancement in the flexural performance of strengthened RC beams.

Investigations of the hybrid beam behavior during three-point bending test

Jaroslav Václavík, Jan Chvojan

Research and Testing Institute Plzen, Dynamic Testing Laboratory, Tylova 1581/46, 30100 Plzen, Czech Republic

chvojan@vzuplzen.cz

Hybrid beam *CFRP* *Bus structure*

Abstract The hybrid beam for bus structure parts is the combination of CFRP plate and hollow profile made from stainless steel. Special intention is focused to lower the bus structure mass and increase stiffness resistance to crash and fatigue damage.

The paper presents the requirements for the hybrid structure and gives results, performed during 3-point bending tests of hollow profiles manufactured from ferritic stainless steel 1.4003. The profiles were filled with two types of foam and CFRP plate SIKA CarboDur® S512 was glued from the bottom of the profile using the adhesive SikaPower® 1277. The measurement of force and beams displacement was supplemented by measurements of strains in several places.

The results of the tests of single and double beems are discussed. When the profile is filled with foam, a plastic joint is formed at an 20% higher load force and approximately the same increase in deflection of the sample was found. When reinforcing the profile only with a CFRP strip on the bottom side, there was no significant increase in strength. It is interesting that the results are the same for both foams, even though the tensile strength of the polyurethane foam was measured to be approximately 2x higher than that of the epoxy foam. At the of the CFRP plates there was measured the stress near the maaterial yield point.

Presented tests are the starting point for the reinforcement of the selected hollow beams for the whole of the bus.

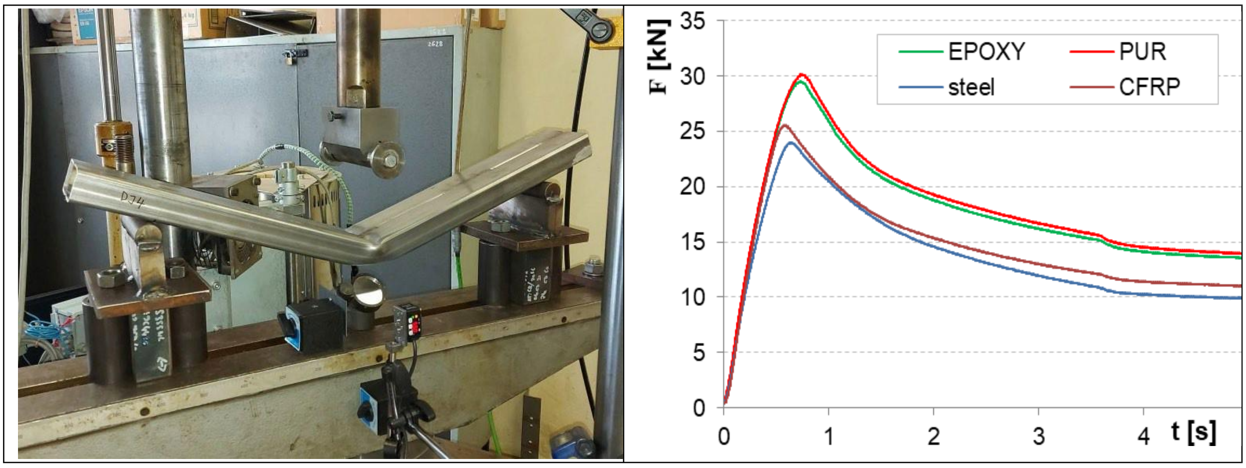


Figure 1 *– Set-up of the 3-point bending test and comparison of the force distribution for steel profile, steel with glued CFRP plate and steel filled with PUR and EPOXY foams*

The article has originated in the framework of M-ERA.NET call 2019 and was supported with Technological Agency of Czech Republic under the No. TH71020003.

Effect of polymer shot addition on mechanical and physical properties of cement composite mortar

Marcin Małek, Waldemar Łasica, Michał Gregorczyk and Emil Kardaszuk

Military University of Technology, Faculty of Civil Engineering, Research Laboratory, 2 gen. S. Kaliskiego st., 00-908 Warsaw, Poland

Cement mortar *Polymer shot* *Waste materials*

Abstract The aim of the research was to identify the basic physical and mechanical properties of prepared cement mortars with the addition of 3, 5, 8, and 10 wt.% polymer shots to the weight of cement. Samples were prepared according to EN 206-1 and a set of tests was performed. In addition, an analysis of the thermal properties of the produced cement composite mortar was carried out. The components of the newly developed cement composites, i.e.: aggregate (quartz sand with a fraction of 0/4); polymer shots (polypropylene polymer shots); CEM VI ECO cement (40 wt.% of Portland clinker, 30 wt.% of ground granulated blast-furnace slag, 30 wt.% of silica fly ash); fluidizing admixture based on aqueous solutions of polycarboxylates was also determined. The addition of polymer waste caused a decrease in the mechanical properties of the designed mortar. This was due to the difficulty in properly mixing and compacting samples with a large amount of additive. In addition, a slight increase in consistency and air content in the produced composites was observed. However, as a mortar, the most important feature was achieved, i.e. decreased thermal insulation, which decrease exponentially with the increase in polymer shots content. As a result, the use of such a cement composite as a finish inside buildings walls will reduce their insulation costs and increase the energy comfort of the used rooms.

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Ultimate Strength Evaluation of Woven Fiber Reinforced Polymer Composites Using Homogenization Theory

Wang Dan, Xin Haohui*, Gao Qinglin, Zhang Hengyu

Department of Civil Engineering, School of Human Settlements and Civil Engineering, Xi'an Jiaotong University, Xi'an, Shanxi, P. R. China

xinhaohui@xjtu.edu.cn

Woven Fiber Reinforced Polymer Composites   *multi-scale simulation*   *Hashin failure criterion*

Abstract Fiber reinforced polymer (FRP) is a kind of multiphase material, its mechanical properties and failure mechanism are closely related to the performance of the component phase, the shape and distribution of the reinforcement phase, and other microscopic characteristics. In order to optimize the structure of FRP, it is necessary to study the influence of microstructure on the macroscopic properties of materials, that is, the influence of multi-scale effect should be studied. In this paper, based on the classical lamination theory, the damage failure process and ultimate strength of 0 °/90 ° fabric reinforced composite were successfully obtained by multi-scale simulation in Matlab software using the Hashin failure criterion. In the process of simulating material damage, the mechanical behavior of materials under various external loads is first described by the allowable bending constitutive model, and then the stresses of resin, 0 ° fiber, and 90 ° fiber of each unit in the representative volume cell (RVE) model are calculated respectively, and then the damage is judged by the damage criterion. Finally, the damage evolution process and the failure of the laminate are described by the method of reduction coefficient and strain iteration.

Notch effect on the fatigue behaviour of AlSi10Mg aluminium alloy obtained by additive manufacturing

R. Fernandes[1*], L. Borrego[1,2], J.S. Jesus[1,3], J.A.M. Ferreira[1], J.D.M. Costa[1]

[1]Univ Coimbra, CEMMPRE, Department of Mechanical Engineering P-3004 516 Coimbra, Portugal

[2]Department of Mechanical Engineering, Lisbon Polytechnic – ISEL R. Conselheiro Emídio Navarro 1, 1959-007 Lisboa, Portugal

[3]Department of Mechanical Engineering, Coimbra Polytechnic – ISEC Rua Pedro Nunes, 3030-199 Coimbra, Portugal

Fatigue *Aluminium alloy AlSi10Mg* *Fatigue Life predictions*

Abstract The fatigue behaviour of the aluminium alloy AlSi10Mg manufactured by laser powder bed fusion for as-build and residual stress relief conditions with different notch geometries will be studied in this work. The fatigue tests (R=0) are carried out, at ambient temperature and in load control mode. The main results showed that the heat treatment applied for stress relieved did not have an influence on the fatigue life, but it resulted in a relieved of residual stresses. The presence of different notches decreased the fatigue life when compared to the specimens without notches. Also, models were successfully applied to predict fatigue life.

Energy field intensity-based approach for notch fatigue analysis of 7050-T6 aluminium alloy under multiaxial loading

R. Branco[1], J.D. Costa[1], L.P. Borrego[2,1], F. Berto[3]

[1] *CEMMPRE, Department of Mechanical Engineering, University of Coimbra, 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*

[3] *Department of Mechanical and Industrial Engineering, NTNU, 7491 Trondheim, Norway*

Multiaxial fatigue *Notch effect* *Life prediction*

Abstract Aluminium alloys have a major application in aviation, aerospace, and automotive industries due to their low density, high strength, good fracture toughness, and attractive cost. In these areas, a considerable number of critical components are exposed to cyclic multiaxial loading making them prone to fatigue failure. The development of accurate multiaxial fatigue life prediction models requires the understanding of at least three main aspects: (i) identification of crack initiation sites; (2) identification of crack growth direction; and (3) assessment of fatigue lifetime. This paper aims to solve these three issues for notched cylindrical bars made of 7050-T6 aluminium alloy subjected to combined bending-torsion loading. The crack initiation sites, and the crack growth directions are predicted from the distribution of the first principal stress at the notch surface. Fatigue crack initiation lives are predicted through the new concept of energy field intensity (see Figure 1). All these three variables are in good agreement with the experimental observations.

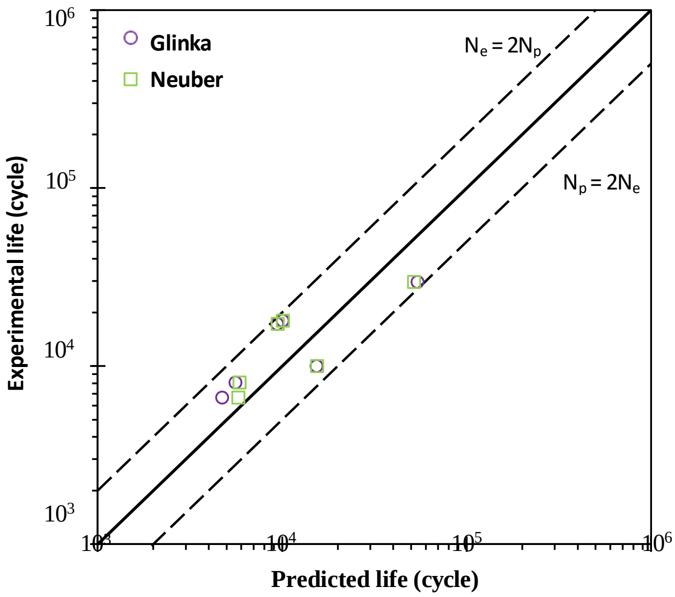


***Figure 1** – Experimental fatigue life versus predicted fatigue life*

Hydrogen interactions with dislocations in relation to hydrogen embrittlement of metals

V.G. Gavriljuk, V.M. Shyvaniuk, S.M. Teus

G.V. Kurdyumov Institute for Metal Physics, Vernadsky blvd. 36, Kiev 03142, Ukraine

gavr@imp.kiev.ua, shyva@imp.kiev.ua, teus@imp.kiev.ua

Hydrogen-dislocation binding *Hydrogen diffusion* *Hydrogen embrittlement*

Abstract. The interaction between hydrogen atoms and dislocations is studied in iron-, nickel- and titanium based alloys which constitute the base for design of three main classes of engineering metallic materials. These studies were performed based on the *ab initio* calculations and experimental studies of the electron structure, X-ray diffraction (omega-scan method), mechanical spectroscopy and tensile mechanical tests.

Using the program package Wien-2k, it is established that hydrogen in iron increases the density of electron states, DOS, at the Fermi level, which suggests the increased concentration of free electrons and is confirmed by the experiment using the elecron spin resonance. The hydrogen effect on the DOS in nickel and titanium in non-monotonous because of the hydrogen-caused phase transformations.

It is also obtained that, as a result, hydrogen decreases the shear modulus and, consequently, the specific energy of dislocations, i.e. their line tension, which should increase their mobility. The hydrogen-enhanced velocity of dislocations was detected in a number of TEM studies and confirmed in our measurements of the strain-dependent internal friction.

Using mechanical spectroscopy, the hydrogen diffusion enthalpy, H_d, and the enthalpy of binding of hydrogen atoms to dislocations, H_b, were measured in a number of austenitic steels, nickel- and titanium-based alloys. The H_d and H_b values determine the condensation temperature of hydrogen atmospheres at dislocations, which was measured in these studies. Consequently, the temperature range for slip of dislocations accompanied by hydrogen atmospheres has been qualitatively estimated.

As shown in a number of studies, hydrogen embrittlement, HE, defined as a degradation of mechanical properties of metallic materials under applied stress in contact with hydrogen, is displayed in a definite temperature range and disappears at sufficiently high strain velocities. The obtained data allow to claim that a reason for the HE phenomenon is the dislocation slip accompanied by hydrogen atmospheres, within of which mobility of dislocations is increased and, consequently, plastic deformation is localized.

For example, due to extremely low values of H_d, □0.2 eV and H_b, □0.03 eV, in the □-Ti alloys, hydrogen embrittlement occurs below the ambient temperature, which provides the opportunity to use hydrogen as a temporary alloying element in technological processing. In contrast, the significantly higher H_d □ 0.5 eV and H_b □0.1 eV in austenitic steels are responsible for HE at temperatures up to □70 □C.

Finally, the binding between hydrogen atoms and dislocations plays the even more significant role in hydrogen embrittlement under electrochemical hydrogen charging, where plastic deformation occurs in the course of charging, and, in contrast to gaseous hydrogenation, the work hardening decreases the plasticity resours and assists the earlier brittleness.

Investigation on geometric imperfections of tensile test specimens using optical full-field measurements and digital twin-based simulations

T. Fekete[1], D. Antók[2], L. Tatár[2], P. Berecki[3]

[1]*Centre for Energy Research, H-1121 Budapest, Konkoly-Thege M. str. 29-33., Hungary*
fekete.tamas@ek-cer.hu

[2]*Centre for Energy Research, H-1121 Budapest, Konkoly-Thege M. str. 29-33., Hungary*

[3]*University of Dunaújváros, H-2400 Dunaújváros, Táncsics Mihály str. 1/A, Hungary*

Digital Twin *FE simulations* *Tensile tests*

Abstract Standard-based evaluations of tensile tests on smooth specimens assume an ideal geometry and a homogeneous, isotropic material. Research over recent years along the Digital Twin (*DT*) concept has built a unified measurement and evaluation system that has enabled the observation of tensile tests with fine temporal resolution and full-field data acquisition technology, and in which the *DT* is based on an advanced second-order continuum mechanics approach. This measurement technique allows to collect much more detailed information about the time evolution of the specimen geometry than that available with standard measurement techniques. With this amount and quality of information, the time evolution of the specimen geometry and the artificial patterns observed on it can be tracked, and the *DT* is sufficiently fine to track the time evolution of the geometry and that of the patterns.

The aim of the research presented here was to investigate whether the theoretical model used and implemented in the *DT* is suitable for evaluating the differences between the real initial geometry of the specimen and its idealised model, and whether the model can be used to explain some currently more challenging phenomena. The specimens were manufactured on a digitally controlled high-precision machining centre. At the end of production, a high-precision coordinate measuring system was used to produce a fine resolution coordinate map showing the finished geometry. *DT* models of the test specimens were produced using two different approaches. First, the initial geometry of the active zone of the sample was considered idealized, i.e., a rectangular slab with edge lengths determined by averaging the corresponding measurement results. In the second case, shape of the specimen was defined by the surfaces best fitting the corresponding measurement results. Local differences between ideal geometry and real geometry are called geometric imperfections. The geometric imperfections of the manufactured specimens are well within the allowed manufacturing tolerances. Simulation results show that computations based on the realistic initial geometry, considering the initial geometric imperfections, follow time evolution of the specimen geometry –including the location of the necking zone– much more correctly than calculations based on the idealised geometry.

The results show that the approach implemented in the *DT* and the models built using it are suitable for modelling even such delicate effects as the effect of manufacturing imperfections in measurements. On the other hand, a geometry is proposed that better conforms to the optical observations compared to standard specimens, while preserving necking behaviour.

Comparative study of hydrogen uptake in low alloyed carbon and austenitic stainless steels under cathodic hydrogen charging in aqueous electrolyte and gaseous hydrogen charging

Daria Pałgan, Markus Uhlirsch, Nuria Fuertes and Birhan Sefer*, SWERIM AB,

**SWERIM AB, Sweden, Senior researcher in Corrosion and Hydrogen Embrittlement,* *birhan.sefer@swerim.se*

Diffusible hydrogen uptake | *Low alloyed carbon steel and austenitic stainless steel* | *Cathodic and hydrogen gas charging* | *Thermal Desorption Spectroscopy with Mass Spectrometry*

Abstract The demand to evaluate the susceptibility of steels to hydrogen embrittlement (HE) in high pressure gaseous hydrogen (H2) environment is rapidly increasing. This is because of the foreseen potential that H2 technologies would contribute to reaching the goal of a fossil-free society. A selection of applications promoting this are replacing coal with H2 in steelmaking, fuel cells and gas turbines. Storage and transportation of H2 are also crucial for this transition. It is well known that steels are susceptible to hydrogen (H) which manifests through failure known as HE. Introducing H into steels is crucial to understanding HE. To design and build H2 safe infrastructures, knowledge of the quantity of H uptake under the steels´ operating conditions is required. To achieve this, a systematic study involving exposure of steel specimens in pressurized H2 environment followed by H analysis is necessary. Commonly, the steels´ sensitivity to HE in lab conditions is performed by using two H charging methods: cathodic charging and gaseous charging. Cathodic charging requires a simple electrochemical setup. It involves immersing the steel in an electrolyte solution and imposing a cathodic current on the steel. There are several parameters that can be optimized to control the amount of H uptake into the steels such as imposed current density, use of recombination poison, charging time, and electrolyte temperature. In contrary, gaseous charging is a less common lab charging method. Gaseous charging requires use of autoclaves for which the labs are required to fulfil strict safety requirements especially when charging at high pressures of H2 and elevated temperatures. Hence, not every lab can perform gaseous charging and therefore the cathodic charging method is preferred. However, it remains unclear whether cathodic charging can produce similar amounts of absorbed H especially diffusible, which is considered as main responsible for causing HE. The main aim of this work is to provide data through optimization of the charging parameters of each charging process (cathodic charging: cathodic current densities imposed, charging times and temperatures of the electrolyte; gaseous charging: different H2 pressures, temperatures and charging times) to achieve similar diffusible H contents. To our best knowledge there are only few research reports available in the up-to- date literature that directly compare the two charging methods in terms of H uptake for steels. Hence, this work would be of great value to the HE scientific community. This work also aims to increase understanding and knowledge on how optimization of parameters affects the H uptake for both charging methods. Specimens of three steels, one low alloyed carbon and two austenitic stainless steels with low and high Ni content were charged using both charging methods. The H content was analysed using thermal desorption spectroscopy with mass spectrometry. For the cathodic charging, the specimens were charged in NaCl solution for the case of the low alloyed carbon steel and in NaOH solution for the case of the austenitic stainless steels. Both electrolytes contained NH4SCN as recombination poison. Cathodic current densities up to 100 mA/cm2 and charging times up to 72 hours were used. Charging at elevated temperatures of electrolyte solutions was also performed where the electrolytes were heated up to 80 °C. For the gaseous charging the specimens were charged in an autoclave and pure H2 pressurized up to 200 bars, at temperatures from room temperature up to 360 °C and with charging times up to 72 hours.

Silver birch and black alder non-destructive wood quality evaluation

Benas Šilinskas[1-2], Darius Danusevičius[2], Marius Aleinikovas[1]

[1] Lithuanian Research Centre for Agriculture and Forestry, Forest Resources, Economics and Policy Department, , Liepu str. 1. Girionys, Kaunas district. Benas.silinskas@lammc.lt/Benas.silinskas@vdu.lt

[2]Vytautas Magnus University Agriculture Academy, Faculty of Forest Sciences and Ecology, Studentu str. 1, Akademija, Kaunas district. Darius.danusevicius@vdu.lt

Modulus of elasticity *Wood hardness* *Non-destructive evaluation*

Abstract Both, the European Green Deal (2019) and the latest European Forest Strategy (2021) emphasize that much more attention needs to be paid to the production of durable wood products from the logs of less valuable deciduous tree species, these contributing to carbon sequestration and retention, also preserving much more valuable forests for biodiversity. Wood from Silver birch (*Betula pendula*) and black alder (*Alnus glutinosa*) tree species are not considered as valuable and are not in high demand, but it has the potential to replace spruce or pine wood and be used in a variety of engineered wood products for construction, as promoted in the new European Bauhaus strategy. In this study wood were taken from experimental Silver birch and black alder objects conducted in Lithuania. These plots were established from the seeds of the best growing trees in Lithuania.

In experimental objects 4 genetic families were chosen for wood quality measurements. 3 model trees were cut from each genetic family. Genetic families were selected by wood hardness measurements conducted in previous studies. By wood hardness we take the hardest, the softest family and two families considered as genetically plastic and non-plastic. Model trees were cut to a 1,1-meter-long logs. All tree trunks were taken until 8 cm diameter of log. All logs were saw to 50X50X1100 mm boards. Boards were measured with PILODYN for wood hardness determination. Non-destructive modulus of elasticity was measured by acoustic tomograph Arbotom 3D. Wood density was measured from the samples taken from boards.

ANOVA Duncan multiple range test was done to measure significant differences between genetic families of wood hardness and non-destructive modulus of elasticity. Pearson correlations were done between these two parameters.

Considering environmental effects on porous concrete applications: an experimental investigation

Aikaterini Marinelli, Lukman Puthiyaveetil Haroon Rasheed

School of Engineering and the Built Environment, Edinburgh Napier University, Merchiston campus, EH10 5DT Edinburgh, Scotland

a.marinelli@napier.ac.uk

Porous concrete *Adverse weather* *Experimental investigation*

Abstract Porous concrete has been gaining increasing attention as a sustainable building material that can improve drainage and reduce runoff in urban areas, enhancing stormwater management (Kevern et al., 2011). Applications of porous concrete include pavement systems (e.g. sidewalks, bike paths, parking lots), flood control infrastructure, green roofs and decorative / landscaping features. A broad range of such examples exist worldwide and demonstrate the versatility and benefits of porous concrete for different construction applications. However, there is limited research on the behaviour of porous concrete in challenging weather conditions (Wu et al., 2016), of particular interest to projects based in Scotland, where high rainfall, low temperatures, and freeze-thaw cycles can impact the material's properties and response. Further to reviewing the current state of knowledge on porous concrete (Zhang et al., 2020, Pieralisi et al., 2017, Abdelhady et al., 2021), a series of experimental tests are developed to investigate the behaviour of certain mix designs of porous concrete with respect to their compressive strengths and permeability, while considering effects from adverse weather conditions. Test results are analysed and compared to conventional concrete to evaluate the potential benefits of using porous concrete in Scotland. This research makes a valuable contribution to the existing body of knowledge on porous concrete and provides data of direct applicability to designers and contractors so that they make more informed decisions about porous concrete applications, while considering environmental effects.

Indicative References

- Abdelhady, A., Hui, L. & Zhang, H. 2021. Comprehensive study to accurately predict the water permeability of pervious concrete using constant head method. *Construction & building materials,* 308**,** 125046.
- Kevern, J. T., Schaefer, V. R. & Wang, K. 2011. Mixture Proportion Development and Performance Evaluation of Pervious Concrete for Overlay Applications. *ACI materials journal,* 108**,** 439-448.
- Pieralisi, R., Cavalaro, S. H. P. & Aguado, A. 2017. Advanced numerical assessment of the permeability of pervious concrete. *Cement and concrete research,* 102**,** 149-160.
- Wu, H., Liu, Z., Sun, B. & Yin, J. 2016. Experimental investigation on freeze–thaw durability of Portland cement pervious concrete (PCPC). *Construction & building materials,* 117**,** 63-71.
- Zhang, Y., Li, H., Abdelhady, A. & Yang, J. 2020. Comparative laboratory measurement of pervious concrete permeability using constant-head and falling-head permeameter methods. *Construction & building materials,* 263**,** 120614.

Post-mortem estimation of hydrogen embrittlement threshold on sustained-load test coupons using fractography and statistics of extreme values

Simon Laliberté-Riverin*, Jonathan Bellemare, Frédéric Sirois, Myriam Brochu,**

Polytechnique Montréal, 2500 ch. de Polytechnique, Montréal, Canada, H3T 1J4

**Current address: Université Laval, 1065 ave de la Médecine, Québec, Canada, G1V 0A6*

simon.laliberte-riverin@gmn.ulaval.ca

***Corresponding author,* m.brochu@polymtl.ca

Hydrogen embrittlement *Crack growth threshold* *Steels*

Abstract Hydrogen embrittlement of electroplated high-strength steel parts in aerospace industry is monitored by periodic mechanical testing of notched coupons with a sustained-load test (SLT) protocol. Four identical samples are loaded at 75 % of their rupture strength for a period of 200 h, and rupture is an indication of hydrogen embrittlement. While this test if efficient to detect hydrogen embrittlement, it does not allow to quantify the degree of embrittlement.

In the present work, we propose a post-mortem method to quantify hydrogen embrittlement by estimating the hydrogen embrittlement threshold corresponding to the onset of subcritical crack propagation. We observed fracture surfaces of a batch of 80 SLT specimens embrittled in different conditions and collected data on the sizes and locations of the zones exhibiting intergranular fracture. With the hypothesis that intergranular zones are generated by the propagation of subcritical cracks, we computed the stress intensity factors (K) associated with each subcritical crack. From the calculated Ks, the smallest values of K were used to estimate the hydrogen embrittlement threshold using statistics of extreme values.

Using this novel method we estimated the hydrogen embrittlement thresholds of cadmium- and chromium-plated specimens between 9 MPa $m^{0.5}$ and 30 MPa $m^{0.5}$, which give slightly conservative estimates compared to the literature reporting values measured on wedge opening load specimens in hydrogen atmosphere. The proposed method is versatile and applicable to broken specimens of any geometry. This method has the potential to provide quantitative assessment of hydrogen embrittlement damage in case of deviations in plating conditions and therefore avoid discarding of expensive aerospace parts.

Hydrogen embrittlement in a 2205 duplex stainless steel plate: Influence of specimen orientation

V. Arniella, J. Belzunce, C. Rodríguez

Simumecamat research group, university of Oviedo, E. P. Ingeniería, campus universitario, 33203, Gijón, Spain

Hydrogen embrittlement *Stainless steels* *In-situ tensile test*

Abstract: The emergence of hydrogen as a new environmentally friendly energy carrier has led to the study of materials capable to store and transport this gas safely and economically. Stainless steels are known for their high anti-corrosion properties, but they are not immune to hydrogen embrittlement. For example, duplex stainless steels have a banded ferrite-austenite microstructure, in which hydrogen permeation and embrittlement is very dependent on the hydrogen diffusion direction. In this work, first at all, hydrogen diffusion coefficients were determined through room temperature desorption curves experimentally obtained after gaseous hydrogen charging, longitudinal, L, and normal, N, samples at high temperature and pressure in a hydrogen reactor. Then, fracture toughness on the same both orientations were also measured by means of in-situ electrochemical hydrogen charged tests performed on precracked SENB specimens. Testing parameters as electrolyte (acid and saline) and applied current density were modified in other to simulate different hydrogen environments, whereas displacement rate was fixed at 0.01 mm/min in most of these tests. Hydrogen embrittlement indexes were calculated comparing the aforementioned results with the fracture toughness measured in air (without hydrogen).

The failed surfaces of all tested specimens were examined under a scanning electron microscope in order to determine the prevalent failure micromechanisms. Tests carried out in absence of hydrogen showed a wholly ductile failure, however, in the *in-situ* hydrogen charged tests, a brittle crack growth initiation region was observed, whose length varied according to the hydrogen environment and with the specimen orientation.

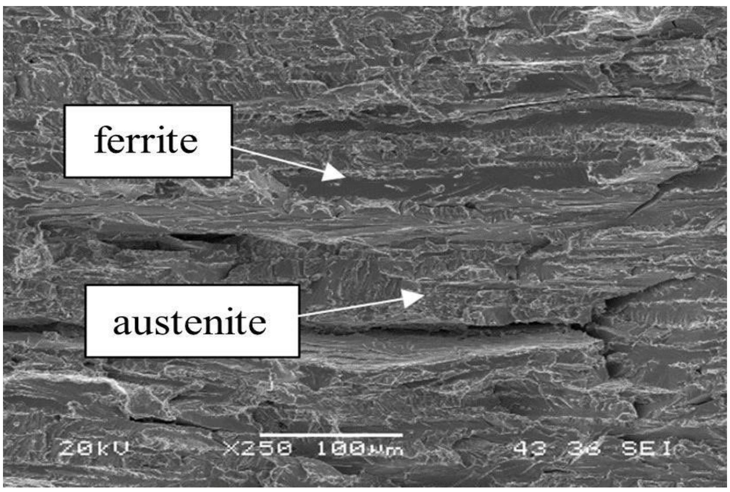


Figure 1 *– Failed surface corresponding to an in-situ hydrogen charged fracture toughness test. Duplex 2205 steel.*

Fatigue fracture characterization of ALSI7MG0.6

Szymon Dziuba[1], Grzegorz Lesiuk[1], Konrad Gruber[2]

[1]Department of Mechanics, Materials Science and Biomedical Engineering, Faculty of Mechanical Engineering, Wrocław Universi-ty of Science and Technology, Smoluchowskiego 25 St., 50-372 Wrocław, Poland

[2]Centre for Advanced Manufacturing Technologies – Fraunhofer Project Centre (CAMT-FPC), Faculty of Mechanical Engineering, Wroclaw University of Science and Technology, Lukasiewicza 5 St., 50-371 Wroclaw, Poland

Additive manufacturing *Aluminium alloy* *Fatigue crack growth behaviour*

Abstract Dynamically developing additive manufacturing (AM) is increasing extent used in various industries, such as aerospace, medicine and automotive. This is due to the possibilities that conventional manufacturing methods do not offer. Such advantages include freedom of design, reduction in the number of technological operations, low level of waste, production time and supply chain cost in low-series production. On the other hand, there are disadvantages, such as the lack of standardization, the problem of repeatability and resistance to fatigue or cracking.

The aim of the undertaken study is additively manufactured aluminium alloy AlSi7Mg0.6, produced by the laser powder bed fusion process (LPBF). It is suitable for parts with complex geometries and thin-walled components. It is excellent for machining and exhibits high corrosion resistance and good deformation tolerance. The material is used in areas such as aerospace engineering, automotive and food industries.

The present study examines the fatigue crack growth behaviour in the linear region of da/dN vs. ΔK diagrams of the as-built AlSi7Mg0,6 produced by LPBF. Specimen building orientation and notch position have been combined to obtain two crack growth orientations variants. In the first variant, the orientation of the notch is perpendicular to the building direction, in the second they are parallel. The obtained results were compared with the results available in the literature (Figure 1). They obtained a similar course of the AlSi10Mg alloy produced by additive manufacturing.

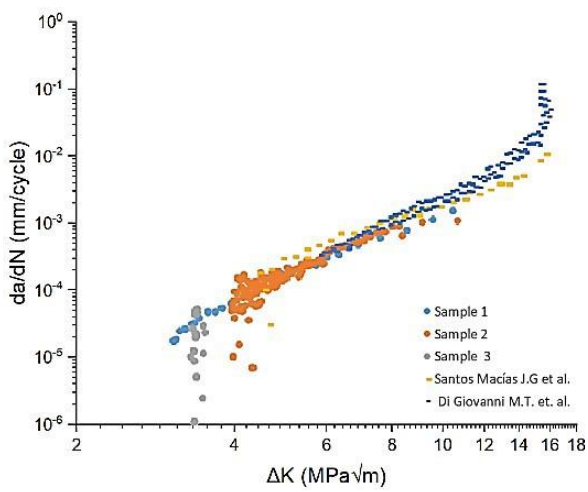


Figure 1 *- Experimental da/dN vs. ΔK curves of AlSi7Mg0,6 compared with AlSi10Mg*

Use of low-quality wood species by densification in load bearing veneer-based composites

Tolgay Akkurt[1], Jaan Kers[2], Anti Rohumaa[2,3]

[1]*Department of Materials and Environmental technology/Tallinn university of Technology Teaduspargi 5, Tallinn, Estonia. tolgay.akkurt@taltech.ee*

[2]*Department of Materials and Environmental technology/Tallinn university of Technology Teaduspargi 5. Tallinn, Estonia*

[3]*Fibre Laboratory, South-Eastern Finland University of Applied Sciences, Vipusenkatu 10, Savolinna, Finland*

Densification *Plywood* *Bending strength*

Abstract The growing demand for renewable raw materials, climate change and the sustainability of the circular economy force manufacturers to explore the use of new and underutilized wood species in wood products. In addition, rising prices and environmental factors contribute to the search for new solutions. The most common wood species used in plywood production in the Nordic countries and the Baltic region is birch (Betula pendula). Previous studies have shown that aspen and alder plywood have lower bending strength than birch plywood, while having lower price and density. The aim of this study was to evaluate the effect of different veneer thicknesses, lay-up systems and veneer densification on the mechanical properties of veneer-based composite produced from low quality and underutilized wood species such as aspen (populus tremula) and black alder (alnus glurinosa). Effects on modulus of rupture (MOR), modulus of elasticity (MOE), adhesive consumption, screw withdrawal, and density were observed.

Three types of veneer-based products were produced: a) all non-densified veneers (S-standard), b) all densified veneers (D) and c) face veneers densified combined to middle layers non-densified veneers (TB). In all these groups, plywood of different thicknesses was made, where the number of veneer layers was 7 and the nominal thickness was 9 mm, 12mm and 18 mm. Three thickness veneers were used in the study: 1.5 mm, 2.6 mm and 3 mm thick veneers which was densified to 1.5 mm. All the parameters of composite production process were the same as for birch plywood.

The obtained results showed that the use of densified veneers as face veneers increased the MOR of aspen and alder plywood by 13% to 38%, respectively, compared to non-densified plywood. In addition, the results show that strength of produced composites with densified face veneers reached the strength properties of birch plywood. All layers densified plywood (D) showed relatively lower strength compared to non-densified and birch plywood due to set memory effect. If the set memory effect can be eliminated in the future, it will allow the production of a composite with much higher mechanical properties.

Hydrogen embrittlement resistance of additively manufactured SS316L: Effects of post-treatments and testing conditions

G. Álvarez[1,2], Z. Harris[3], K. Wada[4], C. Rodríguez[2], E. Martínez-Pañeda[1]

[1]Department of Civil and Environmental Engineering, Imperial College London, London SW7 2AZ, UK, alvarezdguillermo@uniovi.es/e.martinez-paneda@ic.ac.uk

[2]Department of Construction and Manufacturing Engineering, University of Oviedo, Gijón 33203, Spain, alvarezdguillermo@uniovi.es/cristina@uniovi.es

[3] Department of Mechanical Engineering and Materials Science, University of Pittsburgh, Pittsburgh, PA 15261, USA, zdh13@pitt.edu

[4] National Institute for Materials Science (NIMS), 1-2-1 Sengen, Tsukuba, Ibaraki 305-0047, wada.kentaro@nims.go.jp

Laser Powder Bed Fusion (LPBF)   Hydrogen embrittlement   Strain Induced Martensite

Abstract This study investigated the impact of hydrogen embrittlement on the behavior of 316L stainless steel fabricated using both an additive manufacturing technique (laser powder bed fusion, LPBF) and a common manufacturing process (CM). The materials were precharged with hydrogen under conditions of 103 MPa and 270ºC for 400 hours. To evaluate mechanical behavior, uniaxial tensile tests were carried out at both room temperature and -50ºC for four AM conditions: as-built (AB), annealed (ANN), hot isostatic pressed (HIP), and HIP plus cold worked (CW) to 30% of deformation. Results were compared between AM 316L and CM 316L stainless steels in all cases.

At room temperature in the absence of internal hydrogen, all four AM conditions showed significantly reduced ductility compared to CM 316L stainless steel. However, at -50ºC, the ductility of non-pre-charged specimens of AM conditions was similar to that of CM 316L. After the samples were pre-charged with hydrogen, the ductility of all AM conditions was found to be similar to CM 316L at room temperature, with the HIP condition even exceeding the CM material. Notably, the testing of hydrogen-charged samples at -50ºC showed that the ductility of the HIP AM 316L condition was nearly double that observed in CM 316L.

According to ferritscope measurements, the study suggests that the improved performance of the AM 316L condition is due to its reduced tendency to experience strain-induced martensite during deformation, even after significant post-processing treatments. The results demonstrate how the AM 316L can be post-processed using various procedures to exhibit similar or even more resistance to hydrogen embrittlement compared to CM 316L.

Overall, this study highlights the potential for additive manufacturing techniques to produce materials with comparable or improved properties compared to traditional manufacturing methods, while also providing insight into the impact of hydrogen embrittlement on the mechanical behavior of 316L stainless steel.

Microstructure and hardness properties of a s690ql Steel welded joint

Paulo Mendes[1], Mário Monteiro[2], Rui Pedro Silva[3], José A.F.O Correia[2], Abílio de Jesus[2], Manuel Vieira[2], Tiago Pereira[4], Ana Reis[3]

[1]CONSTRUCT, Faculty of Engineering, University of Porto, R. Dr. Roberto Frias, 4200-465, Porto, Portugal, pjmendes@fe.up.pt

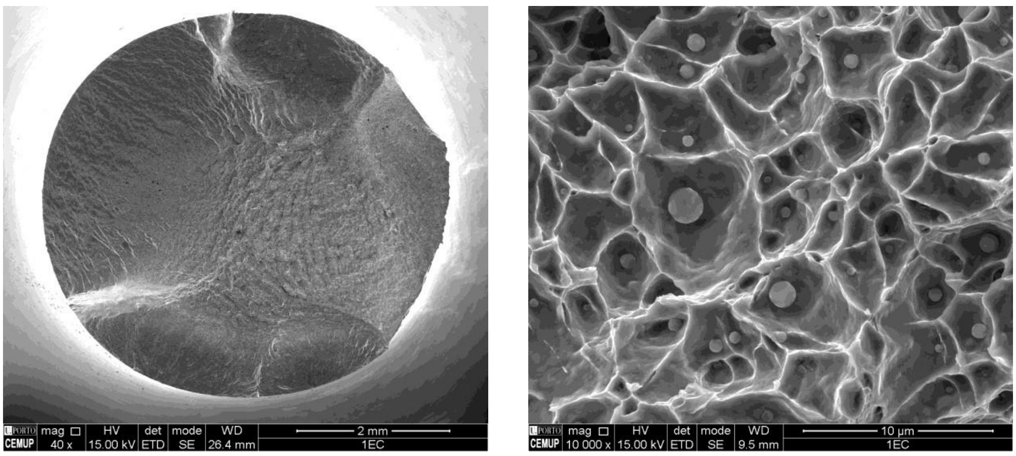
[2]Faculty of Engineering, University of Porto, R. Dr. Roberto Frias, 4200-465, Portugal

[3]INEGI - Instituto de Ciência e Inovação em Engenharia Mecânica e Gestão Industrial, 4200-465, Porto, Portugal

[4]MARTIFER SGPS, Zona Industrial, 3684-001, Oliveira de Frades, Portugal

S690QL Microstructure High-strength steel Welded joints

Abstract Offshore structures, including oil and gas platforms, wind turbines, and wave energy converters, are subject to harsh environmental conditions and high-stress cyclic loading. The reliability and safety of these structures are critical, and the performance of welded joints is a key factor in ensuring their structural integrity considering that welded joints in offshore structures are typically subjected to fatigue loading, which cause material damage and ultimately lead to critical failure. Accurately evaluating the fatigue performance of welded joints fabricated from high-strength steel, specifically the S690QL, is crucial in ensuring the prolonged durability and safety of offshore structures. In this study, rotating bending fatigue test specimens were prepared from butt-welded S690QL plates from various regions of the welded connection, including the base material, heat-affected zone, and weld bead. The fatigue behaviour of the welded joint was analysed using S-N curves, and the hardness properties were assessed through a Vickers hardness testing. Additionally, Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDS) was conducted, which, when correlated, can yield valuable insights into the design and performance of welded joints in offshore applications. This combination of testing and analysis techniques can provide a comprehensive understanding of the mechanical behaviour and properties of welded joints under fatigue loading conditions, which is essential for ensuring the long-term durability and safety of offshore structures.



(a) (b)

Figure 1 – SEM-EDS analysis of a weld material specimen (a) full surface (b) dimples

Acknowledgements

This research was supported by the project grant AARM 4.0 - *Aços de Alta Resistência na Metalomecânica 4.0* with the reference POCI-01-0247-FEDER-068492, co-financed by the European Regional Development Fund (ERDF), through the Operational Programme for Competitiveness and Internationalization (COMPETE2020), under the PORTUGAL 2020 Partnership Agreement. José A.F.O. Correia would like to thank the individual project grant (2020.03856.CEECIND) awarded by national funds (PIDDAC) through the Portuguese Science Foundation (FCT/MCTES).

Hydrogen embrittlement of tempered S41500 martensitic stainless steel

D. Harandizadeh Najafabadi[1], D. Thibault[2], M. Brochu[1]

[1]Department of Mechanical Engineering, Polytechnique Montréal, 2500 Ch. de Polytechnique, Montréal, Canada, H3T 1J4- Davoud.harandi@polymtl.ca

[2] Institut de Recherche d'Hydro-Québec (IREQ) 1800 boul. Lionel-Boulet Varennes, Québec, Canada J3X 1S1

Hydrogen embrittlement *Martensitic stainless steel* *Medium strength steels*

Abstract: 13Cr-4Ni martensitic stainless steels are commonly used to fabricate critical parts of hydro turbines. These alloys, known for their excellent general corrosion resistance, formability, and weldability, are available in the cast (ASTM A352 grade CA6NM) and hot rolled (ASTM A240 grade S41500) forms. Hydro turbines can be exposed to hydrogen during their manufacturing (e.g. due to welding) and while in service (e.g. due to corrosion). Although the 13Cr-4Ni is used after tempering to a hardness below 32 HRC (ASTM A240), previous work studying the behavior of fatigue cracks propagating in CA6NM revealed intergranular cracking. These observations raised questions about the susceptibility of tempered 13Cr-4Ni to hydrogen embrittlement. This work aims to reveal and quantify the effect of hydrogen on the tensile properties of S41500.

Small-size cylindrical specimens (*D*= 4mm) are machined according to ASTM E8 from a wrought S41500 bloc previously quenched and tempered to reach an average ultimate tensile strength of 850 MPa and an average hardness of 22 HRC. Half the specimens are tested in their as-machined condition, and the other half are charged with hydrogen prior to testing. A galvanostatic electrochemical cathodic method is used to charge the samples, and the resulting H concentrations ranged from 1.2 wppm for uncharged samples to 13.5 wppm for samples charged for 28 days. The H concentration of the specimens is measured after testing, using an inert gas fusion method combined with thermal conductivity detection according to ISO 3690. The tensile tests are performed at a strain rate of $1 \times 10^{-5}\, ss^{-1}$, in accordance with the guidelines of ASTM G129 standard. In addition, post-mortem observations of the fractured surfaces were performed.

The main results presented in Figure 1 indicate a plastic elongation ratio ($RE = plastic\ elongation\ of\ H\ charged\ sample/Plastic\ elongation\ of\ uncharged\ sample$) of 0.45 for the sample containing 13.5 wppm of H. The effect of hydrogen on the fracture mechanism is significant. Transitions from dimples to transgranular and finally to intergranular fracture is observed with an increase in the H content. The results of this experimental campaign are the foundation of a substantial research program focusing on the effect of river water on the propagation kinetics of cracks in hydro turbine runners.

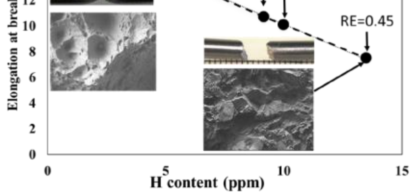


Figure 1 – *Effect of hydrogen on the elongation at break of S41500*

Is Fluid-Structure Interaction the gold-standard method to perform patient-specific in-silico analysis on ascending thoracic aortic aneurysms?

André Mourato[1], Rodrigo Valente[1], José Xavier[1,2], Moisés Brito[1,2], Stéphane Avril[3], António Tomás[4], José Fragata[4,5]

[1]*UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, NOVA University Lisbon, Portugal, af.mourato@campus.fct.unl.pt*

[2]*LASI, Intelligent Systems Associate Laboratory*

[3]*Mines Saint-Etienne, University of Lyon*

[4]*Santa Marta Hospital, Department of Cardiothoracic Surgery*

[5]*Department of Surgery and Human Morphology, NOVA Medical School*

Ascending aortic aneurysms *Blood-vessel interaction* *Patient-specific*

Abstract The current guidelines for diagnosing and treating Ascending Thoracic Aortic Aneurysm (ATAA) need to be revised, although still clinically accepted. Numerical models have been utilized to improve the understanding of ATAA biomechanics and have demonstrated the potential to provide valuable data to stratify the risk of acute complications. However, applying these models in real-life practices is restricted due to various issues, including insufficient accuracy, elevated reporting time, and lack of validation against extensive clinical trials. Over the last decades, Fluid-Structure Interaction (FSI) has been applied to perform patient-specific biomechanical analysis of ATAA. It is known to provide more accurate results at the cost of high reporting time, which may not be suitable for clinical applications. The significance of utilizing FSI in ATAA modelling remains to be determined. Evidence indicates that it is only relevant for diameter variations above 10% that may not occur in ATAA due to the reduction of elasticity. This work aims to examine the impact of modelling the blood-vessel interaction on ATAA biomechanics by comparing the results of Computational Fluid Dynamics (CFD), Reduced Order (RO) and Computational Solid Mechanics (CSM) models against FSI data for different degrees of compliance. To perform these analyses, the first step consisted in reconstructing the patient-specific fluid and solid domains. The reconstruction of both domains was assisted by a Computational Tomography (CT) performed on a 47 years old female with ATAA. The fluid was considered Newtonian and incompressible for the lumen domain and the flow laminar. At the sinotubular junction, a patient-specific inlet flow rate, measured from 3D Phase Contrast Magnetic Resonance Imaging (MRI), was defined and RCR conditions were applied at all outlets. The aortic wall was modelled as a Neo-Hookean, isotropic, incompressible and prestressed material. At the inner surface of the solid domain pressure fields obtained from the CFD and RO models were applied, and the extremities were fixed. The results suggested that the wall movement significantly impacted the peak velocity and Wall Shear Stress (WSS) magnitude. However, the pressure field remained similar despite changes in wall elasticity. The results on the solid domain were not significantly impacted by the variations in the results of the fluid domain, which indicates that pressure is the most critical hemodynamic property to estimate wall mechanics. These results evidenced that more straightforward approaches, such as the coupling of CFD and CSM ones, could accurately recreate the biomechanics of vessels with reduced compliance, as in the case of ATAA.

Patient-Specific Wall Displacement Analysis: A Comparative Study of Fluid Structure Interaction, Computation Fluid Dynamic, and computation Solid Mechanics on Ascending Thoracic Aorta Aneurysm

Rodrigo Valente[1], André Mourato[1], José Xavier[1,2], Moisés Brito[1,2], Stéphane Avril[3], António Tomás[4], José Fragata[4,5]

[1]UNIDEMI, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, NOVA University Lisbon, Portugal,

rb.valente@campus.fct.unl.pt

[2]LASI, Intelligent Systems Associate Laboratory

[3]Mines Saint-Etienne, University of Lyon

[4]Santa Marta Hospital, Department of Cardiothoracic Surgery

[5]Department of Surgery and Human Morphology, NOVA Medical School

Ascending aortic aneurysms *Wall displacement* *Patient-specific*

Abstract Ascending thoracic aortic aneurysm (ATAA) is a potentially life-threatening condition characterized by a bulging or enlargement of the aorta in the chest. As the aneurysm grows, it may dissect or rupture, resulting in severe internal bleeding and even death. Thus, in the supervisors of ATAA, early detection and accurate assessment of the risk of rupture or dissection are critical.

Fluid-structure interaction (FSI) simulation has emerged as a promising tool for predicting ATAA growth and rupture risk. It allows for a thorough examination of the aorta's fluid dynamics and structural mechanics, allowing clinicians to understand better the biomechanical factors that contribute to the progression of ATAA.

Clinicians can eventually predict the risk of rupture and tailor treatment strategies by using FSI simulation to model the hemodynamics of blood flow within the aneurysm with enhanced spatial and temporal accuracy. FSI simulation is a non-invasive, patient-specific computational approach that has the potential to assist for ATAA complications. Nonetheless, FSI necessitates a significant computational effort, and the required time can be excessively long due to aneurism pathology and numerical model complexity.

In this article, we will show how Computational Fluid Mechanics (CFD) and Computational Solid Mechanics (CSM) with patient-specific boundary conditions can produce similar results while requiring significantly less computational effort. This conclusion can be reached by employing patient-specific wall displacement on both numerical models derived from multiple segmentation of 20 CTA-Scans distributed throughout the cardiac cycle.

Direct identification of fracture parameters of wood in Mode I by Digital Image Correlation

Olivier Cochet[1], José Xavier[2,3], Rui Martins[2,3], Rostand Moutou Pitti[1]

[1]Polytech Clermont, Campus Universitaire des Cézeaux, 2 Av. Blaise Pascal, 63100 Aubière, France

Olivier.cochet@etu.uca.fr

[2]UNIDEMI, Research & Development Unit for Mechanical and Industrial Engineering Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, Universidade NOVA de Lisboa, 2829-516 Caparica, Portugal

[3]LASI, Intelligent Systems Associate Laboratory, 4800-058 Guimarães, Portugal

DIC Fracture parameters Mode I

Abstract Wood is an increasingly popular engineering material due to its potential for reducing pollution and combating global warming. Its use in construction has been recognised as a promising solution for sustainable and efficient building design. However, ensuring the safety and reliability of wooden structures requires a comprehensive understanding of the fracture mechanics of wood.

In this study, we investigate the cracking behaviour of softwood species using MMCG specimens. We aim to accurately determine crack length during fracture propagation and related fracture parameters, which is often challenging to obtain in wood. To achieve this, we employ the Arcan system to load the specimen, which has the advantage of inspecting from pure to mixed mode fracture loading to activate different failure modes. Digital Image Correlation (DIC) measures displacement and strain fields near the crack.

Our primary focus is on open I mode crack growth, and we generate force versus crack opening curves from the measurements. In addition, we utilise the imposed displacement compliance method to determine the strain energy release rate for opening mode.

This study highlights the importance of fracture mechanics in ensuring the safety and reliability of wooden structures. Knowledge of the fracture parameters of wood can aid in the design and development of more efficient and sustainable wooden products. Accurate determination of crack length is critical in this regard. Therefore, using digital image correlation techniques and imposed displacement compliance methods can improve our understanding of the fracture behaviour of wood and aid in the design of more reliable and efficient wooden structures.

Fatigue life assessment of WAAM-processed Ti-6Al-4V

Nikolai Kashaev[1], Anton Odermatt[1], Pedro Álvarez[2]

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

[2]IK4-LORTEK, Technological Centre, Joining Technologies Department, Ordizia, 20240, Spain

Wire and arc additive manufacturing *Ti-6Al-4V* *Fatigue analysis*

Abstract. The integrity of a load-bearing structure may degrade during service life due to undetected material defects or accidental damage. Additively manufactured structures are particularly susceptible to fatigue cracking due to stress concentration at possible surface notches or internal material defects. Despite the advantages of arc-based manufacturing techniques, it is still not comprehensively investigated how the manufactured parts fail under cyclic loading. This study aims to investigate the effect of internal material defects on the high-cycle fatigue behavior of WAAM-fabricated Ti-6Al-4V. Furthermore, an emphasis was paid to investigating to which extent the fatigue life prediction model developed and validated for laser beam-welded Ti-6Al-4V joints [1] can be transferred to WAAM-fabricated structures made from this alloy. The model is based on the NASGRO equation in which the short crack growth from the internal defect, such as lack of fusion defect, is taken into account. The results of the study show that by the use of the model, the minimum fatigue life of the fatigue specimens extracted from the WAAM-fabricated structure can be appropriately predicted (Figure 1). The reason that some specimens showed lower predicted fatigue lives in comparison to that experimentally obtained could be due to the effective defect size, which was overestimated by analyzing the fracture surfaces of tested specimens. Thus, a conservative prediction of the fatigue life is achieved.

$$N = \int_{a_i}^{a_f} \frac{1}{C\left[\frac{1-f}{1-R}\Delta K\right]^n \left(1-\frac{\Delta K_{th}}{\Delta K}\right)^p}\, da$$

$$\Delta K_{th} = f(\Delta a)$$

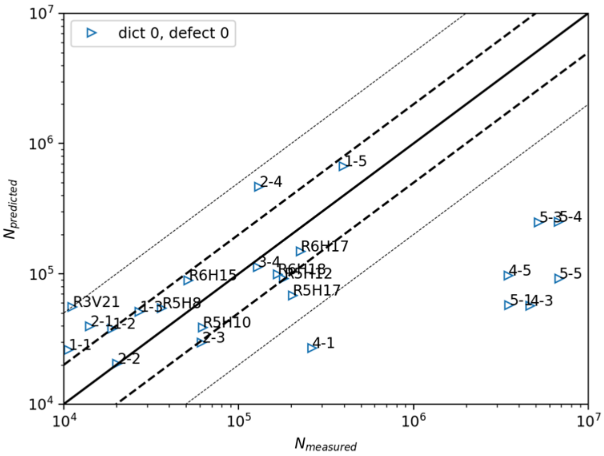


***Figure 1** – Fatigue life assessment model and results of the application of the model represented as experimentally obtained fatigue lives vs. calculated.*

[1] F. Fomin, M. Horstmann, N. Huber, N. Kashaev. Probabilistic fatigue-life assessment model for laser-welded Ti-6Al-4V butt joints in the high-cycle fatigue regime. Int. J. Fatigue 116 (2018) 22-35

A study of the effects of hydrogen on martensitic advanced high-strength steels

Carlo Maria Belardini, Giuseppe Macoretta, Marco Beghini, Leonardo Bertini, Bernardo Disma Monelli, Renzo Valentini

Department of Civil and Industrial Engineering, University of Pisa, Pisa, Italy

carlomaria.belardini@phd.unipi.it

AHSS *Hydrogen embrittlement* *Sheet metal*

Abstract. The automotive industry has been working towards sustainability by reducing the weight of cars while still maintaining safety standards. This has led to the development of high strength steels such as the class known as Martensitic Advanced High Strength Steels (MS-AHSS). One critical issue with MS-AHSS is their susceptibility to hydrogen embrittlement.

In this study, the effects of hydrogen embrittlement on MS-AHSS were investigated. Slow strain rate tensile tests were conducted on electrochemically pre-charged smooth and notched specimens in air. The average hydrogen concentration was measured after each test. The hydrogen loss during the test was preliminarily estimated, showing that it was limited. Fractographic analysis was performed to identify the damage mechanism and the impact of hydrogen on the fracture morphology, both in the fracture nucleation area and on the rest of the specimen.

The results showed that hydrogen significantly reduced the ductility of the tested material, while strength was minimally affected. Fracture morphology showed a progressive transition towards brittle intergranular and quasi-cleavage features as hydrogen content increased, along with the appearance of fisheye features on the final fracture surfaces. Plastic activity was shown to be relevant for the fracture process at all hydrogen concentrations, further reinforcing the theory that hydrogen locally promotes dislocation movement.

Residual mechanical properties and damage accumulation of fiberglass pipes during proportional multiaxial cyclic tests

Artur Kuchukov[1], Artur Mugatarov[2], Oleg Staroverov[2], Elena Strungar[2], Ekaterina Chebotareva[2]

[1]*Perm National Research Polytechnic University, 614990, 29 Komsomolsky prospect, Perm,* *artur.kuchukov.59@mail.ru*

[2] *Perm National Research Polytechnic University*

Composite material *Process of damage accumulation* *Residual mechanical properties*

Abstract Structures strength calculation requires taking into account the degradation of mechanical properties, which occurs due to the accumulation of damage. Uniaxial and biaxial proportional cyclic tests of fiberglass tubular specimens were carried out to study the processes of damage accumulation.

Cylindrical fiberglass tubular samples were obtained by the method of oblique-layer longitudinal-transverse winding. Specimens were tested under conditions of static proportional tension with torsion. As a result of the test, stress-strain curves were obtained using the VIC-3D contactless optical video system and the digital image correlation method. With the help of the AMSY-6 acoustic emission system, defects accompanying the destruction process were identified. After the tests, the fractures of the samples were analyzed using a DinoLite microscope.

Cyclic uniaxial and biaxial fatigue tests of fiberglass tubular samples were carried out. It was found that residual properties decreased as the number of cycles increased. The degradation of characteristics was evaluated according to the model developed earlier by the authors. The boundaries of the damage accumulation process stages were determined. A high descriptive capability of the model was noted. The main defects were identified during the test using acoustic emission.

It was concluded that it is necessary to study the processes of damage accumulation in structural fiberglass under multiaxial cyclic loading, as well as to take into account the mechanical properties degradation in composite structures design.

The work was carried out with the financial support of the Russian Science Foundation (project No. 22-79-00136) at the Perm National Research Polytechnic University.

J-R curve evaluation using CMOD measured by Digital Image Correlation

Aleksandar Sedmak[1], Blagoj Petrovski[2], Nenad Milosevic[1]

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

[2]Innovation center of the Faculty of Mechanical Engineering, Belgrade, Serbia

CMOD *J-R curve* *DIC*

Abstract In the scope of extensive investigation of AA6156 T6 welded panels crack resistance under static and dynamic loading, J-R curve was evaluated using Δa measured by Digital Image Correlation (DIC), as shown in Fig. 1 for two stages of the experiment on a panel with 4 stringers and 3 clips. At the same time, CMOD, acting force and load line displacement were measured in standard way and to evaluate J integral, enablingconstruction of J-R curve through points J-Δa. Two diffrerent welded panels configurations were tested, one with 4 stringers and the other one with additional 3 clips. The applied technique is simple, practical and hase no limitions in respect to material and geomtery.

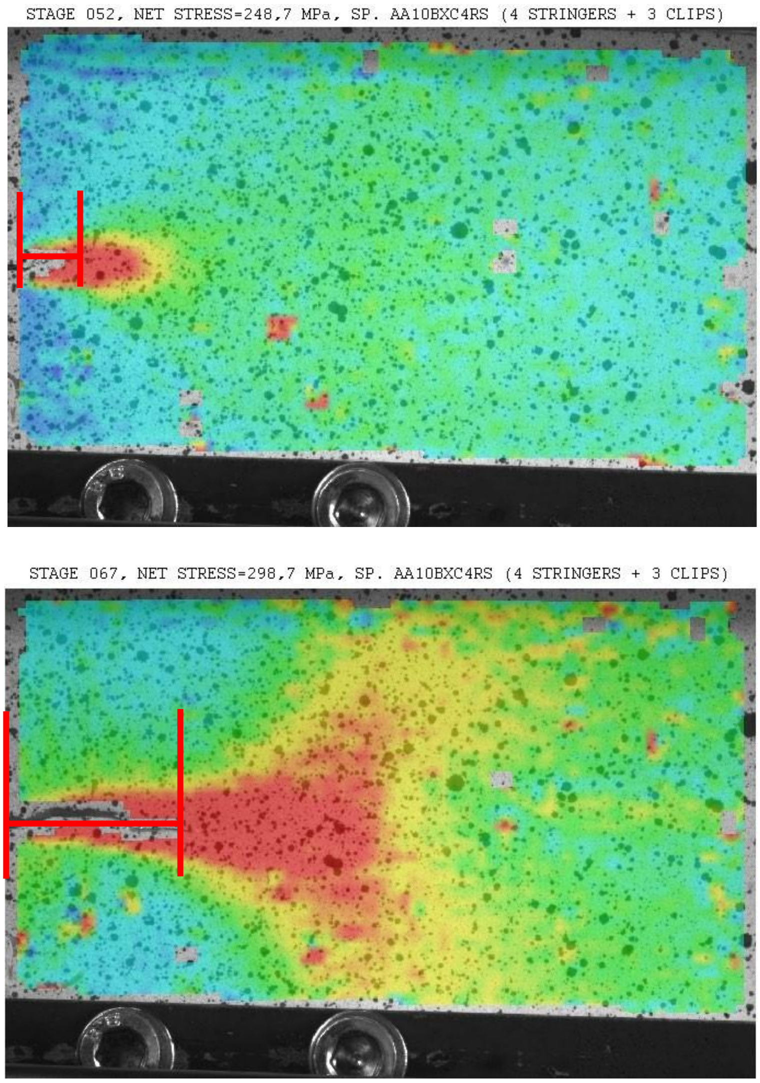


Figure 1 *– Measurement of crack length by using DIC, a) stress 248 MPa, b) stress 298 MPa*

Bainitic rails intended for highly-loaded tracks – the nature of fatigue cracking mechanisms in mixed mode loading conditions

Aleksandra Królicka[1], Grzegorz Lesiuk[1], Dariusz Rozumek[2], Roman Kuziak[3], Krzysztof Radwański[3], Michał Smolnicki[1], Szymon Dziuba[1], A.M.P. De Jesus[4], Jose A.F.O. Correia[4]

[1]*Wroclaw University of Science and Technology, Faculty of Mechanical Engineering, Łukasiewicza 5, 50-370 Wroclaw, Poland*

[2]*Department of Mechanics and Machine Design, Opole University of Technology, Mikołajczyka 5, 45-271 Opole, Poland*

[3]*Łukasiewicz Research Network – Upper Silesian Institute of Technology, K. Miarki 12-14, 44-100 Gliwice, Poland*

[4]*University of Porto, Faculty of Engineering, Rua Dr Roberto Frias, Porto, Portugal*

Bainitic steel *Fatigue crack growth* *Mixed-mode loading*

Abstract In recent years, the application of advanced bainitic steels in railway infrastructure has attracted the interest of researchers and industry due to their promising mechanical properties in comparison to conventional pearlitic steels. The majority of the published works concerned issues related to wear resistance [1], rolling contact fatigue [2], low cycle fatigue [3], fatigue crack growth rate [4,5], and fracture toughness [6]. In the conducted investigations, an effort was focused on determining the influence of the metastable bainitic structure on fatigue cracking processes under mixed-mode loading conditions. The research material was the developed bainitic rail subjected to continuous cooling after the hot forming processes. The microstructure consisted of bainitic ferrite laths characterized by a sub-micrometer scale, retained austenite with filmy and blocky morphology, and a low fraction of M/A constituents. As it is known, especially during heavy loading operating conditions, a complex stress state occurs on the running surface due to material flaws. The issue related to fatigue crack mechanisms subjected to mixed-mode loading conditions in bainitic steels has not been explained in the literature and industrial project reports, which is particularly important in ensuring the integrity of railway tracks. Considering the significance of this issue, the principal motivation of this research was to explain the mechanisms of fatigue fracture of bainitic steel under a complex stress state. Specific mixed-mode conditions (I+II, I+III) and fatigue crack growth rate was related to the microstructure morphology. The results indicate that the mixed-mode loading conditions significantly affect the mechanisms and rate of fatigue fracture. The analysis of investigations provides a good insight into the design of new advanced steels intended for rail infrastructure applications characterized by enhanced fatigue performance with consideration of heavy exploitation conditions.

Bibliography:

[1] Liu J, Li Y, Zhang Y, Hu Y, Shi L, Ding H, et al. Dry Rolling/Sliding Wear of Bainitic Rail Steels under Different Contact Stresses and Slip Ratios. Materials (Basel) 2020;13:4678. https://doi.org/10.3390/ma13204678.

[2] Gui X, Wang K, Gao G, Misra RDK, Tan Z, Bai B. Rolling contact fatigue of bainitic rail steels: The significance of microstructure. Mater Sci Eng A 2016;657:82–5. https://doi.org/10.1016/j.msea.2016.01.052.

[3] Adamczyk-Cieślak B, Koralnik M, Kuziak R, Brynk T, Zygmunt T, Mizera J. Low-cycle fatigue behaviour and microstructural evolution of pearlitic and bainitic steels. Mater Sci Eng A 2019;747:144–53. https://doi.org/10.1016/j.msea.2019.01.043.

[4] Królicka A, Lesiuk G, Radwański K, Kuziak R, Janik A, Mech R, et al. Comparison of Fatigue Crack Growth Rate: Pearlitic Rail versus Bainitic Rail. Int J Fatigue 2021:106280. https://doi.org/10.1016/j.ijfatigue.2021.106280.

[5] Aglan H, Fateh M. Fracture and fatigue crack growth analysis of rail steels. J Mech Mater Struct 2007;2:335–46. https://doi.org/10.2140/jomms.2007.2.335.

[6] Królicka A, Lesiuk G, Kuziak R, Radwański K, Janik A. The role of microstructure morphology on fracture mechanisms of continuously cooled bainitic rail. Metall Mater Trans A 2022.

An analysis of notch sensitivity in the VHCF fatigue regime of S690 steel

Rita Dantas[1,2,3*], Michael Gouveia[1,2], Filipe G. A. Silva[2], Felipe Fiorentin[1,2], Abílio de Jesus[1,2], José A. F. O. Correia[1,2,3], Grzegorz Lesiuk[4]

[1]University of Porto, Rua Dr. Roberto Fria, 4200-465 Porto,

Portugal, rdantas@inegi.up.pt [2]INEGI, Department of Mechanical

Engineering, University of Porto, Portugal [3]CONSTRUCT,

Department of Civil Engineering, University of Porto, Portugal

[4]Department of Mechanics, Materials Science and Biomedical Engineering, Faculty of Mechanical Engineering, Wroclaw University of Science and Technology, ul. Smoluchowskiego 25, PL-50370 Wrocław, Poland

S690 Steel *Notch effect* *VHCF*

Abstract Generally, the notch presence in a structural detail can be characterised by the stress concentration factor (kk_{tt}), or with more accuracy, by the fatigue stress concentration factor (kk_{ff}). The last concept can be defined as the ratio between the fatigue limit of a smooth specimen and the fatigue limit of a notched specimen, which implies the execution of an expensive and time-consuming experimental campaign. Thus, some authors propose different approaches of hot-spot, average-stress, stress-field-intensity or volumetric nature, to predict the fatigue life of notched specimens [1]. However, the notch effect in the very high cycle fatigue (VHCF) regime is not well characterised in literature, as well as the experimental procedure to test notched specimens in an ultrasonic fatigue machine. Consequently, this work aims to evaluate the notch effect in the fatigue behaviour of S690 steel and to study different approaches to predict fatigue notch life in very high-cycle fatigue regimes.

Therefore, an ultrasonic fatigue machine performed an experimental campaign with smooth and notched specimens of S690 steel (Fig.1 (right)). The specimens' different geometries were defined based on an analytical formulation established from the elastic wave theory and complemented with a finite element model, allowing stress amplitude analysis at the critical cross-section (Fig.1 (left)). It was concluded that S690 steel is extremely notch sensitive. Furthermore, the notch effect in fatigue life increases with the number of cycles and all specimens showed crack initiation at the surface.

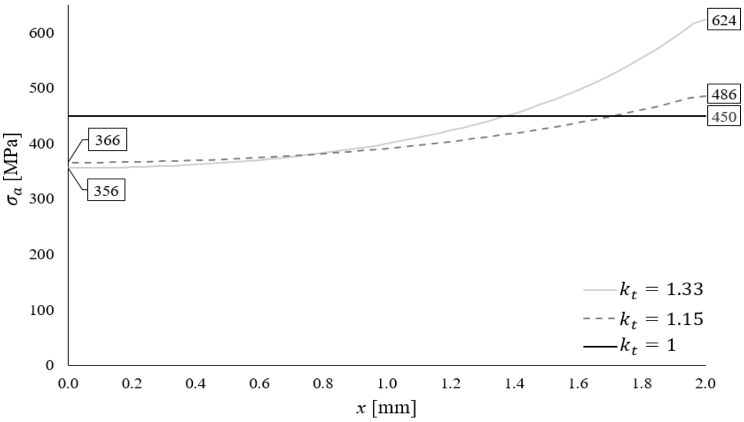


***Figure 1** - Stress amplitude for different kk_{tt} along the critical cross section according to numerical model (left) and smooth and notched specimens analysed (right)*

[1] G. Qylafku, Z. Azari, and G. Pluvinage, "On the fatigue failure and life predition for notched specimens," *Mater. Sci.*, vol. 34, no. 5, pp. 17–26, 1998.

Determining the elastoplastic properties and analysing the fracture behaviour of thin aluminium alloy welds

Z. Silvayeh[1]*, J. Domitner[1], M. Müller[1], P. Auer[1], C. Sommitsch[1], P. Mayr[2]

[1]Graz University of Technology, Institute of Materials Science, Joining and Forming, Research Group of Lightweight and Forming Technologies, 8010 Graz, Austria

zahra.silvayeh@tugraz.at

[2]Technical University of Munich, Chair of Materials Engineering of Additive Manufacturing, Boltzmannstraße 15, 85748 Garching/Munich, Germany

Tailor-welded blank *Weld properties* *Finite element simulation*

Abstract This work presents a straightforward procedure for determining the elastoplastic properties and for estimating the fracture parameters of thin aluminium alloy welds. For that purpose, single-pass weld seams of a commercial 5xxx aluminium alloy were deposited on a 1.2 mm-thick EN AW-5182 aluminium alloy sheet by using the Cold Metal Transfer (CMT) welding process. Samples for uniaxial tensile testing that consisted almost exclusively of the as-welded microstructure were prepared. The exact geometry of each sample including the surface features of the weld seam was captured before tensile testing by using an optical 3D scanning system. A preliminary flow curve for describing the plastic behaviour of the weld metal under uniaxial tension was calculated based on the force-displacement curves monitored in the tensile tests. The meshed geometry of each sample and the flow curve were employed for building a finite element (FE) model of the tensile testing setup. Constitutive parameters for describing the flow curve and the ductile fracture criterion even under multi-axial stresses were iteratively optimized, until good agreement between the force-displacement curves of the tensile tests and of the FE simulations were achieved. The elastoplastic properties and the fracture parameters that were determined on the basis of the presented procedure can be used for simulating forming of tailor-welded blanks (TWB) or for calculating the structural failure of welded aluminium joints.

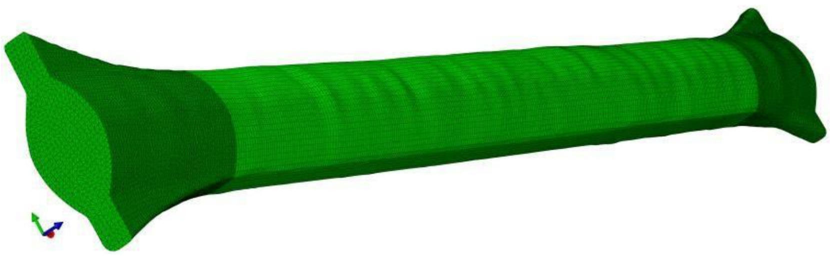


Figure 1 - Scanned and meshed geometry which considers the relevant surface features of a welded sample for uniaxial tensile testing

The critical expansion strain for the onset of structural integrity degradation due to high-temperature hydrogen attack of a carbon manganese steel

R.J. Mostert, A van Zyl, C.C.E. Pretorius, V.M Mathoho

Department of Materials Science and Metallurgical Engineering, University of Pretoria, Private Bag X20, Hatfield 0028, South Africa

roelf.mostert@up.ac.za

Hydrogen service *High-temperature Service* *Damage Development*

Abstract It has earlier been shown that the tracking of HTHA damage in structural steels using expansion strain monitoring is feasible, even for industrial applications. The critical strain where HTHA damage begins to impact the structural integrity of equipment has, however, not been established conclusively. Earlier work has referred to a point of "incipient damage" which was found at the end of the incubation period of the strain-life curve, and was stated to range from 400 microstrain (με) to 1000 με. In addition, a parametrical model, based on HTHA kinetics research reduced to Arrhenius equations, has been proposed in this context. This work led to the development of a "Pw" parameter which is claimed to indicate the onset of critical structural damage as a function of process variables. However, the onset of tensile degradation as a function of the Pw- parameter has not been fully explored.

Samples of a structural C-Mn steel were exposed to 46 bar pure hydrogen at 550 °C in an autoclave for various exposure periods. Some samples were instrumented with a high temperature strain gauge to track the accelerated expansion strain. Samples of all three orientations relative to the plate rolling direction were thereafter subjected to tensile testing. The results demonstrated that severe degradation of the tensile ductility occurred after experiencing expansion strains much smaller than that anticipated earlier, especially for samples in the plate through-thickness orientation. For these samples, the incipient damage, as far as tensile ductility is concerned, could be identified as being in the order of 75 με. After approximately 140 με expansion, ductility degradation approached 100 %. Using the Pw-model derived from the McKimpson and Shewmon work for the process conditions resulting in the critical strain, it was found that the actual Pw-values were 0.7 to 0.76 times smaller than that calculated from the previously proposed model, irrespective of whether the low or high H_2pressure model was used. The existing Pw-equations overpredicted the time required for incipient damage by a factor of ~30 times (low pH_2 model) to ~1900 (high pH_2 model). In addition, it was found that, for the trough-thickness samples, the actual Pw -values at the onset of degradation was only separated by 1 – 3 % of the Pw- value at the saturation of damage. The results were interpreted using high-resolution SEM imaging.

Impact Analysis of an Adhesive Joint Using a Meshless Method

L.D.C. Ramalho[1], I.J. Sánchez-Arce[2], Diogo C. Gonçalves[1], R.D.S.G. Campilho[1,3], Jorge Belinha[1,3]

[1]INEGI, Institute of Mechanical Engineering, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal

lramalho@inegi.up.pt

[2] Universidade de Trás-os-Montes e Alto Douro, Quinta de Prados 5000-801 Vila Real, Portugal

[3] 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

Adhesive Joints *Meshless methods* *Impact*

Abstract Due to increasing concerns over climate change the need to reduce the weight of transportation methods is of paramount importance since it leads to a lower energy consumption, and in turn this leads to lower emissions. In this aspect adhesive joints offer an advantage over other joining methods, like bolting or riveting, since adhesive are significantly lighter than the metals used in bolts or rivets. In this context it is important to properly assess the capabilities of adhesive joints before they are used in vehicles. Meshless methods are one of the possible ways to analyse adhesive joints. Currently the meshless methods works dedicated to adhesive joints only consider their static behaviour. However, their dynamic behaviour is just as important, especially when considering their use in vehicles where adhesive joints can be subjected to impacts and loading conditions that can vary significantly over time. So, the present work aims at performing an impact analysis of an adhesive joint using a meshless method, to assess the capabilities of this tool in this type of analysis.

Application of the dual-adhesive technique for static improvement of single-step joints

D.F.T. Carvalho[1], R.D.S.G. Campilho[1,2], L.D.C. Ramalho[2], R.D.F. Moreira[1,2], K. Madani[3]

[1]*ISEP—School of Engineering, Polytechnic of Porto, R. Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal.*

[2]*INEGI—Institute of Science and Innovation in Mechanical and Industrial Engineering, Pólo FEUP, Rua Dr. Roberto Frias, 400, 4200-465 Porto, Portugal.*

lramalho@inegi.up.pt

[3]*Department of Mechanical Engineering, University of Sidi Bel Abbes, BP 89 Cité Ben M'hidi, Sidi Bel Abbes 22000, Algeria*

Adhesive joint *Cohesive zone modelling* *Crack propagation*

Abstract The constant search for new and more efficient production methods leads industry to increasingly adopt adhesive bonding. This joining method aims to replace conventional joining methods such as bolting/riveting and welding and is already prevalent in the aeronautics and automotive industries. One of the main allies to the widespread use of this type of joint is the development of highly accurate computer-aided numerical methods capable of assisting in the design and joint strength prediction, leading to validation of different solutions and respective industrial implementation. Different modifications to the conventional designs are addressed in the literature to achieve the best results, including geometrical and material modifications. In this work, the strength of single and double-adhesive single-step joints in aluminium adherends of the AW 6082-T651 is experimentally and numerically studied for different overlap lengths (L_O). Three types of adhesives were considered, from brittle to ductile, along with different adhesive combinations in the dual-adhesive technique. The experimental work was mainly used for numerical model validation. The numerical analysis took advantage of triangular cohesive zone models (CZM) and included the study of peel and shear stresses, strength, and energy to failure. It was possible to validate the CZM accuracy by comparison with the experimental data. The analysis carried out showed that the two-adhesive technique did not reveal significant increases in strength compared to single-adhesive joints, although in the damage tolerance and dissipated energy the performance increase is noticeable, especially in joints with higher L_O.

eXtended Finite Element Method applied to the tensile strength evaluation of scarf adhesive joints

I.R.S. Araújo[1], G.J.C. Pinheiro[1], R.J.B. Rocha[2], R.D.S.G. Campilho[1,2], L.D.C. Ramalho[2], K. Madani[3]

[1]*ISEP—School of Engineering, Polytechnic of Porto, R. Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal.*

[2]*INEGI—Institute of Science and Innovation in Mechanical and Industrial Engineering, Pólo FEUP, Rua Dr. Roberto Frias, 400, 4200-465 Porto, Portugal*

[3]*Department of Mechanical Engineering, University of Sidi Bel Abbes, BP 89 Cité Ben M'hidi, Sidi Bel Abbes 22000, Algeria*

lramalho@inegi.up.pt

Adhesive joint *eXtended Finite Element Method* *Crack propagation*

Abstract Adhesive joints are increasingly used in various industrial sectors and, depending on the application, different types of configurations can be considered. The most common and academically studied joint configuration is the single-lap joint. However, there are other configurations such as the scarf joint which, although it has some complexity in the manufacturing process, obtains a better stress distribution when compared to single and double-lap joints. Although scarf joints have already been studied in the literature, the number of studies that analyse different geometries and adhesives is still scarce, as is the validation of robust and reliable numerical techniques for the design of structures with this type of joints, which enable its application in structural projects. The objective of this work is the parametric numerical study of scarf adhesive joints in tension with different adhesives (Araldite® AV138, Araldite® 2015 and Sikaforce® 7752) and different scarf angles or □ (3.43°, 10 °, 15°, 20°, 30° and 45°) by the eXtended Finite Element Method (XFEM). Initially, the experimental results obtained in a previous work are described, for the purpose of validating the obtained numerical results. The developed numerical work includes the analysis of failure modes, peel, and shear stress distributions in the adhesive in the elastic regime, distribution of the damage variable, joint strength and energy dissipated at failure. With the work carried out, the coherence of the numerical results with the experimental ones was observed, with emphasis on the joint strength as a function of □. It was found that joints with a=3.43° present the best results in terms of tensile strength of the joints. The adhesive Araldite® AV138 presents the best tensile behaviour, regardless of the □ value. Based on the results obtained, it was considered that the XFEM is a tool that can be accurately used to design scarf adhesive joints.

The thermal influence on the material durability of additive manufactured glass fibre reinforced polymer with embedded fibre Bragg grating sensor

Magdalena Mieloszyk[1], Ruta Rimasauskiene[2], Marius Rimasauskas[2], Anita Orłowska[3]

[1]*Institute of Fluid Flow Machinery, Polish Academy of Sciences, Fiszera 14, 80-231 Gdansk, Poland,*

mmieloszyk@imp.gda.pl

[2]*Kaunas University of Technology, Studentu 56, Kaunas 51424, Lithuania*

[3]*Institute of Fundamental Technological Research of the Polish Academy of Sciences, Pawinskiego 5B, 02-106 Warsaw, Poland*

Additive manufacturing *Structural Health Monitoring* *fibre Bragg grating sensors*

Abstract The goal of the paper is to analyse the influence of embedded fibre Bragg grating (FBG) sensors on additive manufactured (AM) glass fibre reinforced polymer (GFRP) samples structure and durability. The samples were manufactured using the modified fused deposition modelling (FDM) method. During the AM process in the middle of some of the samples, FBG sensors were embedded. The AM process did not influence the FBG sensors. The sensors were applied for strain measurements during the thermal and tensile tests.

The samples (without and with embedded FBG sensors) were divided into two sets. One of them was exposed to assumed values of temperatures (in a range of 10°C to 50°C) under stable relative humidity values (20% and 95%) in an environmental chamber. While the second set remained intact. Then the tensile test was performed on all samples to analyse the embedded FBG sensors influences on AM GFRP samples durability. Additionally, the samples structure (after manufacturing, after thermal tests, and after tensile test) was measured using SEM microscope and THz spectrometer. The analyses allowed better understanding of the influence of the temperature on the GFRP material structure as well as the breaking process during the tensile test.

It was concluded that embedded FBG sensors can be applied for strain measurements of AM GFRP elements exposed to thermal and mechanical loading. Additionally, it was observed that the sensors influence on the material durability was neglected and the AM method can be applied to manufacturing smart structures.

Fatigue behaviour and numerical assessment of welded EN AW 7020 tube joints under multiaxial loading

Jenny Köckritz[1], Thomas Fürstner[1], Robert Szlosarek[1], Matthias Kröger[1]

TU Bergakademie Freiberg, Institute for Machine Elements, Engineering Design and Manufacturing. Agricolastraße, 09599 Freiberg

jenny.Koeckritz@imkf.tu-freiberg.de

Weld assessment *Multiaxial loading* *Aluminium*

Abstract Cargo bicycle frames have to fulfil highest lightweight requirements and are subjected to demanding loading conditions, which lead to multiaxial stresses in critical weld regions. Reliable fatigue assessment is crucial for a fast development and production process, especially for small batch sizes. In this study, several numerical weld assessment methods are compared with experimental results in the case of multiaxially loaded EN AW 7020 (AlZn4,5Mg1) tungsten inert gas (TIG) welded tube connections with no subsequent heat treatment. Their applicability on the use case of a cargo bicycle frame manufactured with the same material and weld method is discussed.

For the numerical and experimental investigations, simplified tube-plate joint specimen with fillet welds are utilized. Fatigue tests are performed with fully reversed, in phase bending and torsion, causing multiaxial loading of the weld. This loading is subjected to the specimen with a constant amplitude as well as a load collective. The load collective was obtained from representative driving situations with the cargo bicycle.

The welds are assessed with several numerical assessment methods, including effective notch method, hot spot stress method and a solver-specific hot spot stress-based assessment method. For the solver-specific weld fatigue assessment method several modelling parameters proved to be critical for a reliable result, such as the material parameters themselves and the bending ratio. Element size and accurately placed weld connectors showed to have less significant influence.

For the constant amplitude loading the numerical and experimental results display some divergence, with all assessment methods showing exceedingly conservative lifetimes. In contrast, for the load collective, the hot spot stress-based solver-specific assessment method leads to satisfactory compliance with the experimental results.

Influence of the rivet-die offset on the integrity of self-piercing-riveted joints

J. Domitner[1], Z. Silvayeh[1], J. Stippich[1], P. Auer[1], N. Gubeljak[2], J. Predan[2]

[1]*Graz University of Technology, Institute of Materials Science, Joining and Forming, Research Group of Lightweight and Forming Technologies, 8010 Graz, Austria,*

josef.domitner@tugraz.at

[2]*University of Maribor, Faculty of Mechanical Engineering, Chair of Mechanics, 2000 Maribor, Slovenia*

Lightweight design *Self-piercing riveting* *Joint integrity*

Abstract Self-piercing riveting (SPR) has become a key technology for cost-efficient mechanical joining of metal components in the serial production of lightweight car bodies. Although the SPR process is basically quite stable and reliable, the occurrence of irregular process conditions cannot be excluded. Such conditions may affect the formation of a proper interlock between the rivet and the components to be joined, which affects the load-bearing capacity of the joint. Therefore, the present work investigates the influence of different offsets between the rivet and the die on the integrity of SPR lap joints of 1.5 mm-thick EN AW6016-T4 aluminum alloy sheets. Flat and pip dies and high-strength steel rivets of different hardness were used for joining. The quality of the joints was assessed based on characteristic cross-section features (height of the rivet head, horizontal undercut of the rivet, minimum bottom thickness of the lower sheet), and the shear-tensile strength of the lap joints was tested under quasi-static loading. Moreover, a three-dimensional (3D) finite element (FE) model of the riveting process was created. This model enabled predicting the influence of the offset between the rivet and the die on the integrity of the joint. The offset had notable influence on the flaring behavior of the rivet and thus on the symmetry of the joint, the influence on the shear-tensile strength of the joints was just moderate.

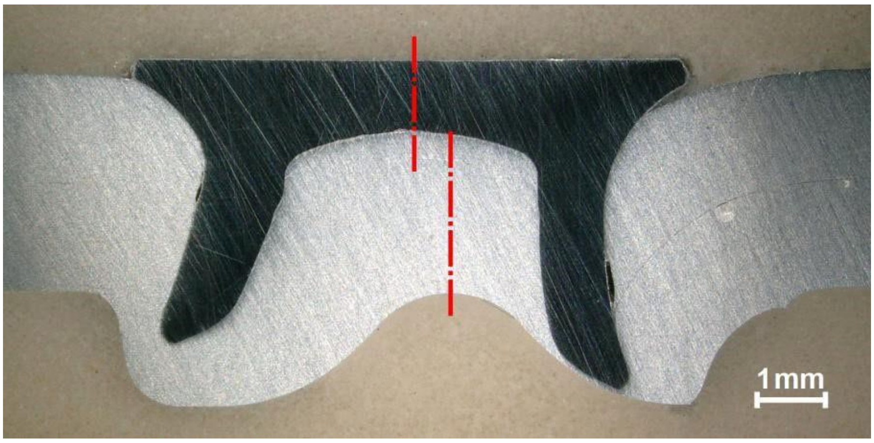


Figure 1 - Asymmetric cross-section of a typical SPR joint that consists of two 1.5 mm-thick EN AW-6016-T4 sheets. The joint was produced with the initial offset of 1 mm between the rivet axis and the die axis

Modelling the high-speed punching process of copper sheets

D. Gomboc[1,2], P. Auer[1], M. Unterrainer[3], Z. Silvayeh[1], C. Sommitsch[1], J. Domitner[1]

[1]*Graz University of Technology, Institute of Materials Science, Joining and Forming, Research Group of Lightweight and Forming Technologies, 8010 Graz, Austria*
josef.domitner@tugraz.at

[2]*University of Maribor, Faculty of Mechanical Engineering, Chair of Mechanics, 2000 Maribor, Slovenia*

[3]*MARK Metallwarenfabrik GmbH, 4528 Spital am Pyhrn, Austria*

Electromobility *Copper* *Punching*

Abstract Because of the strong trend towards the electrification of vehicles the demand for copper consumed by the automotive industry is expected to grow significantly during the next decade. Hence, increasing attention must be paid to the efficient processing of copper and its alloys, which particularly includes punching/blanking, forming and joining of sheet metals. During punching severe plastic deformation at high strain rates as well as notable friction- and deformation-induced heating occur at the punching edge. As these effects may influence the process characteristics, they must also be considered in the numerical simulation of punching processes. This work presents a 2D axisymmetric finite element (FE) model for investigating high-speed punching of 1.6 mm-thick sheets of technically pure oxygen-free (OF) copper at room temperature. The model included the elastic steel tools (punch, die) and the elastoplastic copper sheet. Yielding and fracture of the copper sheet were considered at different strain rates and temperatures. The yield curves and the fracture parameters for strain rates between ≈ 10^{-3} s^{-1} (quasi-static) and ≈ 10^{3} s^{-1} (high-speed) and between room temperature (RT) and 300 °C were determined based on uniaxial tensile testing and inverse modelling of the testing procedure. The geometry of the punched metal piece predicted by the model was compared with the geometry of pieces produced using a test rig and captured using an optical 3D measuring system. Moreover, the force-displacement curves of the punch calculated in the simulation and measured in the experiments were compared. Good agreement between the simulation and the experiment was generally achieved, which demonstrates that the presented model can be reasonably used for analysing the punching process. Small differences in the results are attributed to the anisotropy of the mechanical properties of the copper sheet that have not been considered in the 2D axisymmetric model.

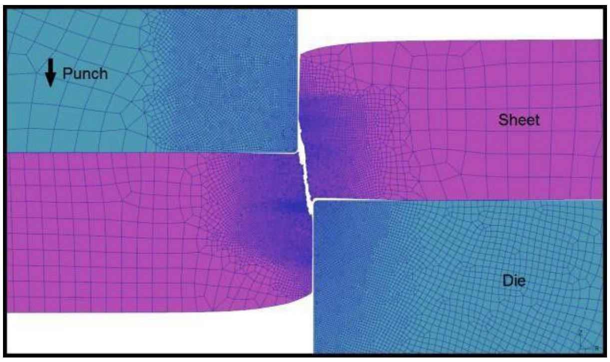


Figure 1 - Punching edge of the copper sheet as predicted by the FE model

Fundamental insights into the hydrogen embrittlement of pipelines in high-pressure gaseous environments

Frank Cheng
fcheng@ucalgary.ca

Dept. of Mechanical & Manufacturing Engineering, University of Calgary, Calgary, AB, T2N 1N4, Canada

Hydrogen embrittlement *Pipelines* *Density functional theory*

Abstract Hydrogen has become a critical player in energy transition and achievement of the 2050 net-zero target. Hydrogen delivery is integral to the entire value chain of hydrogen economy. Of various modes for hydrogen distribution, pipelines provide an economical and effective means to transport hydrogen with an increased capacity over wide ranges and long distances. Safety is paramount for hydrogen transport in pipelines. Pipeline steels are prone to hydrogen embrittlement (HE) in high-pressure hydrogen gas if hydrogen (H) atoms can generate from the gaseous environment and enter the steels. The HE can compromise structural integrity and cause failures of the pipelines.

Compared with HE occurrence in aqueous environments, the HE of hydrogen pipelines is associated with distinct features. Major gaps exist in both fundamental and applied aspects. This talk will provide fundamentals of the gaseous HE of steels, detailing unique features of the problem. A thermodynamic model is developed to evaluate the feasibility of H atom generation from high-pressure gaseous environments under pipeline operating conditions. The density functional theory (DFT) is used to determine the stable configurations for H atom adsorption and absorption on crystalline lattice plane, grain boundaries and dislocations. It is expected that the research outcomes fill the gap to understand the fundamentals of gaseous HE of pipelines, contributing to improved integrity and safety for hydrogen trabsport.

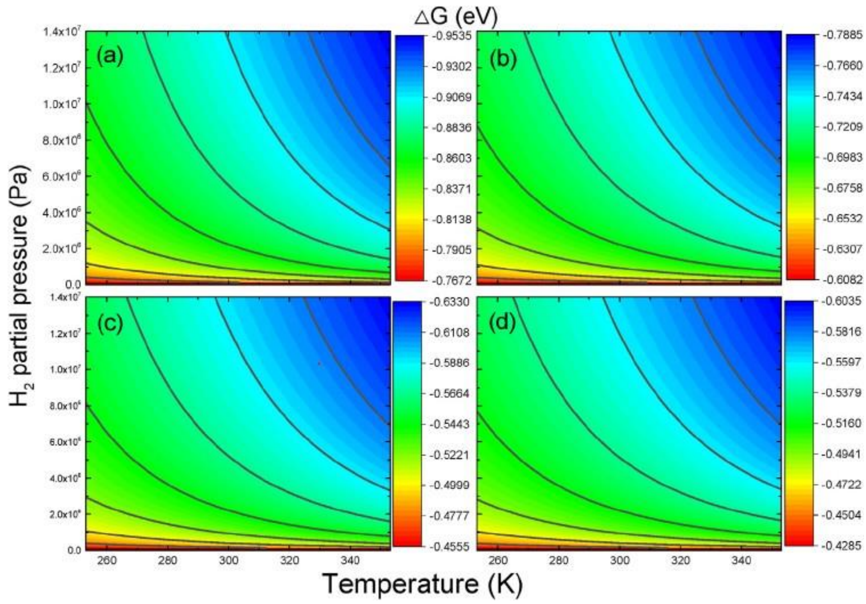


Figure 1 *- Change of Gibbs free energy of dissociative adsorption of hydrogen on Fe (100) plane under various H atom coverages (monolayer) (a) 0.25, (b) 0.50, (c) 0.75, (d) 1.00,*

Study of hydrogen atom distribution at metallurgical features and mechanical defects contained in pipeline steels by scanning Kelvin probe force microscopy and finite element modeling

Qing Hu, Frank Cheng
fcheng@ucalgary.ca

Dept. of Mechanical & Manufacturing Engineering, University of Calgary, Calgary, AB, T2N 1N4, Canada.

Hydrogen atoms *Pipeline steels* *Scanning Kelvin probe force microscopy*

Abstract In this work, a new method by combining scanning Kelvin probe force microscopy (SKPFM) measurements with finite element (FE) analysis was used to study the hydrogen (H) atom distribution in metallographic phases contained in X80 pipeline steel. The H atom diffusion was calculated by classic diffusion equations, which were formulated by FE analysis under the effect of concentration and stress gradients. The SKPFM measured and mapped the topographic profile and Volta potential of the microphases before and after H-charging.

The ferrite contained in the steel has a smaller height than the bainite upon etching due to preferential dissolution in the solution. The bainite is more stable than the ferrite, as indicated by the smaller Volta potential and thus the greater work function of bainite than ferrite. However, the H-charging elevates the electrochemical dissolution activity of both microphases, as shown with increased Volta potentials and thus the decreased work function. The H atoms tend to accumulate at ferrite, which has a greater H-binding energy, making the H-atom concentration at ferrite much greater than the bainite. The results imply that, compared with bainite, ferrite is the location to accumulate more H atoms, initiating cracks once the local H-atom concentration reaches a threshold value. In bainite, the H-atom concentration in the lattice sites is greater. However, in ferrite, the H-atom concentration in the trap sites is much greater.

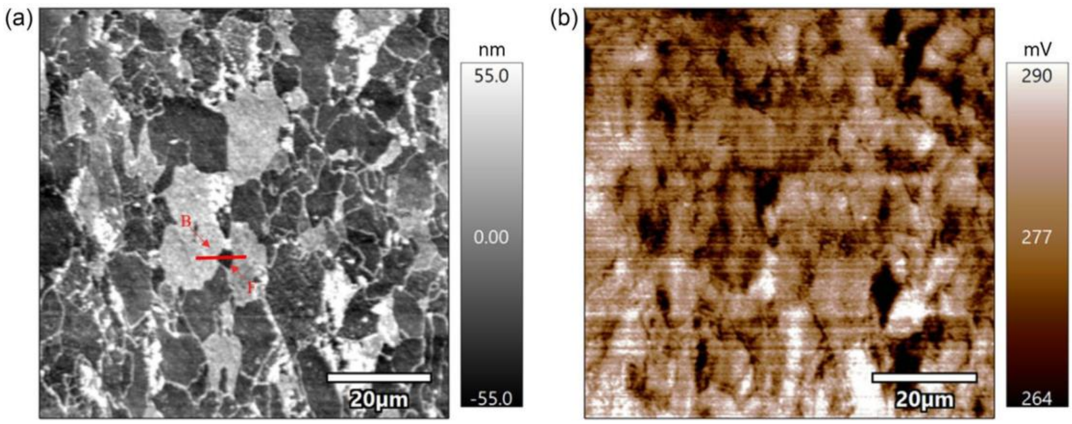


Figure 1 *- SKPFM measurements of X80 steel sample: a) topographic profile, b) Volta potential map.*

Multiscale modelling of mechanical behaviour of 3D printed continuous carbon fibre polymer composites under thermal loading

Isyna Izzal Muna, Magdalena Mieloszyk

Institute of Fluid-flow Machinery, Gdansk, Poland

Composite materials *Additive manufacturing* *Multiscale modelling*

Abstract The rapid advancement of manufacturing techniques and the design of new materials and structures in the engineering sector has piqued the interest of industry and scientific research. Carbon fibre reinforced polymer (CFRP) elements created using AM techniques outperform printed samples made of pure polymers. In terms of real-world application of these printed materials, such elements can be exposed to a variety of environmental factors, with temperature influence being one of the most common. Temperature has a strong influence on the matrix material used to join CFRP components, resulting in a reduction in material strength. The goal of the present study is to perform multiscale modelling of unidirectional (UD) CFRP composite manufactured with the FDM method under various thermal loadings.

The simulation will be performed using molecular dynamics (MD) at nanoscale and finite element method (FEM) at micro-macroscale. Abaqus software is the main tool for FEM modelling and LAMMPS package is employed for MD simulation. The reinforcement material used is continuous carbon fibre (CCF) while thermoplastic PLA is used as matrix material. The multiscale simulation consists of three stages: First, the curing process of the matrix polymer which will be performed by MD simulations to predict the cure-shrinkage and thermomechanical properties. Second, to evaluate the homogenized orthotropic elastic moduli, coefficient of thermal expansion (CTE), and cure-shrinkage strain of the lamina, a microscopic structure generation based on Random Sequential Absorption (RSA) analysis using the periodic boundary condition (PBC) will be performed. Ultimately, deformation and degradation of mechanical properties was predicted by macroscopic FEM using the homogenized method obtained from microscale.

The material's behaviour such as stiffness and elastic modulus are compared for several thermal groups: intact (without thermal loading), continuous, and cyclic temperatures. The obtained numerical results from multiscale simulation are then validated with the experimental results.

The effect of artificial ageing on corrosion-induced micro-cracking of Al-Cu-Li 2198 alloy

Margarita Christina Charalampidou[1], Nikolaos Alexopoulos[1], Stavros Kourkoulis[2]

[1]Research Unit of Advanced Materials, Department of Financial Engineering, School of Engineering, University of the Aegean, 41 Kountourioti str, 82132 Chios, Greece

[2]Lab of Testing and Materials, Department of Mechanics, National Technical University of Athens, 9 Heroes Polytechniou Str., 15773 Athens, Greece

Corrosion *Aluminium* *cracking*

Abstract Improvement in energy efficiency and mechanical performance along with maintenance of damage tolerance in aviation industry led to the development of new, lighter metallic structures with improved mechanical properties. Third generation Al-Cu-Li alloys developed to replace the conventional aluminium alloys, since they can offer weight and energy savings as well as enhanced property balance and corrosion resistance. Their improved mechanical properties are attributed to their complex 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 due to the different microstructural characteristics of the matrix and therefore increase their corrosion susceptibility. Corrosion of aluminum alloys includes several mechanisms; one of the most common corrosion-induced mechanism is the formation of micro-cracks which propagate in the material's interior reducing the effective thickness and consequently its mechanical performance and structural integrity.

The material used in this study was a wrought aluminium alloy 2198 which was received in sheet form of 3.2 mm nominal thickness. Specimens of AA2198 were exposed to artificial ageing heat-treatment for different times to simulate the different ageing tempers. Afterwards, exposure of the specimens to exfoliation corrosion (EXCO) was performed according to specification ASTM G34, in order to investigate the effect of artificial ageing kinetics on corrosion-induced micro-cracking formation and propagation. Cross-sections of the corroded specimens were examined with light optical microscopy in order to measure the depth of attack in each different temper.

Acknowledgment: The work has been financed by the Hellenic Foundation for Research and Innovation H.F.R.I.-Project ID 03385 Acronym CorLi-Corrosion susceptibility, degradation and protection of advanced Al-Li aluminium alloys.

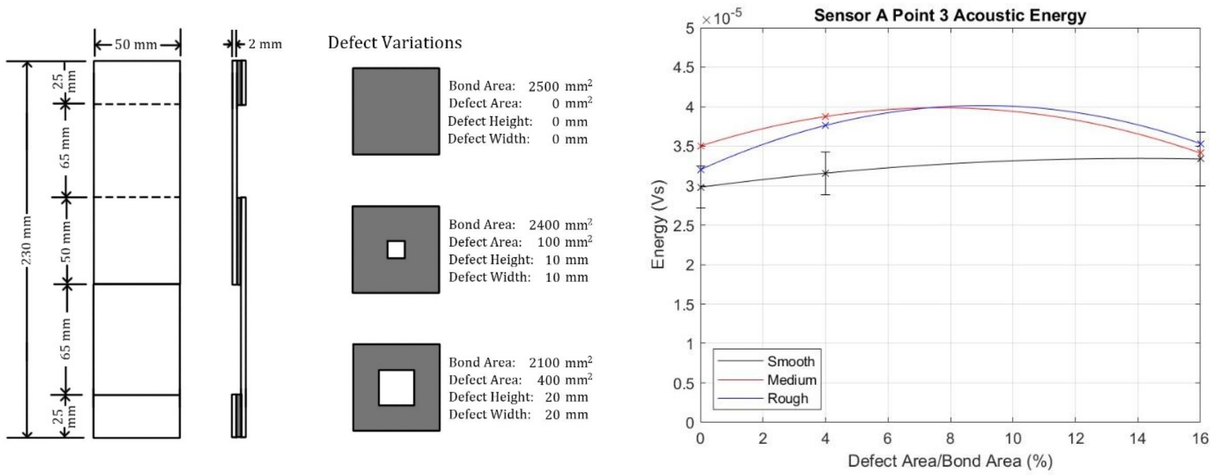
Kissing Bond and Interfacial Quality Detection in Adhesive Bonds Using Hsu-Nielsen Source and AE Sensors

Callum Selfridge, Cameron Gerrie, Sean Gerrie, Anil Prathuru and Ghazi Droubi

School of Engineering, Robert Gordon University, Aberdeen AB10 7GJ, UK

Adhesive bond *Aerospace applications* *SHM*

Abstract This study used non-destructive testing (NDT) to evaluate the use of adhesive bonds for aerospace applications, with a focus on the effects of defects within the bond. This is of importance as adhesive bonds see widespread use in the aerospace industry due to their strength and light weight. However, it is harder to maintain adhesive bonds as in most cases defects within the bond cannot be visually identified and the strength of the bond cannot be fully restored outside of full disassembly and remanufacture of the joint. This study investigated single lap joints (SLJs) with aluminium adherends bonded together using a Permabond TA4246 acrylic adhesive. The specimens were formed using a modified version of the ASTM D-1002 standard with an enlarged bonded area of 50mm x 50mm to allow for effective development of kissing bond defects within the samples. Different bonding conditions were investigated through altering the roughness of the aluminium using grit paper and introducing kissing bond defects by applying PTFE spray to the bond area. The geometry of the specimens is shown in Figure 1a.



(a) **(b)**

Figure 1. (a) Specimen geometry and defect variations; **(b)** Acoustic energy obtained from a sensor 60 mm from the defect and PLB location, for the first 50 μs of the signal.

Pencil lead break (PLB) testing in accordance with ASTM E976-15 (2021) was performed on the SLJs using acoustic emission (AE) as a form of NDT to try and identify the presence of the defects. The PLB testing focused on the plausibility of using fundamental zero-order antisymmetric mode propagation as the means of identifying and sizing the defects, through analysis of the time, frequency, and time-frequency domain of the signals. It was found that PLB testing has the potential to identify defects through acoustic energy, although it suffers from inaccuracy. The identified trend was an increasing acoustic energy in the first 50 μs of a signal from a distance of 60 mm, with defect area, for the smooth surface samples, shown in Figure 1b. This trend was confirmed by other sensor and break configurations; however, it is inaccurate due to the large standard deviation. The first 50 μs of the signal corresponds to a period that maximises the signal reflection in the bond area, while minimising reflections out with the bond area that reach the sensor.

On the identifiability of sheet metal anisotropic plasticity constitutive parameters using the Arcan test and full-field measurements

J. Henriques[1, 2, *], A. Andrade-Campos[1, 2], J. Xavier[2, 3]
joaodiogofh@ua.pt

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

[2]*Intelligent Systems Associate Laboratory (LASI), 4800-058 Guimarães, Portugal*

[3]*Research and Development Unit for Mechanical and Industrial Engineering (UNIDEMI), Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, NOVA University Lisbon, 2825-149 Lisbon, Portugal*

Sheet metal *Anisotropic plasticity* *Arcan test* *Full-field measurements*

Abstract The development of sheet metal parts is increasingly aided by numerical simulation, where the results are heavily influenced by the constitutive parameters of the material. Accurate results depend on the calibration of the constitutive models, which determine the behaviour of the material during the forming process, including anisotropy. To fully characterise the mechanical behaviour of the material, mechanical testing is essential. However, classical mechanical tests may not provide sufficient kinematic data. However, modern technology now enables the measurement of diverse strain states using heterogeneous test setups and full-field measurements. In addition, new heterogeneous test configurations have emerged, where full-field measurements can be coupled with inverse identification techniques, such as the virtual fields method (VFM), to fully characterise the material behaviour with a reduced number of experimental tests. However, the accuracy of this methodology is influenced by a variety of factors, including the test configuration, the constitutive model and the selection of a suitable identification strategy. The Arcan test is a unique testing setup that enables the variation in the loading direction in a standard uniaxial tensile testing machine. While this test has been used in sheet metal plasticity, it is not commonly used for calibrating plastic constitutive models in heterogeneous test design. However, the Arcan test offers the potential for interesting heterogeneous test configurations. This work aims at evaluating various Arcan test configurations through simulation and measuring their mechanical state heterogeneity using a set of indicators. The simulation results are then used to generate deformed speckle pattern images that are analysed using digital image correlation (DIC) to obtain kinematic data. The results are then used to calibrate the sheet metal constitutive parameters using the VFM through an inverse identification approach.

Acknowledgements

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A study of the effects of hydrogen on martensitic advanced high-strength steels

Carlo Maria Belardini, Giuseppe Macoretta, Marco Beghini, Leonardo Bertini, Bernardo Disma Monelli, Renzo Valentini

Department of Civil and Industrial Engineering, University of Pisa, Pisa, Italy

carlomaria.belardini@phd.unipi.it

AHSS *Hydrogen embrittlement* *Sheet metal*

Abstract. The automotive industry has been working towards sustainability by reducing the weight of cars while still maintaining safety standards. This has led to the development of high strength steels such as the class known as Martensitic Advanced High Strength Steels (MS-AHSS). One critical issue with MS-AHSS is their susceptibility to hydrogen embrittlement.

In this study, the effects of hydrogen embrittlement on MS-AHSS were investigated. Slow strain rate tensile tests were conducted on electrochemically pre-charged smooth and notched specimens in air. The average hydrogen concentration was measured after each test. The hydrogen loss during the test was preliminarily estimated, showing that it was limited. Fractographic analysis was performed to identify the damage mechanism and the impact of hydrogen on the fracture morphology, both in the fracture nucleation area and on the rest of the specimen.

The results showed that hydrogen significantly reduced the ductility of the tested material, while strength was minimally affected. Fracture morphology showed a progressive transition towards brittle intergranular and quasi-cleavage features as hydrogen content increased, along with the appearance of fisheye features on the final fracture surfaces. Plastic activity was shown to be relevant for the fracture process at all hydrogen concentrations, further reinforcing the theory that hydrogen locally promotes dislocation movement.

Effect of strain rate and hydrogen on the mechanical behaviors of Aluminium alloys

Mehmet Furkan Baltacıoğlu, Burak Bal

burak.bal@agu.edu.tr

Department of Mechanical Engineering, Abdullah Gül University, 38080 Kayseri, Turkey

Hydrogen Embrittlement *Strain Rate* *Aluminum*

Abstract Materials need to withstand very different loading conditions under their service life. Mechanical tests are very critical methods to understand material behaviour under different loading conditions. In the mechanical tests, many material properties can be tested and strain rate can affect these properties. Also, atomic hydrogen can degrade the mechanical properties of metallic materials, called as hydrogen embrittlement. During production stage and also service conditions, hydrogen can diffuse into the materials and can affect their mechanical behaviour. Both of these effects (hydrogen embrittlement and strain rate sensitivity) can have mutual effect on materials which can be very catastrophic. Despite there are studies which focus on this research topic, to understand its exact nature, they should be studied in detail. In this study we present the effect of hydrogen on strain rate sensitivity of Aluminium materials. Our findings are some of the steps on revealing the complicated behaviour of hydrogen and its effect on mechanical behaviour.

Investigations of the hydrogen – defect interactions by Molecular Dynamics

Mehmet Fazil Kapci, Burak Bal

[1]*Department of Mechanical Engineering, Abdullah Gül University, 38080 Kayseri, Turkey*

burak.bal@agu.edu.tr

Hydrogen Embrittlement *Molecular Dynamics* *Dislocation*

Abstract Hydrogen embrittlement is a type of fracture mechanism that can affect wide range of metallic materials. Once the hydrogen diffuses into crystals it can reside in interstitial sites or accumulate in the crystal defects that possess high hydrostatic stresses. To reveal the defect – hydrogen interactions constitutes an important role on understanding hydrogen embrittlement phenomena. In the study, the effect of the hydrogen on the mobility of two edge dislocations and crack propagation was investigated by Molecular Dynamics (MD). Single crystal and bi-crystal α-Fe simulation cells was constructed by locating ½<111>{110} and ½<111>{112} dislocation pile-ups in the center and hydrogen atoms were introduced into structures. A static shear load was applied to both hydrogen free and hydrogenated cells to observe the effect of the mobility on edge dislocations. Additionally, uniaxial tension simulations of the constructed cells were performed to observe the effect of the mobility change on stress-strain response. Results showed that unlike the HELP mechanism, hydrogen decreases the velocity of the edge dislocations. However, the shielding effect was observed on the dislocation – grain boundary interaction. Furthermore, hydrogen induced hardening was observed from the tensile simulations due to the pinning effect of hydrogen on dislocations. Also, accumulation of the hydrogen atoms within the grain boundaries observed to annihilate plasticity under loading. To understand the crack propagation under hydrogen environment, MD simulations was performed on FCC aluminum containing mode I crack. After the hydrogen introduction into crystals, tensile loading was applied perpendicular the crack tip. Results revealed that hydrogen presence ahead of the crack tip enhances the dislocation nucleation.

Numerical simulation of the processes of cyclic loading of samples made using additive manufacturing technology

Mullakhmetov Maksim N., Ilinykh Artem V., Pankov Alexandr M., Lykova Anastasiya V., Permyakov Gleb L.

Perm National Research Polytechnic University, 614990 Perm, Russia
m.mullahmetov59@gmail.com

Fatigue *Additive manufacturing* *Numerical simulations*

Abstract The paper presents the results of a numerical and experimental study of the cyclic loading of structural alloys made by using the "CMT (Cold Metal Transfer)" technology. The specimens were made from titanium alloy. Cyclic test of specimens with concentrators was carried out. In addition, numerical simulation of the deformation processes of specimens with plastic behavior of the material was carried out. Comparison of the results of numerical simulations and experiment results is important for identifying mechanical properties of anisotropic additive materials. Using of numerical and experimental methods make it possible to investigate and predict the properties of materials better, in the context of the search "technology-material-specimen-construction"

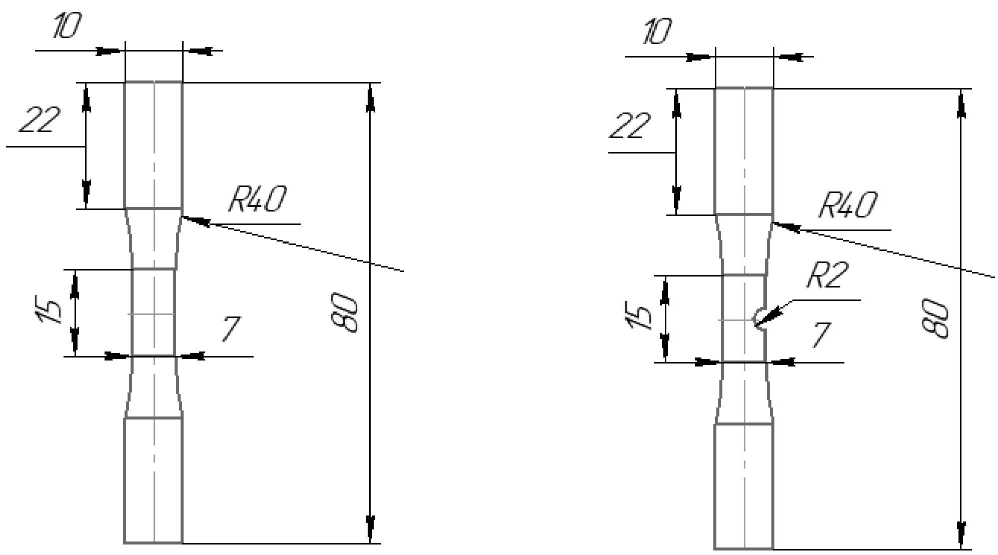

***Figure 1** – specimens for tests*

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Advanced materials under extreme conditions: Structure prediction, structure-property relationship and mechanical properties

Dejan Zagorac[1,2]

[1]Materials Science Laboratory, Institute of Nuclear Sciences "Vinča", University of Belgrade, Belgrade, Serbia
dzagorac@vinca.rs

[2]Center for synthesis, processing, and characterization of materials for application in extreme conditions "CextremeLab", Belgrade, Serbia

Advanced materials | *Theoretical and experimental data* | *Structure-property relationship*

Abstract Innovative materials used in high-technology applications are called advanced materials. High technology is the technology at the cutting edge, bringing the most complex or the newest technology on the market, such as computers, space technology, aircraft, nuclear technology, etc. Also, advanced materials can be typical traditional materials (e.g., metals, ceramics, polymers) whose properties have been enhanced or developed. This talk will cover the theoretical investigation of various advanced materials with connection to the experimental results (e.g. oxides, sulfides, nitrides), especially under the influence of extreme pressure and temperature conditions. Furthermore, a plethora of state-of-the-art quantum mechanical methods will be presented, including Density-functional theory (DFT), and structure prediction methods, as well as some newly developed methods applied on so far unknown materials and structures. Structure–property relationship will be presented in great detail and since many of the investigated materials show a large number of desirable properties for industrial applications, *ab intio* calculations of various properties, focusing on elastic, and mechanical properties under extreme conditions will be presented and compared with experiments when available. Such mechanical properties are one of the key factors in structural integrity and materials degradation dealing with the ability of a structure to support a designed structural load without breaking and could help prevent failures in future designs.

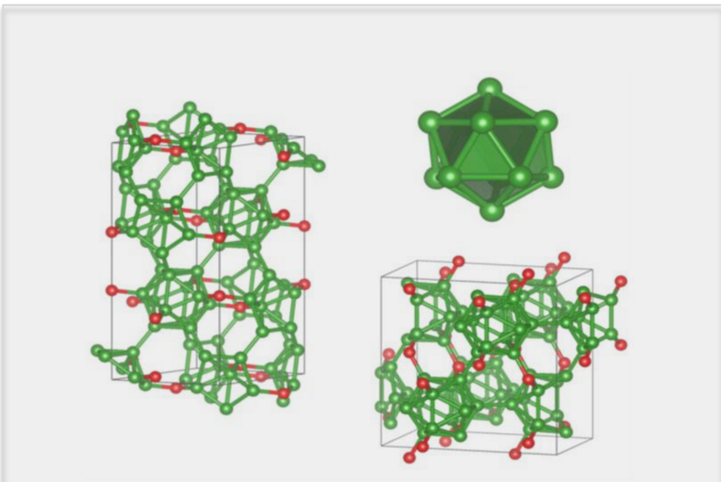


Figure 1 *– complex structure of α-B_6O (left) and β-B_6O (right) consisted of B_{12} icosahedra (above) investigated at high pressure regime.*

Theoretical investigations and QM modelling of hydrogen-based materials

Dejan Zagorac[1,2], Jelena Zagorac[1,2], Milos B. Djukic[3], Tamara Škundrić[1,2], Milan Pejić[1,2], Burak Bal[4], Christian J. Schön[5]

[1]Materials Science Laboratory, Institute of Nuclear Sciences "Vinča", University of Belgrade, Belgrade, Serbia
dzagorac@vinca.rs

[2]Center for synthesis, processing, and characterization of materials for application in extreme conditions "CextremeLab", Belgrade, Serbia

[3]University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade 11120, Serbia

[4] Department of Mechanical Engineering, Abdullah Gül University, 38080 Kayseri, Turkey

[5]Max Planck Institute for Solid State Research, Nanoscale Science Department, Stuttgart, Germany

Hydrogen *Ice-water* *Fe-H system*

Abstract Since its discovery hydrogen has been one of the most interesting elements in scientific research, with a variety of possible compounds and applications. Of special interest in materials engineering is hydrogen embrittlement, which has gained particular importance in recent years. This talk will be divided into two parts where in the first one we shall present the most recent results on water/ice models. Due to their great importance in science, technology, and the life sciences, water and ice have been extensively investigated over many years. In particular, hexagonal ice *Ih* has been of great interest since it is the most common form of ice, and several modifications, *Ih(a), Ih(b)* and *Ih(c)* are known, whose structural details are still under discussion. Here, we will present an alternative theoretical model, called *Ih(d),* for the hexagonal ice modification in space group *P63/mmc* (no. 194), based on first-principles calculations [1]. In the second part, we will show results on the Fe-H system. In the past, most of the work on iron hydrides has been focused on hydrogen-rich compounds since they have a variety of interesting properties at extreme conditions (e.g. superconductivity). However, we present the first atomistic study of an iron-rich Fe_4H compound which has been predicted using a combination of data mining and quantum mechanical calculations.

References:

[1] Jovanović, Dušica, Zagorac, Dejan, Schön, J. Christian, Milovanović, Branislav and Zagorac, Jelena. "A new theoretical model for hexagonal ice, Ih(d), from first principles investigations" Zeitschrift für Naturforschung B, vol. 75, no. 1-2, 2020, pp. 125-128. https://doi.org/10.1515/znb-2019-0164

Mechanical Characterization of an Asymmetric Sandwich Composite Composed by Stone and Cork

João Marques[1], Virgínia Infante[2], Pedro Amaral[2]

[1]*Instituto Superior Técnico, ULisboa, Av. Rovisco Pais 1, 1049-001 Lisbon, Portugal*

[2]*LAETA, IDMEC, Instituto Superior Técnico, ULisboa, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal*

SHM *Ageing* *Damage detection*

Abstract Sandwich composites have been a growing subject of interest to various industries; thus it has become essential to monitor these structures. There is a need to implement damage identification and characterization strategies. Furthermore, structures are exposed to environmental factors, and it is important to characterize how those factors affect the material's characteristics. This work aims to study the reliability of the implementation of strain gauge sensors, the mechanical properties as well as the failure modes of an asymmetric sandwich composite made by a core of cork agglomerate, two fibre-reinforced epoxy skins and a natural stone on top. Furthermore, this study has also the goal of evaluating the effect of aging on the said composite. Aging test was carried out and bending tests were performed to characterize both aged and unaged composites. The data obtained using strain gauges proved that repeatability and reproductively of the results was achieved for each condition (aged and unaged). With that, the composite's mechanical properties were calculated in both conditions. The tests revealed the ability of the strain gauge sensors to detect damage.

Mechanical behaviour and failure modes of the selected carpentry joints in flexural elements

Anna Karolak, Jerzy Jasieńko

Faculty of Civil Engineering, Wroclaw University of Science and Technology, Wybrzeze Wyspianskiego 27, Wroclaw 50-370, Poland

carpentry joints *mechanical behaviour* *flexural elements*

Abstract

Paper presents the mechanical behaviour of the selected longitudinal carpentry joints. These joints were applied in historical timber structures over time to obtain the desired length of the wooden element in the structure. Joints could have various forms, from the simpliest and commonly used lap joint to the sophisticated stop-splayed scarf joint, also called the 'bolt of lightning' used e.g. in the designs of the Italian Renesaince masters: Leonardo da Vinci and L.B. Alberti.

Although the literature presents some descriptions of these types of joints, researchers indicate the need to conduct more research on this topic to obtain more data and a more complete description of their static behaviour and failure patterns, as well as to determine the most advantageous methods of repairing and strengthening these joints in existing objects.

Therefore, as part of the scientific project, extensive research was conducted on selected longitudinal joints in flexural elements. Laboratory experimental tests were performed on technical scale beam models with reconstructed connections according to the geometry of the historical joints (Figure). The tests confirmed that the selected longitudinal joints in the flexural elements could transfer small bending moments. The load-carrying capacity of the beams with the joints was examined and the failure modes of the tested joints were described in the paper.

The results of the research showed that the load-carrying capacity of the beams with joints was several dozen percent in relation to the capacity of the continuous beam. On the basis of the failure images obtained in the tests, the locations of particular stress concentrations and the failure modes that occurred for the individual joints were identified. The results obtained from the tests conducted may be helpful in assessing the static work of historical wooden structures with carpentry joints and in engineering practise when designing and carrying out repair and conservation works in historic wooden buildings.

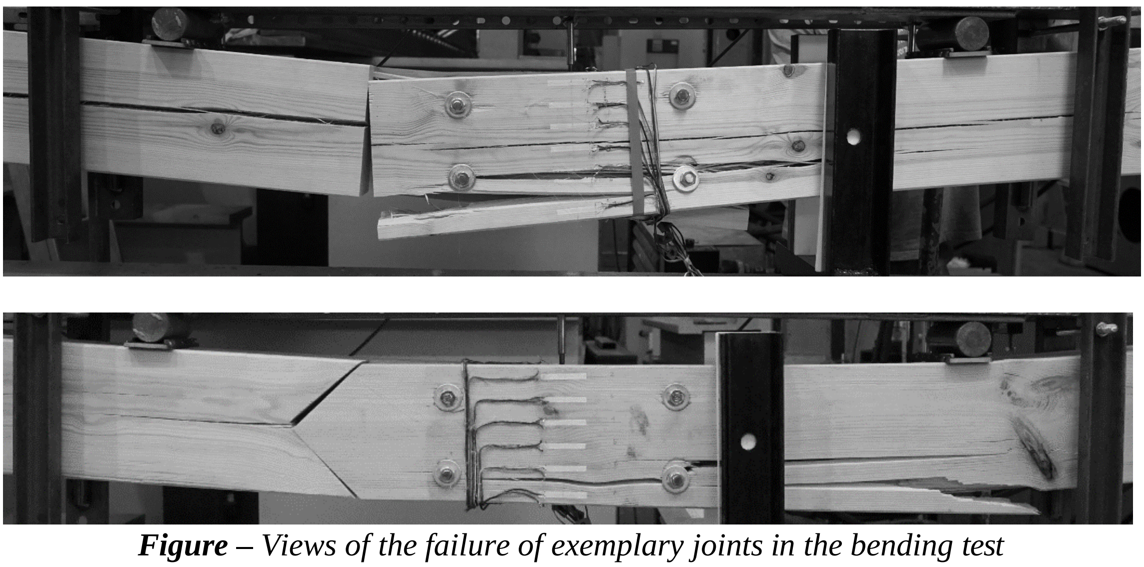


***Figure** – Views of the failure of exemplary joints in the bending test*

Delamination of multilayered viscoelastic inhomogeneous beams under moving loading

Victor Rizov

Department of Technical Mechanics, University of Architecture, Civil Engineering and Geodesy, 1 Chr. Smirnensky blvd, 1046 – Sofia, Bulgaria

v_rizov_fhe@uacg.bg

Viscoelastic behavior *Moving loading* *Delamination*

Abstract One of the important tenors for gaining efficiency in present-day engineering is to intensify the use of advanced high-performance structural materials. Typical examples for such highly efficient materials are multilayered inhomogeneous systems. Components of load-carrying engineering structures made of multilayered inhomogeneous materials, however, tend to develop delamination during use. Therefore, their safe operation and lifetime are severely limited by delamination fracture. Besides, it is of frequent occurrence engineering structures to be under mobile external loading. This theoretical paper describes a delamination analysis of a multilayered inhomogeneous load-carrying beam structure under an external force that movies slowly at a constant velocity along the upper surface of the structure (Fig. 1).

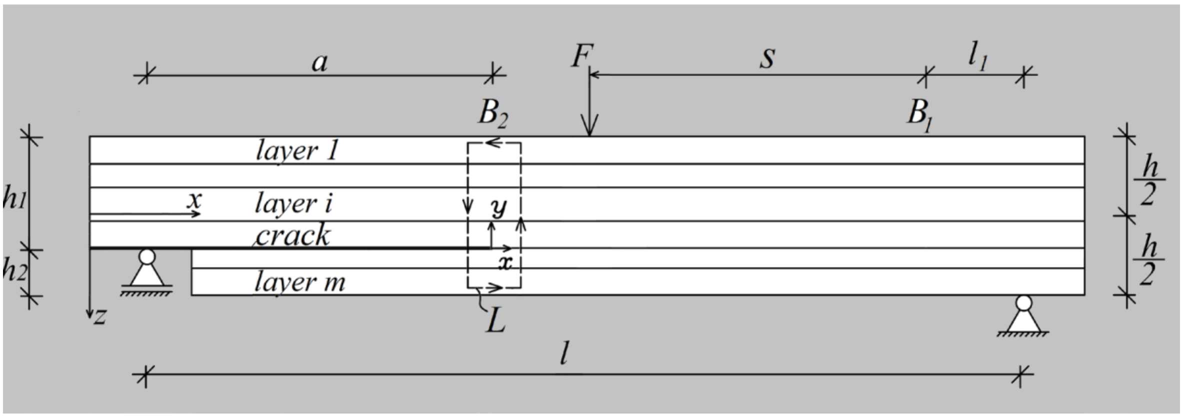


Fig. 1. *Multilayered beam with a delamination crack loaded by a mobile force, F .*

When determining the strain energy release rate, the beam is treated by using a non-linear viscoelastic model under time-dependent stress. Since the layers are inhomogeneous, the model parameters are smooth functions of the beam longitudinal coordinate. The *J*-integral method is used to examine the strain energy release rate solution. The ascendency of the mobile loading parameters over the strain energy release rate is inquired into. One of the momentous conclusions is that the strain energy release rate grows continuously with time under the mobile loading considered in this paper. It is also seen that the growth of the velocity of the motion of the external force results in reduction of the strain energy release rate. The modus presented in this paper allowed us to examine the dependence of delamination on the continuous variation of the parameters of the model along the length of the layers.

Longitudinal fracture of functionally graded beams with non-linear rheological behaviour

Victor Rizov

Department of Technical Mechanics, University of Architecture, Civil Engineering and Geodesy, 1 Chr. Smirnensky blvd, 1046 – Sofia, Bulgaria

v_rizov_fhe@uacg.bg

Longitudinal fracture *Non-linear rheological behavior* *Functionally graded beam*

Abstract The constantly growing use of functionally graded materials in advanced engineering structures puts high requirements towards their fracture behavior. This theoretical paper is devoted to a non-linear rheological model and its application in fracture analysis of a load-carrying beam-like engineering structure with an arbitrary number of longitudinal vertical cracks (Fig. 1).

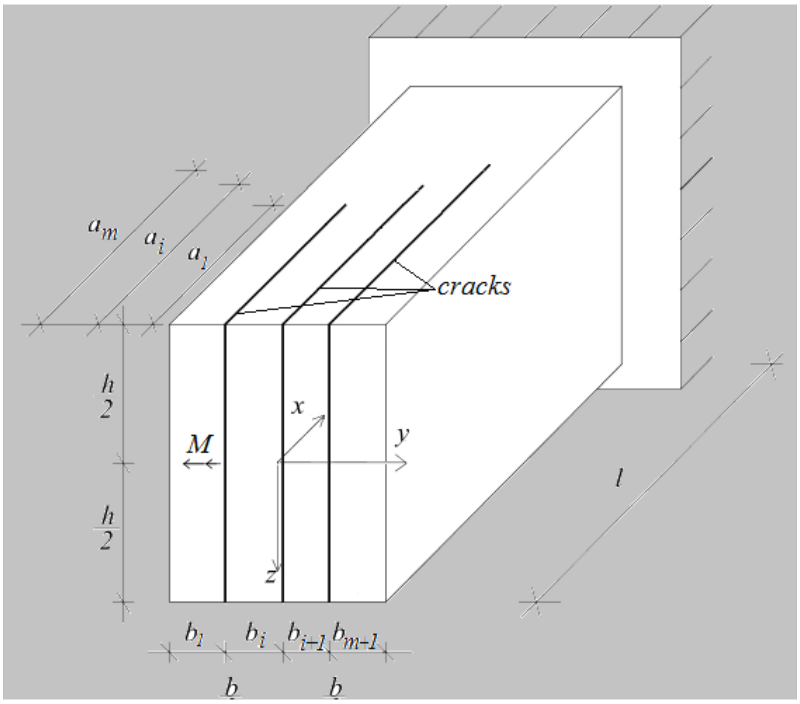


Fig. 1. *Beam structure with an arbitrary number of longitudinal cracks.*

The functionally graded beam researched in this paper has viscoplastic behavior. The rheological model is structured by springs, dashpots and a frictional slider (the latter takes into account the plastic strains in the beam). The rheological model is with two consecutive units. Solutions of the time-dependent strain energy release rate for each crack in the functionally graded beam structure under external mechanical loading are found-out by making use of the rheological model. The time-dependent balance of the energy for each crack is examined for control of the solutions extracted. The solutions take into account the viscoplastic behavior and the progressive variation of the properties in the beam structure. It is shown that the solutions extracted in this paper can be turned to use to examine the relation between the distribution of mechanical properties and the longitudinal fracture in engineering structural components produced of functionally graded engineering materialswith viscoplastic behavior.

Probabilistic fatigue crack growth rates of structural steels based on modified UniGrow model

Bruno Pedrosa[1], José Correia[2], Grzegorz Lesiuk[3], Joel de Jesus[4], Ricardo Branco[5], Carlos Rebelo[1]

[1]University of Coimbra, ISISE, ARISE, Department of Civil Engineering, Coimbra, Portugal

[2]CONSTRUCT and Faculty of Engineering, University of Porto, 4200-465 Porto, Portugal [3]Wroclaw University of Science and Technology, Department of Mechanics, Materials and Biomedical Engineering, Wrocław, Poland

[4]Department of Mechanical Engineering, Lisbon Polytechnic - ISEL. Rua Conselheiro Emídio Navarro 1, 1959-007 Lisboa, Portugal

[5]CEMMPRE, Centre for Mechanical Engineering, Materials and Processes, University of Coimbra, Mechanical Engineering Department, Pinhal de Marrocos, 3030-788, Coimbra, Portugal

FCG *S355* *UniGrow*

Abstract The UniGrow model is an analytical procedure to assess fatigue crack growth (FCG) rates based on elastic–plastic crack tip stresses and strains. The assumption is that FCG can be considered as a process of successive crack re-initiations resulting from material damage in the crack tip zone. The main parameters of this model are the crack tip radius and the process block size. In this paper, FCG rates of S235 and S355 carbon steels were analyzed. These materials were chosen because they are commonly used in civil engineering structures that are subjected to fatigue loading conditions, namely bridge structures. Residual stress intensity factor was evaluated by means of experimental, analytical and numerical approaches. During fatigue crack growth tests of S355, applied load and crack opening displacement were recorded for several cycles in order to evaluate crack opening force and U parameter. Lower values of applied stress ratio originated lower values of U parameter which means that mean stress effect increases. Residual stress intensity factor increases when the applied stress intensity factor range increases showing that these parameters are linearly dependent. Fatigue crack growth rates were correlated with effective stress intensity factor ranges showing that crack closure effects were successfully considered since experimental results from tests with different stress ratios converged in a unique FCG curve. In what concerns numerical approach, used only for S355, it intended to show that stress-strain field ahead of the crack tip can also be assessed by means of numerical procedures. The value of the crack tip radius, $\rho\rho^*$, was defined by correlation with experimental and numerical values of residual compressive stress field ahead of the crack tip while for the process block size, $\delta\delta_{pp}$, a new expression was proposed which relies on effective stress intensity factor range and cyclic yield strength. Mean and characteristic values of cyclic material properties were used to assess SWT damage within the block size ahead of the crack tip for several stages of FCG tests. Mean FCG predictions based on this approach presented very good correlation with experimental data and characteristic FCG predictions can be considered a reliable and safe design approach.

Acknowledgements This work was also financially supported by national funds through the FCT/MCTES (PIDDAC), under the MIT Portugal Program under the project MIT-EXPL/SOE/0054/2021. This work is also a result of Agenda "NEXUS: Innovation Pact Digital and Green Transition – Transports, Logistics and Mobility", nr. C645112083-00000059, investment project nr. 53, financed by the Recovery and Resilience Plan (PRR) and by European Union - NextGeneration EU. Bruno Pedrosa would like to thank the Ph.D. research grant (SFRH/BD/145037/2019) awarded by national funds (PIDDAC) through the Portuguese Science Foundation (FCT/MCTES).

Properties and applications of cold sprayed Ti-6Al-4V coatings in additive manufacturing

Wojciech Żórawski[1], Medard Makrenek[2], Anna Góral[3] Dominika Soboń[1]

[1]*Faculty of Mechatronics and Mechanical Engineering, Kielce University of Technology,*

Tysiąclecia Państwa Polskiego 7, 25-314 Kielce, Poland,
ktrwz@tu.kielce.pl

[2]*Faculty of Management and Computer Modeling, Kielce University of Technology*

[3]*Institute of Metallurgy and Materials Science, Polish Academy of Sciences, Cracow*

Cold spraying *Ti-6Al-4V* *Additive manufacturing*

Abstract; New low-cost manufacturing technologies are the basis for further development in many branches of industry. Titanium alloys, with their high strength-to-weight ratio and excellent corrosion resistance in many media, including seawater, are an irreplaceable material for many applications in aerospace. Currently used technologies for manufacturing titanium components, which involve casting, forging, extrusion, and machining, are expensive and labor-consuming. Moreover, the production process of many parts leads to significant material losses that can reach up to 60%. Therefore, direct production of titanium is crucial in the aviation industry. Additive manufacturing technology allows the manufacture of parts of machines based on layer by layer deposition. This process allows for the production of components with complex shapes and, additionally, significantly lowers time and cost. Recently, cold spraying has joined the group of applied additive technologies such as selective laser sintering (SLS) or direct metal deposition (DMD).

The objective of the presented studies was to analyze the microstructure and mechanical properties of a cold sprayed Ti-6Al-4V structure for application in additive manufacturing. The coatings were sprayed using the Impact Innovations 5/8 system with the robot Fanuc M-20iA at Kielce University of Technology. The feedstock used for this study was commercial Ti-6Al-4V powder with a "coral-like" morphology. The working gases used in this process were nitrogen and helium in equal proportions. The coatings sprayed onto the titanium mandrel had a thickness of 15 mm. The microstructure and chemical composition of the powder and the coating were analyzed by means of SEM Jeol JSM-7100, and their phase composition was studied using a Bruker D8 Discover diffractometer. The micromechanical testing of coatings was carried out with the use of the nanoindentation technique (Nanovea) with a Berkovitz indenter (the Olivier and Pharr methodology). The topography of the coatings after spraying was analyzed by means of a Talysurf CCI-Lite non-contact 3D profiler. The high kinetic energy of feedstock particles and their morphology caused significant deformation, and particular splats strongly adhered to the substrate and to each other. Throughout the cross-section, the coating was homogenous and exhibited negligible porosity. On the other hand, histograms and probability distributions of the hardness and Young's modulus of cold sprayed coating showed significant differences. X-ray diffraction analysis indicated that the deposited coating had the same phase structures as the feedstock.

Ballistic Impact Detection via Physics-Informed Machine Learning: A Methodology Integrating Neural Networks with Reduced Order Model Updating

Vasiliki Panagiotopoulou, Claudio Sbarufatti, Marco Giglio

Politecnico di Milano, Department of Mechanical Engineering, Via La Masa 1, 20156, Milano, Italy

Artificial Neural Network *Physics-informed Machine Learning* *Ballistic Impact*

Abstract A Digital Twin (DT) is a virtual representation of a physical asset, built to support engineering decisions, especially in real time applications. However, challenges emerging from the high computational cost and time burdens associated with DTs based on high fidelity models, as well as the limited available data covering the full environmental and operational envelope of the structure, make their use demanding. Additionally, traditional Machine Learning (ML) techniques tend to behave as black boxes, providing predictions which might not be physically consistent. In attempt to address those limitations, a traditional ML algorithm is constrained by known physical relations described by an analytical model, which represents the physics-informed term, while is trained using less numerical data of a high-fidelity reduced order model. Specifically, the physics-informed model engages physical meaning and replaces parts of the training process that allows better understanding and interpretation of results, while maintaining a high level of performance and flexibility to various structural monitoring problems. The proposed Physics-Informed Machine Learning method is applied as a model updating tool for the transmission shaft of a military helicopter, and for purposes of anomaly detection in case of a ballistic impact occurrence. In particular, the research is condicted within SAMAS 2, a project aiming the development of a Structural Health Monitoring and Prognosis (SHMP) tool for corrosion degradation and bullet impact damages on military helicopters.

SAMAS 2: Structural Health and Ballistic Impact Monitoring and Prognosis on a Military Helicopter

Vasiliki Panagiotopoulou, Claudio Sbarufatti, Marco Giglio

[1]*Politecnico di Milano, Department of Mechanical Engineering, Via La Masa 1, 20156, Milano, Italy*

Structural Health Monitoring *Corrosion Degradation* *Ballistic Impact*

Abstract The development of a Structural Health Monitoring and Prognosis (SHMP) tool for corrosion degradation and bullet impact damages is matter of SAMAS 2, a project coordinated by the European Defense Agency (EDA) and funded by 2 EDA Member States (Italy and Poland). Specifically, military helicopters are subjected to different kinds of damages and degradations, as a consequence of their operative conditions and mission scenarios. In particular, the helicopter tail drive line (TRDL) is the only transmission path for the engine to transmit power to the tail rotor, meaning that there is no redundant backup. On top of that, due to its extend but also its vulnerability by nature, TRDL is the system more likely to be shot by bullet and consequently to compromise the whole structural assessment as well as the safety of the crew. Additionally, corrosion is considered as a critical parameter for the helicopter safety and the maintentance costs, and thus reliable methods to predict fatigue strength degradation due to corrosion pits can be a relevant improvement for efficient evaluation of inspection intervals. The aim of SAMAS 2 is to integrate and adapt sensing information so to monitor parameters which are related to a specific degradation phenomenon. Using the knowledge obtained by the continuous monitoring, alarms are provided to pilots in case of damage identification, making it possible to land the helicopter and execute more precise inspection, repairs and substitutions if necessary. The main characters involved in SAMAS 2 are Finite Element Models (FEM) and algorithms, the former providing a low cost knowledge (vibration data) upon which training the advanced algorithms in damage detection. The diagnostic knowledge would then serve as an input for prognostic, thus coming to an estimation of the Residual Useful Life (RUL) distribution, representing the time driving the TRDL to catastrophic failure.

The current paper is a summary of the advances in the project, covering all the involved engineering areas, from the adopted sensor network and analytical or empirical models, to the FEM simulation based on Reduced Order Modeling techniques and coupling with Machine Learning algorithms (Digital-Twin model), thus coming to the definition of a robust methodology for SHM design. The possibilities for result exploitation, as well as the points requiring further advances, are going to be presented.

Failure analysis of a composite structural spar and rib-to-skin joints

Wojciech Skarka[1, 3], Ramesh Kumpati[1], Michał Skarka[2]

[1] *Department of Fundamentals of Machinery Design, Silesian University of Technology, Konatskiego 18A, 44-100 Gliwice, Poland,*

wojciech.skarka@polsl.pl

[2] *Faculty of Aerospace Engineering, Delft University of Technology, Kluyverweg 1, 2629 HS Delft, The Netherlands*

[3] *SkyTech eLab LLC, Konarskiego 18C, 44-100 Gliwice, Poland*

Composite material *Structural analysis* *T-Joints*

Abstract The mechanical efficiency of a composite structure often depends on the strength of the joints that connect different parts to form a load path. Composite T-joints are commonly used in aerospace, marine, and civil engineering applications due to their lightweight and high strength properties. The complex stress distribution and geometric variations in these joints can lead to premature failure, careful attention is necessary in wing structures at skin-to-spar and skin-to-rib joints that are subjected to extreme load conditions. One type of structural joint is the composite sandwich with monolithic laminated material, which can offer significant advantages such as increasing material bending rigidity without adding considerable weight. Several approaches have been proposed to improve the performance of this joint and especially T-joints, and reduce the risk of failure. These include optimizing the joint geometry and laminate stacking sequence, improving the manufacturing process, and using advanced materials such as nanocomposites and hybrid composites. However, the mechanical behavior of this type of component has not yet been fully explored. This research aimed to study the modes of structural failure that include matrix cracking, fiber breakage, and interlaminar shear of these joints under tension, compression and shearing loads using the finite element method and also verify the different types of joints along with solar panel configuration. The obtained numerical results were validated by experimental tests and these best results are used for unmanned aerial vehicle structures especially integrated with solar panels.

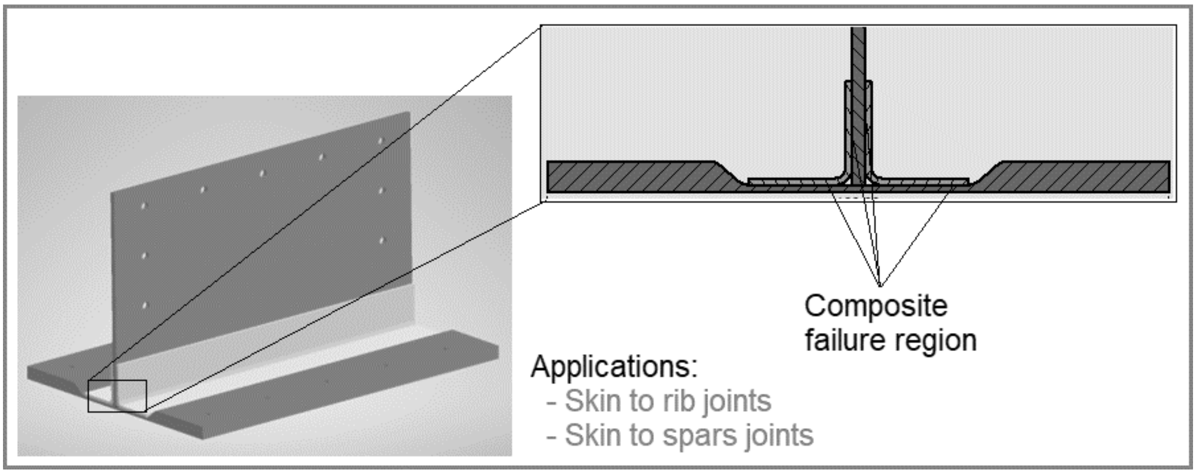


Figure 1 *– Schematic diagram of composite structural joint*

Aerodynamic optimization of UAV

Wojciech Skarka[1, 2] Bartosz Rodak[1]

[1]Department of Fundamentals of Machinery Design, Silesian University of Technology, Konarskiego 18A, 44-100 Gliwice, Poland

wojciech.skarka@polsl.pl

[2] SkyTech eLab LLC, Konarskiego 18C, 44-100 Gliwice, Poland

Aerodynamic analysis *Optimization* *Drag Force Minimization*

Abstract The article deals with the issue of determining the aerodynamic loads on the connection of the wing with the nacelle, as well as their minimization. Research works are aimed at minimizing the loads and maximizing the parameters of ultra-light composite structures of Unmanned Aerial Vehicles used for long-endurance flights. The load-bearing structures of such UAVs are extremely light, which imposes additional requirements on minimizing the loads on the structure. As part of the research, the problem of modeling complex geometrical structures of the connection of the wing and the nacelle is also solved, which guarantees easy parameterization of the geometry and its transfer between CAD and CAE systems. The right approach to geometric modeling through the structuring of geometry, the appropriate methodology of model construction guarantees the transferability and reusability of the model.

The loads were determined using CFD simulations. Minimization of these loads could be achieved by parameterizing the geometry of the outer skin and then using optimization methods. The article describes optimization using DoE and gradient optimization method. In the summary, both methods were compared with each other in terms of minimizing aerodynamic loads and the level of minimization of aerodynamic loads of the optimized sewing geometry were compared to the aerodynamic loads of original geometry.

The result is used in the construction of a measuring nacelle for long-endurance and high-altitude measurements of air pollution.

Load analysis on the drone protection cage increasing collision resistance

Wojciech Skarka[1, 3], Magdalena Szczepanek[1], Maciej Pośpiech[1], Aleksander Jassak[1], Jakub Żymełka[1], Michał Pokrzywa[1] Michał Górka[1], Roman Niestrój[2]

[1] *Department of Fundamentals of Machinery Design, Silesian University of Technology, Konarskiego 18A, 44-100 Gliwice, Poland*

wojciech.skarka@polsl.pl

[2] *Department of Electrical Engineering and Computer Science, Silesian University of Technology, Akademicka 2A, 44-100 Gliwice, Poland*

[3] *SkyTech eLab LLC, Konarskiego 18C, 44-100 Gliwice, Poland*

Load analysis *Protection cage* *Collision resistance*

Abstract Drones are being used in more and more new fields, including those where there are many obstacles that a drone can hit while performing its task. Along with this has grown the need to prevent drone from damage when it crashes into obstacle. such protection will also enable the use of drones in new applications involving operating in a very small space with a high probability of collision. One of the solutions to this problem is to put the drone into a protecting cage. This paper presents the results of load analysis on drone protecting cage. The proposed cage has a specific structure and consists of an external mesh with specially shaped nodes and topology of mesh elements. The whole cage is suspended on a gimbal type connection that increases the collision capabilities and minimizes the impact of collisions on the drone's behavior and cage load. The unusual construction of the drone itself, and in particular the arrangement of the drone's propellers, allows you to maximize the operational possibilities. Analise was carried out under different conditions. The drone has crashed into different obstacules with different forces. The results show how the loads are distributed through out the cage and gimbal element and how they affects the drone inside.

The tests were carried out both in a simulation environment and on built demonstrators in laboratory conditions and simulated operational conditions.

Investigation of full-field material properties of welded joint using DIC

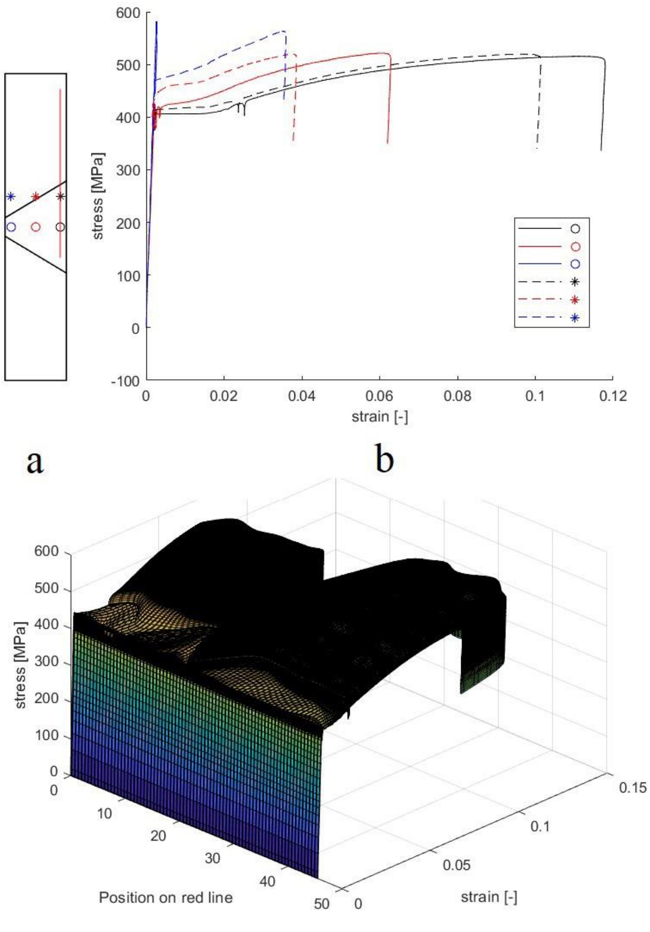
Koščo, T., Chmelko, V.

Slovak University of Technology, Faculty of Mechanical Engineering, Námestie Slobody 17, 812 31 Bratislava, Slovakia

tomas.kosco@stuba.sk

Digital image correlation *Welded joint* *Material properties*

Abstract Use of full-field non-contact experimental methods such as digital image correlation to obtain material properties has gained importance in recent years. Techniques such as VFM or FEMU are playing an increasingly important role. The presented contribution deals with the investigation of full-field material properties of X52 pipeline steel welded joint. Engineering stress-strain diagrams as well as true stress-strain diagrams have been evaluated or estimated in every point of the weld cross section except the edge. All the important mechanical characteristics such as Young modulus, Yield stress, plastic part of tensile diagram as well as the transition of Poisson's ratio from elastic to plastic region have been obtained in all locations. Full tensile diagram including the fracture strain has been obtained in selected locations. Fig. 1b shows partial tensile diagrams belonging to points on Fig. 1a. Fig. 1c shows the surface of all tensile diagrams from red line on Fig. 1a. From obtained data full-field maps of Young modulus, yield stress and other parameters have been evaluated. Presented work also comment



all the advantages and drawbacks of used approaches and methods.

***Figure 1** – a) Positions on weld b) Tensile diagrams c) Surface from line*

Data-driven spectral damage estimator for non-stationary vibration loading

Arvid Trapp, David Fräulin, Marcin Hinz, Peter Wolfsteiner

Munich University of Applied Sciences, Dachauer Str. 98b, 80335 Munich

arvid.trapp@hm.edu

random vibration loading *non-stationary loading* *neural networks*

Abstract Fatigue is the failure of materials due to cyclic loading. In order to design structures against material fatigue – to ensure the structural integrity, a fatigue assessment is carried out. This involves the prediction of load spectra and their comparison with stress-life curves to determine the lifetime of components. Statistical approaches, such as the Dirlik method, use the power spectral density (PSD) for this purpose. But it only applies for stationary Gaussian loading. In order to predict load spectra for general vibration loading, we propose the design of a data-driven damage estimator based on the non-stationarity matrix. The non- stationarity matrix is a spectral representation of kurtosis that can be processed via linear systems theory. The aim of the subsequent damage estimator is to improve the prediction of fatigue strength under generally (realistic non-stationary) vibration loading, while maintaining the advantages of a statistical fatigue assessment such as computational speed. Neural networks are used to design the damage estimator. This paper describes the training data generation using synthetic models and real load data, the definition of the in- and outputs of the network, its architecture and implementation in program code. The results are evaluated in form of fatigue analyses using established tools and can be reproduced via the open-source python package pyRaTS. An outlook will show how the developed approaches can be further developed towards analytical solutions.

Experimental investigation of the bending behavior of Spanish *Eucalyptus globulus* LVL

Majano-Majano A[1], Gonzalo-Calderón L[1], Lara-Bocanegra AJ[1], Aira-Zunzunegui JR[1], Xavier J[2,3]

[1]*School of Architecture, Universidad Politécnica de Madrid, Avda. Juan de Herrera 4, 28040 Madrid, Spain*

almudena.majano@upm.es

[2]*UNIDEMI, Research & Development Unit for Mechanical and Industrial Engineering, Department of Mechanical and Industrial Engineering, NOVA School of Science and Technology, Universidade NOVA de Lisboa, 2829-516 Caparica, Portugal*

[3]*LASI, Intelligent Systems Associate Laboratory, 4800-058 Guimarães, Portugal*

Eucalyptus LVL *Bending capacity* *Hardwood*

Abstract *Eucalyptus globulus* Labill. is one of the hardwood species growing in Europe with the best mechanical properties and great natural durability, very abundant on the Atlantic coast of the Iberian Peninsula. However, the use of sawn timber (ST) and glued laminated timber (GLT) produced from this species is limited due to difficulties in the sawing and drying process. In order to expand its possibilities of use, the manufacture of eucalyptus laminated veneer lumber (LVL) is proposed, thus obtaining a product with very high structural performance that overcomes the production difficulties of ST and GLT. The present work aims to obtain a first approximation of the main mechanical properties of LVL made of *Eucalyptus globulus* from Spain. Flatwise and edgewise bending tests are carried out on samples from boards of two different thicknesses and with different longitudinal and transverse veneer arrangements. The results suggest that LVL made from *E. globulus* of Spanish origin could be one of the structural wood-based products with the highest mechanical performance on the European market.

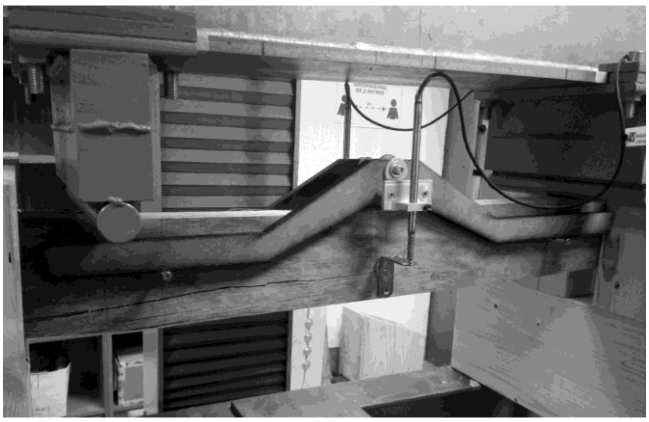


Figure 1 *- Eucalyptus LVL edgewise bending test*

The Effect of Temperature on Power Transformers Continuously Transposed Cables Mechanical Performance

G. Cipriano[1], E. Emanuel Almeida [2], R. Castro Lopes[2], A. Pedro Lima[2], A. A. Soto-Rodriguez[2], Daniel F.O. Braga[1], Miguel O. Gomes[1], Viriato, N.[1], Sousa, P.J.[1]

[1]INEGI, Campus da FEUP, Universidade Do Porto, Rua Dr. Roberto Frias, 400 4200-465, Porto, Portugal

[2]EFACEC Energia S. A., São Mamede de Infesta, Portugal

Experimental Mechanics *Elevated temperatures* *Case Study*

Abstract Electrical Power Transformers are subject to challenging mechanical loading, due to their regular operation and assembly, but also due to sporadic events like short circuits. Such events lead to elevated temperatures within several components such as the insulators or the Continuously Transposed Cables (CTC), which may affect the mechanical response of these components and the system as whole.

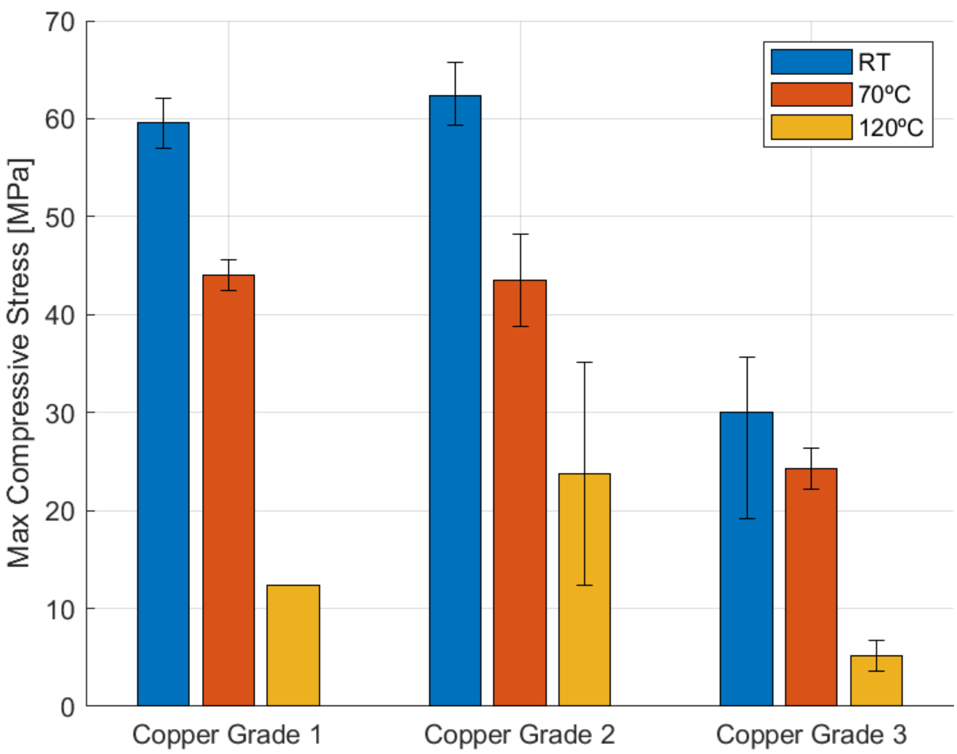


***Figure 1** – Effect of temperature in buckling strength of CTCs*

Experimental characterization of inflation mechanical properties of aortic wall

Hugo Mesquita[1], Rodrigo Valente[2], Daniela Azevedo[1], Francisco Queirós de Melo[1], Pedro Sousa[1], Tiago Domingues[1], Paulo Tavares[1], José Xavier[2], Pedro Moreira[1]

hmesquita@inegi.up.pt

[1]Inegi, Rua Dr. Roberto Frias 400, 4200-465 Porto

[2]Nova School of Science & Technology, Largo da Torre, 2829-516 Caparica

Aortic wall *Mechanical properties* *Experimental System*

Abstract Degraded mechanical properties in the aortic wall can lead to the formation of aortic aneurysms, which may result in life-threatening ruptures. Current diagnostic criteria using maximum aortic diameter fail to predict this critical moment in many patients, highlighting the need for more accurate prediction methods. A monitored pressurization system to deform a specifically designed balloon that mimics aortic wall deformation in the human body was developed, allowing to obtain empirical results for aortic wall properties. Using digital image correlation software with two cameras, we are able to capture and analyze three-dimensional deformations. This allows to accurately characterize the mechanical properties of the tested materials in a state that closely resembles real blood inflation. The use of silicones with known properties as a phantom of the aorta allowed us to better develop the pressurized balloon geometry while confirming the accuracy of the experimental approach as the empirical mechanical properties obtained closely relate with the documented values. Upon having results with several silicone phantoms, we got the mechanical properties of a healthy pig aorta. The proposed experimental system serves as a valuable tool for studying the mechanical properties of the aortic wall and may aid in the development of accurate diagnostic methods for predicting aortic aneurysm rupture.

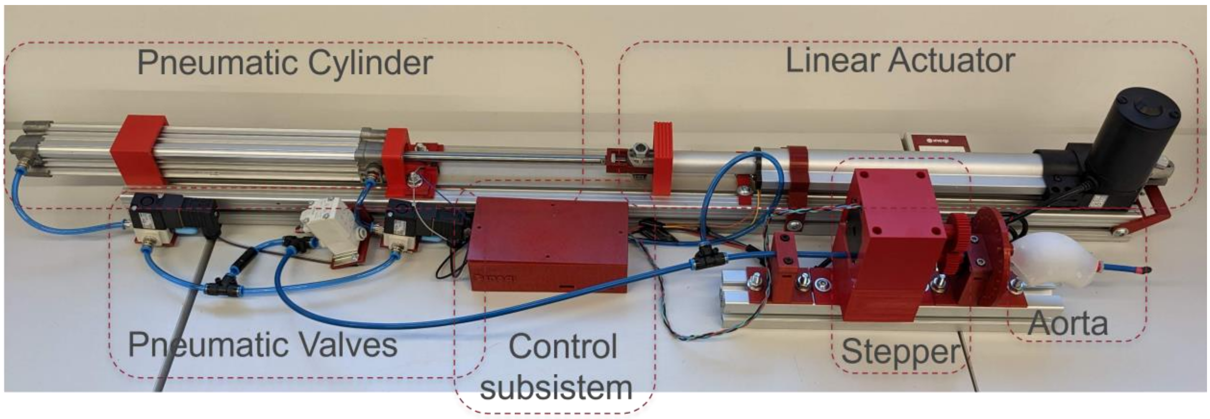


***Figure 1** – Experimental System without DIC sub-system*

This work was developed in the scope of the project AneurysmTool - Refª PTDC/EMD-EMD/1230/2021, funded by "FCT Projetos I&D" of the "Fundação para a Ciência e a Tecnologia"

Experimental monitoring of falling metallic shelter during seismic simulation

Francisco Afonso[1], Pedro Sousa[1], Nuno V. Ramos[1], Alexandre Brás Santos[1], Paulo Tavares[1], Pedro Moreira[1], Sajjad Hosseini[2], João Gomes Ferreira[2]
fafonso@inegi.up.pt

[1]*INEGI, Rua Dr. Roberto Frias Nº 400, 4200-465 Porto, Portugal*

[2]*Instituto Superior Técnico, Av. Rovisco Pais, Nº 1, 1049-001 Lisboa, Portugal*

Seismic Engineering *Instrumentation* *Camera Tracking*

Abstract The focus of this paper is the monitoring of the position, velocity and acceleration of several targets placed on the surface of a metallic shelter, which stands on top of a building structure who is made to withstand seismic activity.

This test was conducted using a camera system to track the previously mentioned targets through the resulting footage, due to the dimension of the structure atop which the shelter rests, three high-speed cameras were positioned facing its three different levels. Eight accelerometers were also developed and attached to different parts of the shelter. A triaxial seismic platform is used to apply bursts of growing intensity until the structure's failure.

The position, velocity and acceleration of each target was successfully recorded using the cameras, with the exception of situations where they're hidden from their field of view. Seven out of the eight accelerometers were able to record results from the test.

Figure 1 *- Metallic shelter and building structure before the trial.*

Surface defect detection systems for railway components

Francisco Afonso, Pedro Sousa, Susana Aguiar, João Nunes, Nuno Viriato, Frederico P. Direito, Paulo Tavares, Pedro Moreira
fafonso@inegi.up.pt

INEGI, Rua Dr. Roberto Frias Nº 400, 4200-465 Porto, Portugal

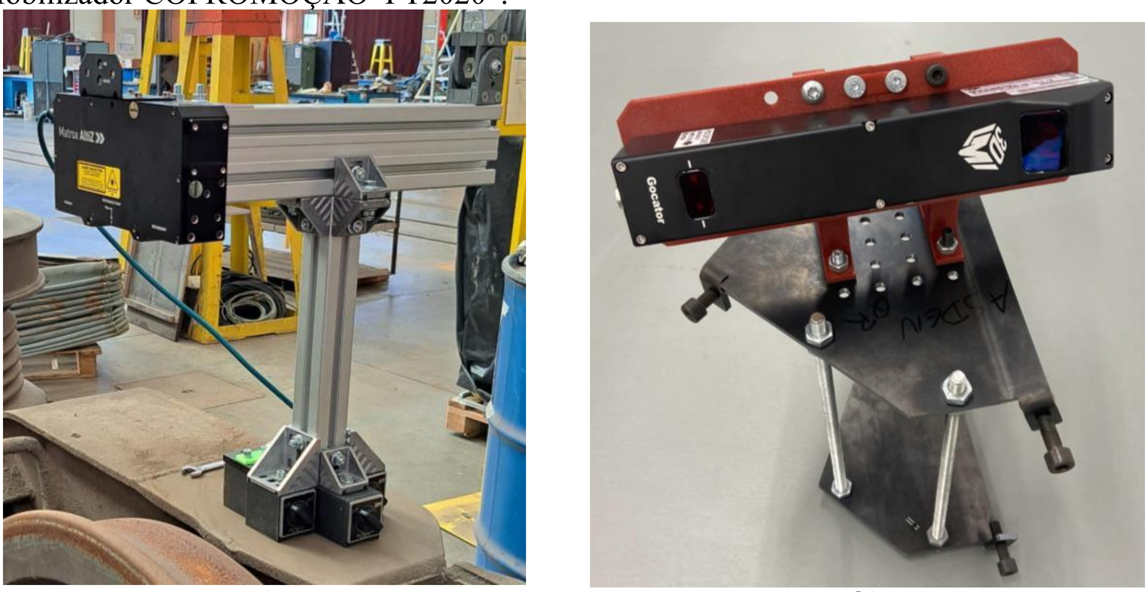
Laser Sensor *Defect detection* *Railway*

Abstract Defects located both in the railway tracks and the wheels of the train can become critical to the well-functioning of the railway system, going as far as to halt the movement of trains or require manual intervention to avoid accidents. In that regard, as part of the Ferrovia 4.0 project which aims to improve Portuguese railways, two systems were developed to detect surface level defects in these areas.

Both systems implement 3D laser line sensors to measure profiles, these sensors are equipped with cameras, a laser and work using the principle of triangulation, where the laser line appears deformed from the point of view of the cameras due to the object under evaluation's surface. An algorithm was developed, for each system, allowing the implementation of different metrics and their respective tolerances, warning the user when a defect is detected and, in the case of the railway track defect detection system, the presence of defects is also transmitted to a maintenance platform. Both algorithms compare the profiles of both the railway tracks and train wheel to their respective defect free templates, acquired beforehand. While the railway tracks system is to be implemented on a fully assembled train carriage, the wheel system was developed for application in repair shop environment.

Both systems are able to successfully compare the profiles captured during trials to their respective templates, warning the user every time a profile went outside the established tolerances which, in turn, can easily be adjusted, and successfully communicated with the maintenance platform when a defect was detected.

This work was developed in the scope of the project FERROVIA 4.0, nº 46111 which has received funding from "ANI - Agência Nacional de Inovação, S.A" through the programme "Mobilizador COPROMOÇÃO PT2020".



a) b)

Figure 1 - *Developed systems: a) wheel defect detection, b) railway tracks defect detection.*

Development of a photogrammetric system for railway retaining walls analysis

Francisco Afonso, Pedro Sousa, Nuno Viriato, Francisco Barros, Paulo Tavares, Pedro Moreira

fafonso@inegi.up.pt

INEGI, Rua Dr. Roberto Frias Nº 400, 4200-465 Porto, Portugal

Photogrammetry *Point cloud* *Railway*

Abstract Retaining walls are often located near railway tracks, this can pose a problem due to the shifting of the land over time which may cause landslides, obstructing the railway and requiring manual intervention. As part of the Ferrovia 4.0 project which aims to improve Portuguese railways, a system was developed to capture the 3D shape of railway retaining walls as the train passes by.

The system makes use of two cameras and their lenses, positioned at different angles to more easily obtain details of the retaining wall. An algorithm was developed, allowing the system to capture several photographs as the train passes through an area of interest, these images are then processed using Pix4Dmapper, resulting in the cloud point locations of the retaining wall. The system starts and ends its acquisition automatically, depending on its GPS coordinates or on the computer's available RAM memory.

The system successfully captures images of areas of interest and it was possible to observe the influence of gain, exposition time and aperture in their tridimensional reconstruction. The resulting point clouds can be further analyzed to identify areas that may require intervention.

This work was developed in the scope of the project FERROVIA 4.0, nº 46111 which has received funding from "ANI - Agência Nacional de Inovação, S.A" through the programme "Mobilizador COPROMOÇÃO_PT2020".

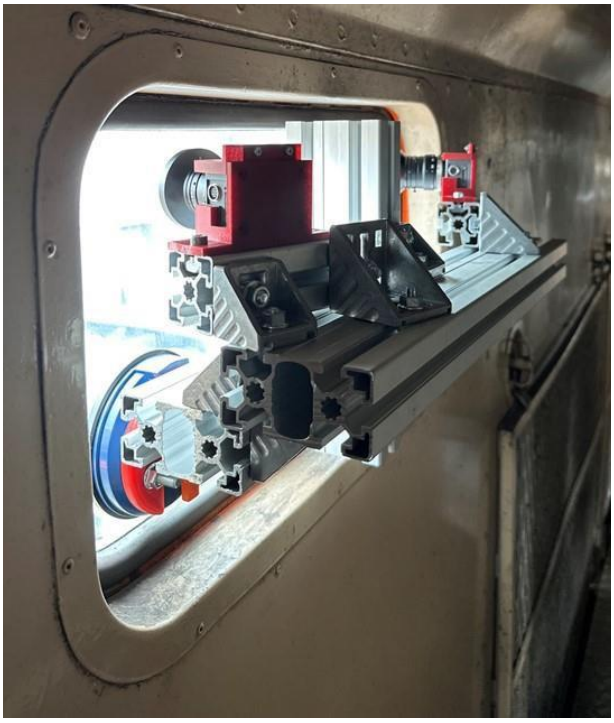


Figure 1 *– Photogrammetric camera system and its structure assembled in the locomotive.*

Experiments for a Reliability-Based Fatigue Analysis Applied in Leaf Spring Suspensions of Freight Wagons

V.M.G. Gomes[1,2], N.M.P. Pinto[1], P.A Montenegro[1], J.A.F.O Correia[1,2], R. Calçada[1], A.M.P de Jesus[1,2]

[1]*Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, 4200-465 Porto,* vtgomes@fe.up.pt

[2]*INEGI, Institute of Science and Innovation in Mechanical and Industrial Engineering, Campus FEUP, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal*

Leaf Springs *Fatigue Analysis* *Reliability*

Abstract Significant financial cuts in recent decades have resulted in disinvestment in the growth of the Portuguese railway sector. With environmental issues gaining importance in recent years, the railway industry has been identified as a critical element for the development of a sustainable economy. The rail vehicle has been planned for exporting in the goods sector. However, the dynamics of sales have necessitated the logistics sector's efficient management and maintenance of their resources in order to respond to customer demand efficiently. This is only achievable if the health status of the components is properly understood. This information is especially critical in components that provide a high level of risk. The leaf springs that constitute the suspension of goods wagons are one of these elements. Leaf spring fracture is often caused by fatigue, and its failure might result in vehicle derailment. A real-time monitoring campaign of the stress magnitudes applied to the leaf springs is carried out to determine the health condition of the leaf springs. A real-time monitoring campaign of the stress magnitudes applied to the leaf springs is carried out to determine the health condition of the leaf springs. Electric strain gauges are used to monitor surface deformations, whereas potentiometers are utilized to collect data related to leaf loading. The obtained loading data is analyzed using the Rainflow method (Figure 1 – right) and posteriorly is converted into a loading distribution. The loading distribution which is posteriorly compared with the fatigue strength distribution of the material. Additionally, collected data also permits to be used to calibrate numerical models that can contribute to the creation of a hybrid digital twin model for fatigue prediction. Hybrid digital twin model developed based on the presented methodologies can be used as a tool for maintenance practices, as well as reducing fatigue in leaf springs.

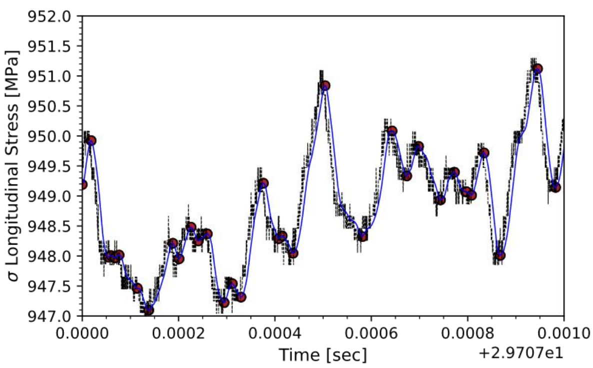


***Figure 1** – Left - Leaf spring suspension , Right – Stress signal for Rainflow Analysis.*

Acknowledgments

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3D DIC deformation monitoring of rotor blades with moving cameras

Pedro J. Sousa, Francisco Barros, Rodrigo Valente, Tiago Domingues, Paulo J. Tavares, Pedro M. G. P. Moreira

INEGI, Universidade de Engenharia da Universidade do Porto, Rua Dr. Roberto Frias 400, Porto 4200-465, Portugal

psousa@inegi.up.pt

3D-DIC *Deformation monitoring* *Dynamic loading*

Abstract Wind turbines are a sustainable energy source with high power generation capability, which is significantly limited by its relatively high maintenance costs. The MAREWIND project (https://www.marewind.eu/) aims to develop new methods to evaluate the displacement caused by wind forces in the aerofoil, with the goal of providing insights regarding its structural integrity. One possible solution focuses on the development of non-destructive methods, namely with 3D Digital Image Correlation (3D-DIC) with independent cameras on Unmanned Aerial Vehicles (UAV), using Structure from Motion (SfM) and GPS-based synchronization. SfM is an image processing technique which determines the spatial position of the camera at each image acquisition, as well as the camera's intrinsic parameters, through feature matching operations.

Laboratory tests have been conducted on a recreational model aircraft using two industrial cameras handheld by different people, while time synchronization between them was implemented with two independent u-blox ZED-F9T high-precision GPS synchronization modules. The obtained results were validated using a 3D-DIC based approach with static cameras, and it was possible to achieve results with errors under 4%. This approach aims to reduce the maintenance costs in wind turbines and consequently improve the appeal of this sustainable energy source. Furthermore, this method can be adapted to perform DIC in structures which are out of reach.

Acknowledgments
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Advanced Optical Sensing Technologies: Methodologies and Applications

Job Silva, Tiago Domingues, Nuno Viriato, João Nunes, Pedro Sousa, Pedro Moreira

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

Distributed Fiber Optic Sensing (DFOS) *Fiber Bragg Gratings (FBGs)* *Structural health monitoring (SHM)*

Abstract Optical sensing technologies play a crucial role in Structural Health Monitoring (SHM) and Integrated Vehicle Health Management (IVHM), as they enable precise and continuous measurements, facilitating early detection of potential failures, proactive maintenance strategies and contributes to the longevity and safety of various structures.

Fiber Bragg Gratings (FBGs) measure strain and temperature with high precision, providing valuable insights into the behavior and health of structures. Distributed Fiber Optic Sensing (DFOS) takes this a step further by enabling continuous and distributed sensing along the entire length of optical fibers.

To comprehensively evaluate the advantages and drawbacks of the aforementioned optical sensors in practical applications, this presentation will feature diverse optical sensors employed in various real-life scenarios, such as bridges, wind turbine blades, and vehicle chassis components. Our objective is to conduct a thorough assessment of the advantages and disadvantages offered by these optical sensors when utilized in practical applications.

Based on the study cases, can be concluded, optical sensors offer benefits such as immunity to electromagnetic interference, minimal signal loss, compact size, and corrosion resistance, but their high cost and fragility can present limitations. The requirement for meticulous installation and protection of optical fibers within both the structure and the external environment can render them less suitable as the preferred solution.

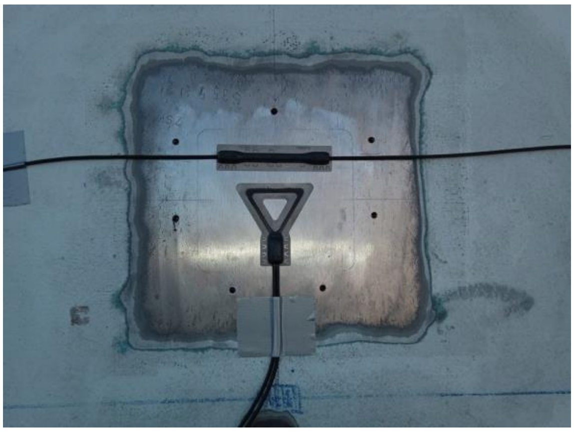


Figure 1 - *The application of Fiber Bragg Grating Technology (FBG) sensors on a structure.*

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the grant agreement No. 952960. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

Predictive Analysis of Structural Damage in submerged Structures: A Case Study Approach using Neural Networks

Alexandre Santos[1], Hugo Mesquita[1], Tiago Domingues[1], Rogério F. F. Lopes[1,2], Pedro Sousa[1], M. P. L. Parente[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]Department of Mechanical Engineering, Faculty of Engineering, University of Porto, 4200- 465 Porto, Portugal.

Fluid Structure Interaction *Wave loads* *Aquatic Lander* *Neural Networks*

Abstract Offshore structures play an important role in the exploration and production of valuable energy resources from marine environments. The reliability and safety of these structures are of utmost importance, making it essential to accurately predict and assess potential structural damage.

This research aims to develop a predictive neural network algorithm for structural damage in submerged structures from the ocean state and afterwards comparing it to a real-life case of a 6-month experiment.

Historic data from an oceanic buoy was used to determine the sea conditions required to create numerical models to simulate the flow and loading conditions acting on the Gravity-based structure (GBS).

The strains experienced by the GBS, obtained in FSI simulations in conjunction with corresponding sea states will be used as inputs to train the predictive neural algorithm.

As a part of this research, a gravity-based structure was designed and produced. The structure will be deployed into the ocean at a depth of 30 meters to provide an empirical case to compare against the simulated neural network. The GBS is highly-monitored using Fiber Bragg Grating sensors and strain gauges. The strains measured during the testing period will be used to validate the predictive model developed and eventually train a more reliable model.

The proposed methodology evidences the potential of neural networks in accurately forecasting structural damage in offshore structures, enabling proactive measures to mitigate structural damage and enhance their overall reliability and longevity and provides valuable insights for future research.

Acknowledgments
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the grant agreement No. 952960. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

Monitoring system for the Leixões bascule bridge

Nuno Viriato[1], Job Silva[1], Susana Aguiar[1], Pedro Sousa[1], Andreia Flores[1], Pedro Moreira[1], Mário Vaz[2], Luís Cunha[3], Dantas da Rocha[3], António Tavares[3]

[1]INEGI, Campus da FEUP, R. Dr. Roberto Frias 400, 4200-465 Porto, Portugal.

[2]FEUP, Faculty of Engineering of the University of Porto

[3]Administration of the Ports of Douro, Leixões and Viana do Castelo, SA

Instrumentation Sensors Structural health monitoring (SHM)

Abstract Structural Health Monitoring (SHM) involves the acquisition and analysis of data collected from different sensors to monitor changes in the mechanical behaviour of any kind of structures (fixed or moving), aiming the early detection of failures or breakdowns that could compromise its safety. These methods are applied in different types of structures such as: buildings, metallic structures, bridges and vehicles, in order to reduce the costs of its operation.

The bascule bridge of Leixões (Ponte Móvel of Leixões - Figure 1) is a unique structure, of large dimensions and some complexity, that connects two shores of the port. This bridge allows pedestrian and vehicles traffic, but also permits the entry of large container ships. It is a metallic structure driven by four hydraulic cylinders that opens several times a day for the passage of ships. With the growth verified in the traffic of vehicles and ships, the load on the structure and the number of opening manoeuvres increased and some unexpected problems occurred, which led to interventions on the bridge outside the maintenance plan originally specified. Unexpected stops lead to interruptions in traffic, increasing costs and putting port operations at risk.

To ensure a more efficient operation of the bascule bridge, APDL decided to implemented a monitoring system to allow an effective maintenance based on the structural behaviour of the bridge main components. All the data collected by de SHM is stored, which will allow access to the wear evolution and ensure a reliable record of the bridge operation. In this way, it is possible to verify at an early stage the existence of anomalous behaviour/failures that may occur in the components as well as any accidental occurrence that may cause damage.

This paper describes the approach followed to apply SHM to the bridge. To monitor the structural behaviour of the bascule bridge, approximately, 80 sensors (40 sensors for each bascule tray) were installed. These sensors are able to measure stresses, temperatures, tilts, triaxial accelerations and hydraulic pressures, in specific locations. Parallel to this, a specific software was developed that enables the acquisition and record of all the signals, and also can emitted warnings to the APDL maintenance team, in case of unexpected behaviours.

Figure 1 – Leixões Bascule

Optimization of 3D printing parameters for PEI using a DOE

Rodrigo Praça[1], Tiago M.R.M. Domingues[2], Gonçalo P. Cipriano[2], Pedro J. Sousa[2], Pedro M.G.P. Moreira[2]

[1]*Department of Mechanical Engineering, Faculty of Engineering, University of Porto, 4200-465 Porto, Portugal.*

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

Fused filament Fabrication *High-performance plastics* *Design of Experiments*

Abstract Fused Filament Fabrication (FFF) is a widely used additive manufacturing process that utilizes thermoplastic materials to create objects with complex geometries. This study focuses on the utilization of high-performance plastics, specifically Ultem® 1010 (PEI - Polyetherimide), in the FFF process to produce components with enhanced strength, toughness, and superior performance at elevated temperatures. The objective of this research is to investigate the impact of temperature-related printing parameters, including nozzle, bed, and chamber temperatures, on the ultimate tensile strength of PEI samples. The experimental work was conducted using additive manufacturing equipment developed by INEGI, and a central composite design-of-experiments methodology was employed.

To begin, various testing standards and sample configurations were explored, considering ISO 527-2 5A, ASTM D638 V, ISO 527-2 1BA, and ASTM 3039. A total of 57 specimens were produced based on the defined design-of-experiments. Subsequently, these specimens were subjected to quasi-static tensile testing using a universal testing machine developed by INEGI. The deformation experienced by the specimens was measured using digital image correlation.

The findings revealed that increasing the temperature generally resulted in improved tensile strength of the PEI samples. Among the studied parameters namely nozzle, bed, and chamber temperatures, the bed temperature exhibited the most significant influence. Moreover, the interactions between the temperature parameters were found to have minimal impact on the tensile strength. Through the analysis, a regression model was developed, which predicted and optimized the tensile strength based on the three temperature parameters. The model was further validated through experimental testing.

This research contributes to a better understanding of the relationship between temperature-related printing parameters and the mechanical properties of PEI samples produced by FFF. The results provide valuable insights for optimizing the FFF process and enhancing the performance of structural components.

Exploring Structural Simulation Methods for Railway Systems: A Review

Tiago M.R.M. Domingues, Job Silva, Alexandre Santos, Pedro M.G.P. Moreira

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

Structural Simulation Methods *Railway Systems* *Structural Integrity*

Abstract Railway vehicles play a crucial role in transportation, and countries like Portugal are making significant investments in their development. However, due to their intricate nature, these vehicles require sophisticated structural analyses and simulation tools have become indispensable in this field.

This study aims to examine analysis methods and software options for railway vehicles, specifically focusing on multi-body analyses, finite element method (FEM) analyses and preprocessing software for meshing purposes.

A review of available software applications for structural analyses in railway systems was made, emphasizing the key features, strengths, and weaknesses of each software package. Furthermore, the study assesses the capabilities and limitations of each analyses type for and the possibilities regarding the interaction of several methods.

The outcomes of this research will serve as a valuable resource for researchers and engineers involved in the development, analysis, and optimization of railway vehicles. Ultimately, this study will aid in the selection of appropriate software and analysis methods, facilitating accurate and efficient structural simulations in the railway industry.

This work is a result of Agenda “Produzir Material Circulante Ferroviário em Portugal”, nr C645644454-00000065, financed by the Recovery and Resilience Plan (PRR) and by European Union – NextGeneration EU.

Crashworthiness topology optimisation of a crash box to improve passive safety during a frontal impact

Christian J. G. Silva[1], Rogério F. F. Lopes[1,2], Tiago Domingues[2], M. P. L. Parente[1], Pedro M. G. P. Moreira[2]

[1]*Department of Mechanical Engineering, Faculty of Engineering, University of Porto, 4200-465 Porto, Portugal.*

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

Topological Optimisation Crashworthiness Passive Safety ECE R29

Abstract This research focuses on the application of topology optimisation algorithms for improving the crashworthiness of heavy passenger vehicles, particularly coaches (M3 Class III vehicle), in frontal impact conditions. The objective is to find the optimal arrangement of material to minimize compliance while meeting a volume constraint as to improve the structure of the vehicle for energy absorption.

The concept of crashworthiness design is crucial in the automotive industry, particularly in enhancing passenger safety. It aims to develop structures that can absorb maximum energy while minimizing intrusion, to maintain the driver's survival space. If so, crashworthiness design deals with conflicting objectives, and optimisation methods can be used to find a compromise between these parameters. Despite this potential, the application of topological optimisation in the context of vehicle structure crashworthiness is still limited. One of the main challenges is the nonlinear nature of crash simulation that results in high computational costs, thus deeming the application of these kind of approaches impractical.

To account for said obstacle, this study performs the optimisation process on a single component, a crash box, employing a MATLAB code built with the optimisation algorithms, that iteratively interfaces with Abaqus® where the crash simulation is performed. The goal is to, subsequently, incorporate the optimised component into the coach chassis baseline and test it according to ECE R29 regulation.

This research contributes to the limited existing literature on the topic of crashworthiness design of heavy passenger vehicles by proposing an optimised coach chassis with improved structural performance, enhanced for energy absorption, that ensures the physical integrity of the driver. Additionally, it addresses the lack of regulations dedicated to frontal impact of bus structures by adapting a truck-based regulation, such as ECE R29, and applying it to determine the structural response of the dynamic explicit model.

The Effect of Strain-Rate on the Mechanical Performance of Direct Energy Deposition and Hybrid Direct Energy Deposition, Selective Laser Melting

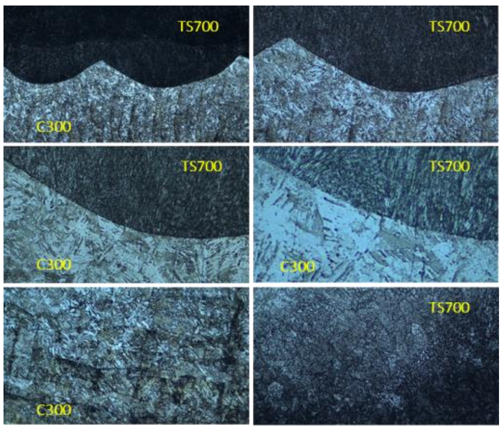
Daniel F.O. Braga[1], Lucas Azevedo[2], G. Cipriano[1], Miguel O. Gomes[1], Pedro J. Sousa[1], Pedro M.G.P. Moreira[1]

[1] INEGI, Campus da FEUP, Universidade Do Porto, Rua Dr. Roberto Frias, 400, 4200-465, Porto, Portugal

[2] Quantal S. A., Rua São Cristóvão, 95, 4480-430, Rio Mau, Vila do Conde, Portugal

Experimental Mechanics *Elevated strain-rates* *Additive Manufacturing*

Abstract Metal additive manufacturing (AM) and especially direct energy deposition (DED) through laser metal deposition (LMD), enables economically viable, high performance, optimized components, such as, nickel alloy complex geometry turbine blades. Also, when combined with complementing technologies such as selective laser melting (SLM) and various post processing techniques, advanced products in less technological intensive industries may also be developed with added value features. One example of such is tooling for high temperature forming, with integrated optimized cooling and simultaneous high wear resistance surfaces. However, these AM processes result in complex microstructures which affect their mechanical performance, especially given the demanding loading scenarios which the applications they are designed for require. This study aims to study the effect of strain-rate on the mechanical performance of metal additive manufacturing nickel alloys and hybrid LMD-SLM dissimilar materials. Special purpose testing apparatus was developed, and tensile testing was performed at various strain-rates from quasi-static to high strain-rate.



a) b)

***Figure 1** – Hybrid SLM-LMD coupon manufacturing a) and dissimilar material interface b)*

Acknowledgement

The authors acknowledge the project POCI- 01-0247-FEDER-072260, financed by European Funds, through program COMPETE2020, under the Eureka smart label S0318-STREAM -Surface TREatment for Additive Manufacturing.

Savitzky-Golay Smoothing and Differentiation Filters for Damage Identification in Plates

J. V. Araújo dos Santos[1], H. Lopes[2]

[1]*IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal*

viriato@tecnico.ulisboa.pt

[2]*DEM-ISEP, Instituto Politécnico do Porto, Porto, Portugal*

Damage Identification   *Savitzky-Golay Filters*   *Modal Strains*

Abstract The aim of this paper is to present a baseline-free method for the identification of slot edges in a square plate. The slots, created by reducing the plate thickness, have different geometries and are placed in several locations. We make use of Savitzky-Golay smoothing and differentiation filters for the computation of modal strains. These modal strains are computed by differentiating the modal displacements (mode shapes), which are obtained by the finite element method. A discussion on the set of Savitzky-Golay filter parameters to obtain the best damage identifications is presented. The influence of noise on the quality of these damage identifications is also studied. The norm of strains is found to be very sensitive to the stiffness decrease, allowing the identification of single damage (one slot) and multiple damages (three slots). Figure 1 shows the identification of a multiple damage case, consisting of three slots.

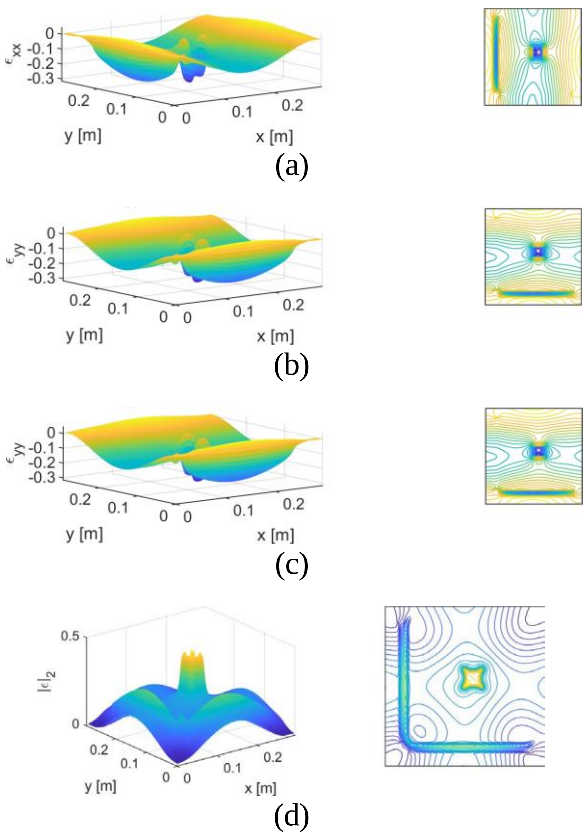


Figure 1 *– Identification of three slots with modal strains of third mode shape:*
(a) ε_{xx}, *(b)* ε_{yy}, *(c)* γ_{xy}, *and (d)* $\|\varepsilon\|_2 = \left(\varepsilon_{xx}^2 + \varepsilon_{yy}^2 + \gamma_{xy}^2\right)^{1/2}$

Kissing Bond and Interfacial Quality Detection in Adhesive Bonds Using Hsu-Nielsen Source and AE Sensors

Callum Selfridge, Cameron Gerrie, Sean Gerrie, Anil Prathuru and Ghazi Droubi

a.prathuru@rgu.ac.uk

School of Engineering, Robert Gordon University, Aberdeen AB10 7GJ, UK

Abstract This study used non-destructive testing (NDT) to evaluate the use of adhesive bonds for aerospace applications, with a focus on the effects of defects within the bond. This is of importance as adhesive bonds see widespread use in the aerospace industry due to their strength and light weight. However, it is harder to maintain adhesive bonds as in most cases defects within the bond cannot be visually identified and the strength of the bond cannot be fully restored outside of full disassembly and remanufacture of the joint. This study investigated single lap joints (SLJs) with aluminium adherends bonded together using a Permabond TA4246 acrylic adhesive. The specimens were formed using a modified version of the ASTM D-1002 standard with an enlarged bonded area of 50mm x 50mm to allow for effective development of kissing bond defects within the samples. Different bonding conditions were investigated through altering the roughness of the aluminium using grit paper and introducing kissing bond defects by applying PTFE spray to the bond area. The geometry of the specimens is shown in Figure 1a.

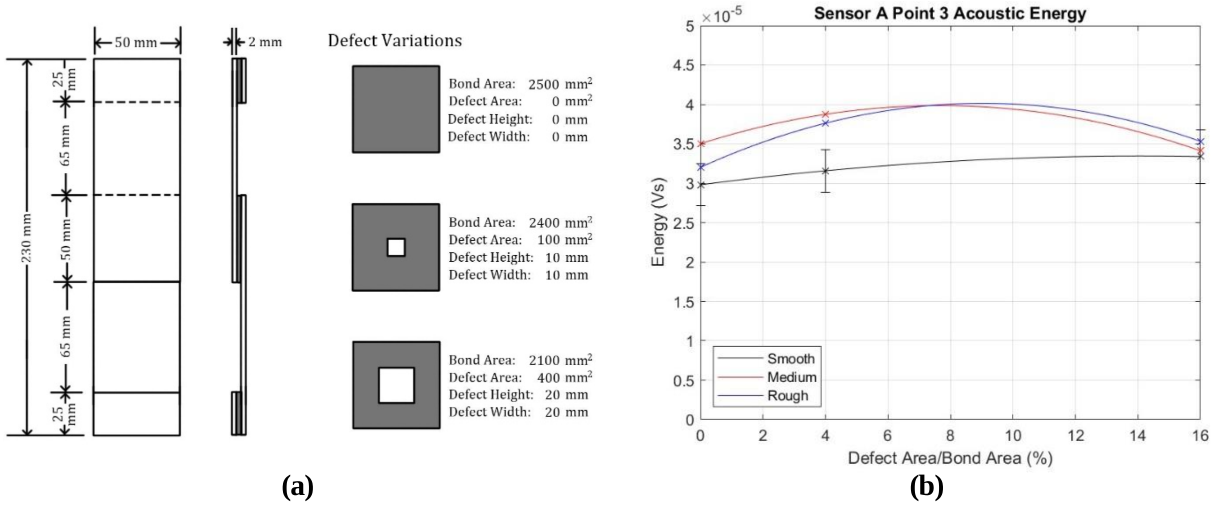


Figure 1. (a) Specimen geometry and defect variations; **(b)** Acoustic energy obtained from a sensor 60 mm from the defect and PLB location, for the first 50 μs of the signal.

Pencil lead break (PLB) testing in accordance with ASTM E976-15 (2021) was performed on the SLJs using acoustic emission (AE) as a form of NDT to try and identify the presence of the defects. The PLB testing focused on the plausibility of using fundamental zero-order antisymmetric mode propagation as the means of identifying and sizing the defects, through analysis of the time, frequency, and time-frequency domain of the signals. It was found that PLB testing has the potential to identify defects through acoustic energy, although it suffers from inaccuracy. The identified trend was an increasing acoustic energy in the first 50 μs of a signal from a distance of 60 mm, with defect area, for the smooth surface samples, shown in Figure 1b. This trend was confirmed by other sensor and break configurations; however, it is inaccurate due to the large standard deviation. The first 50 μs of the signal corresponds to a period that maximises the signal reflection in the bond area, while minimising reflections out with the bond area that reach the sensor.

Tension/Torsion UFT for Different Axial/Shear Stress Ratios

Luis Reis[1,2,*], Henrique Lopes[1], Pedro Costa[2,3], Manuel Freitas[2,3]

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

[2]*IDMEC, Instituto Superior Técnico, Av. Rovisco Pais, 1, 1049-001 Lisboa, Portugal*

[3]*Atlântica, Instituto Universitário, Fábrica da Pólvora de Barcarena, 2730-036 Barcarena, Portugal*

VHCF *Multiaxial loading* *UFT*

Abstract In order to complete fatigue tests between 1E6 and 1E10 cycles, or the so-called Very High Cycle Fatigue (VHCF) regime, the ultrasonic fatigue testing (UFT) technique was developed. Resonant principles are used in UFT procedures to produce high-frequency cyclic loads. Every machine component needs to be carefully designed and have a consistent displacement behavior in order to produce resonance. When compared to traditional fatigue testing procedures, the concepts that are followed allow for high time and energy performance. The current work uses several specimen designs on a cutting-edge ultrasonic fatigue testing device that can generate a mix of tension/torsion and multiaxial stresses. By ensuring the largest stress amplitude in the major throat, the new specimens demonstrated their dependability. Presenting experimental findings from tension/torsion fatigue tests conducted under three distinct shear/axial stress ratios, it can be seen that the Very High Cycle Fatigue regime allows for accurate fatigue testing.

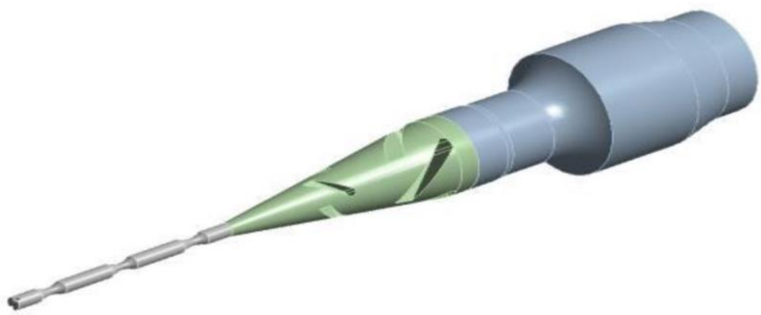


Figure 1 *– Specimen, horn, and booster*

The HELP+HEDE model for hydrogen embrittlement in metals: New insights and experimental/modeling confirmations

Milos B. Djukic[1], Jovana Perisic[1], Muhammad Wasim[2], Gordana Bakic[1], Aleksandar Sedmak[1], Bratislav Rajicic[1]

[1]*University of Belgrade, Faculty of Mechanical Engineering, Kraljice Marije 16, Belgrade 11120, Serbia*

mdjukic@mas.bg.ac.rs

[2]*Department of Civil & Infrastructure Engineering, RMIT University, Melbourne, 3000, VIC, Australia*

Hydrogen Embrittlement Steel Mechanisms

Abstract A selection of suitable materials is critical for the safety of any hydrogen application. Most engineers know that hydrogen embrittlement and other hydrogen-specific damaging mechanisms of various metallic materials represent serious threats. The deleterious hydrogen effects and provoked degradation of mechanical properties of steel are expressed in diverse forms and often in opposite ways, including both softening and hardening phenomena, depending on three main factors: material, mechanic, and environmental. The HELP+HEDE model for synergistic action of hydrogen embrittlement (HE) mechanisms defined that the previous HELP mechanism activity is not always necessary for the activation and the observed complete predominance of the HEDE mechanism ("non-HELP mediated decohesion" process activation) at high local/global hydrogen concentrations in steels [1-3]. According to the HELP+HEDE model, the degree and nature of decreases in the material's resistance to the crack propagation (steady-state linear decrease or the sudden drop) in steel are strictly related to the local/global hydrogen concentration in metals. Therefore, the synergistic effects of HE mechanisms are reflected through the corresponding predominance of HELP (at lower hydrogen concentration) or HEDE mechanism (at higher hydrogen concentration after reaching the critical local/global concentration) of hydrogen embrittlement. In our recent attempt to provide further progress in understanding the synergy of HE mechanisms, we proposed the unified HELP+HEDE model [3]. Accordingly, the "local HEDE micro-incidents" (grain boundary decohesion, fissures, and initial IG micro-cracks) as discrete micro-scale incidents, appear at a high local hydrogen concentration, but at still moderate global concentration, lower than the critical [3]. In such a case, the HELP mechanism is still predominant (HELP+HEDE, HELP>HEDE), macroscopically speaking. According to the unified HELP+HEDE model, for the full macro HEDE mechanism manifestation (sharp drop in macro-mechanical properties and crack propagation resistance) and its dominance (HELP+HEDE, HEDE>>HELP), the necessary prerequisite is "the macro-volume effects" of HEDE. This means the appearance and accumulation of a large enough number of local HEDE micro incidents in a small volume. The new "local HEDE micro-incidents" concept at the local hydrogen concentration above the critical one, tries to bridge the gap between the various scales (macro, micro-meso, and nano-atomic) in the understanding of the physics of HE.

[1] M.B. Djukic, V. Sijacki Zeravcic, G.M. Bakic, A. Sedmak, B. Rajicic, The synergistic action and interplay of hydrogen embrittlement mechanisms in steels and iron: Localized plasticity and decohesion, Engineering Fracture Mechanics 216 (2019), p. 106528. https://doi.org/10.1016/j.engfracmech.2019.106528

[2] M.B. Djukic, V. Sijacki Zeravcic, G.M. Bakic, A. Sedmak, B. Rajicic, Hydrogen damage of steels: A case study and hydrogen embrittlement model, Engineering Failure Analysis, 58 (2015), pp. 485-498. https://doi.org/10.1016/j.engfailanal.2015.05.017

[3] M. Wasim, M.B. Djukic, T.D. Ngo, Influence of hydrogen-enhanced plasticity and decohesion mechanisms of hydrogen embrittlement on the fracture resistance of steel, Engineering Failure Analysis 123 (2021), p. 105312. https://doi.org/10.1016/j.engfailanal.2021.105312

The concept of the stress dead zones formulating the line spring model as an approach to the behaviour of a part through crack in an elastic plate

Francisco Q. Melo, , Vasco Amorim, Hugo Mesquita, Francisco Afonso, Paulo J. Tavares, Pedro G. Moreira

INEGI, Campus da FEUP, Universidade Do Porto, Rua Dr. Roberto Frias, 400, 4200-465, Porto, Portugal

Part-trough crack *Stress Dead Zone* *Line-spring model*

Abstract The stress distribution in flat plates containing plane cracks and subjected to a uniform remote stress field shows zones exposed to a high-stress level compared with nominal values, while some other have almost negligible stress levels, as a result of the redistribution of internal forces. The zones with a negligible stress field can be disregarded in analytical calculations, assuming that the material in that zone behaves as if it wasn't present. The removal of such stress "dead" zones, usually close to the crack mating faces, takes to a useful simplification in the structure shape model. This modified geometry enables the implementation of simple analytical algorithms in the evaluation of stiffness factors necessary in the computation of the associated stress-intensity factor along the crack line. The accuracy of such models depends mainly on the precise delimitation of the *SDZ*, *Stress Dead Zones*, at crack vicinity, in the structural component. Experiments were conducted in laboratory premises for SDZ delimitation, using Digital Image Correlation to obtain reliable area results.

Ackowledgements:
The authors wish to thank the support of this work to Project "PRODUTECH R3- Mobilizing Agenda for the Production Technologies Sector for Reindustrialization", nr C645808870 -00000067, investment project nº 60, financed by the Recovery and Resilience Plan (PRR) and by European Union – Next Generation EU.

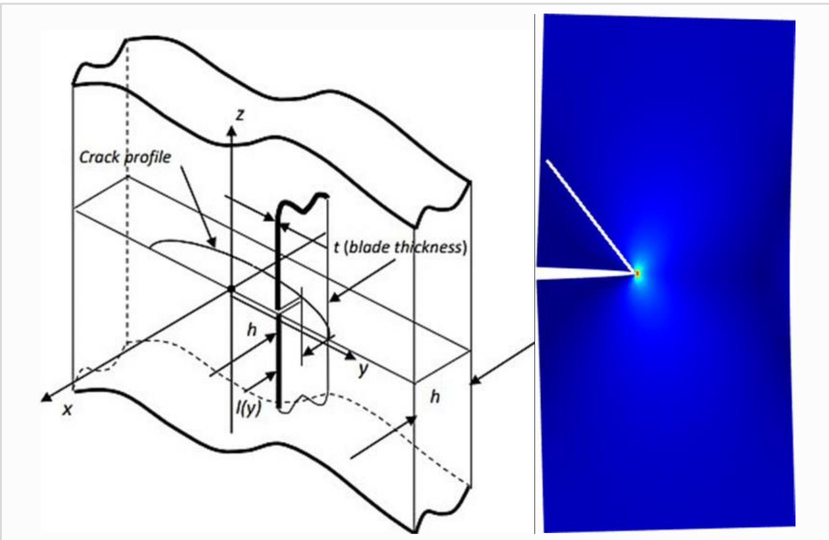


***Figure 1** – Line spring model as a structural approach to a part-through crack ligament and a stress "dead" zone by finite element analysis of a side edge cracked plate*

References

[1] – Farahani, B. *et al*., "*Advancement on Optical Methods in Stress Dead-Zone characterisation and SIF evaluation*", Engineering Failure Analysis, Elsevier, Vol. 140, Oct 2022, 106493

[2] - Farahani, B. *et al.*, "*Stress Dead Zone Concept by High Resolution Optical Techniques*", VIRTUAL 20th International Colloquium on Mechanical Fatigue of Metals 15–17 September 2021 Wrocław, Poland

Effect of seawater corrosion on the mechanical behavior of S690 steel

Ana Dantas[1,2,3,*], Rita Dantas[1,2,3], Gonçalo P. Cipriano[2], Abílio de Jesus[1,2], Grzegorz Lesiuk[4], Carlos Fonseca[1], Pedro Moreira[2], José A.F.O. Correia[1,2,3]

[1]*University of Porto, Rua Dr. Roberto Fria, 4200-465 Porto, Portugal,* *adantas@inegi.up.pt*

[2]*INEGI, Department of Mechanical Engineering, University of Porto, Portugal*

[3]*CONSTRUCT, Department of Civil Engineering, University of Porto, Portugal*

[4]*Department of Mechanics, Materials Science and Biomedical Engineering, Faculty of Mechanical Engineering, Wroclaw University of Science and Technology, ul. Smoluchowskiego 25, PL-50370 Wrocław, Poland*

S690 Steel   Mechanical Properties   Corrosion   Offshore structures

Abstract The marine environment can be considerably hostile to engineering metallic structures due to several factors, such as constant exposure to seawater, sunlight, marine life, and wind and wave action. When protected by coatings, a base material used in structures exposed to seawater can retain its original properties, however when unprotected, it can rapidly corrode, leading to degradation of mechanical. For instance, this is evident in offshore wind turbine foundations, where measures like surface coating and cathodic protection are employed. Nevertheless, these protections have a finite duration and can lead to premature damage before it can be addressed and repaired [1]. Additionally, the maintenance of such underwater structures is logistically complex and limited. Therefore, the characterization of the material for this corrosive environment is of crucial importance.

High-strength structural steels have been, in recent decades, a material of significant interest for offshore structures, including wind turbines and oil platforms. The S690 steel, due to its high strength, enables weight reduction of such structures, providing an advantage in terms of operational performance, transportation, and assembly. Consequently, it is essential to investigate and characterize the mechanical properties of S690 steel in non-corroded and corroded conditions [1].

In this work, a mechanical characterization and microstructural analysis of the S690 steel was conducted, taking into account the environmental conditions usually present in marine environments. As a result, a three-electrode setup has been implemented in order to accelerate the corrosion of specimens, as well as study the material corrosion resistance. Quasi-static and Charpy impact tests were conducted on both corroded and non-corroded specimens in accordance with the respective norms ASTM E8 and DIN EN 10045-1 [2, 3].

References

[1] A. Mehmanparast and A. Vidament, "An accelerated corrosion-fatigue testing methodology for offshore wind applications," *Eng Struct*, vol. 240, p. 112414, 2021, doi: https://doi.org/10.1016/j.engstruct.2021.112414.

[2] ASTM International, *ASTM E8/E8M-22 : Standard Test Methods for Tension Testing of Metallic Materials*. 2022.

[3] European Standard, *DIN EN 10045-1: Metallic materials - Charpy impact test - Part 1: Test method*. 1990.

Acknowledgements

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Finite Element Modeling of Concrete Prisms Strengthened with NSM and EBR CFRP Laminate Systems

Ahmed H. Selim, Shahed Alhomsi, Haider Hasan, Jamal A. Abdalla, Rami A. Hawileh

Department of Civil Engineering, American University of Sharjah, Sharjah, United Arab Emirates

jabdalla@aus.edu

Fibre Reinforced Polymer *Near Surface Mounted* *Externally Bonded*

Abstract In this study, two Finite Element (FE) models are created to simulate 4-point loading tests to compare two types of flexural strengthening of concrete prisms: (1) near surface mounted (NSM) grooves with epoxy bonded Carbon Fibre Reinforced Polymer (CFRP) laminates placed inside the grooves; (2) Externally Bonded Reinforcement (EBR) with epoxy bonded CFRP laminates mounted on the subtrace surface of the concrete prisms. Investigation was carried out to assess the efficiency and feasibility of using NSM and EBR strengthening systems using CFRP laminates. The finite element modelling of the prisms is performed using the commercial software, ABAQUS. The two concrete prisms strengthened with CFRP are then analysed to assess their performance. The FE results of the prisms showed that the ultimate load for the prism strengthened with the EBR-CFRP laminates is 2213 N and that for the prism strengthened with the NSM-CFRP laminate is 2341 N. This increase corresponds to a percentage difference of 6%. Thus, it could be concluded that the proposed strengthening systems are equivalent in retrofitting and strengthening reinforced concrete (RC) beams. In addition, the developed models could be utilized as a validated source to conduct parametric studies on both systems to examine the effect of different parameters on the flexural performance of RC member.

Behaviour of normal and recycled aggregates beams strengthened with different types of externally bonded shear reinforcement

Jamal A. Abdalla, Rami A. Hawileh, Maha Ass'ad, S. S. Ahmed, A. Omer, O. Abdulkadeer

Department of Civil Engineering, American University of Sharjah, P.O. Box 26666, Sharjah, United Arab Emirates

jabdalla@aus.edu

Abstract This study aims at investigating the effect of strengthening shear-deficient recycled aggregate concrete (RAC) beams with carbon fiber-reinforced polymer (CFRP) laminates. Four RAC beams were cast, three of which were strengthened with different CFRP shear strengthening configurations: U-wraps bonded at 45º, continuous U-wraps along the shear span, and side-boned laminates. In addition, one RAC specimen was left unstrengthen to act as a benchmark specimen. For comparison purposes, an additional four normal aggregate concrete (NAC) beams were cast, three of which are strengthened with similar CFRP schemes as that of the RAC, and one was left unstrengthen. All beams are loaded under four-point bending tests, and the results in terms of shear force-deflection graphs and failure modes are analyzed and compared. Experimental results indicated that the shear force values obtained in NAC and RAC beams are comparable. In fact, the percentage increase in the shear strength compared to the respective control beam was higher for RAC beams than that of NAC beams. This proves the effectiveness of using different shear strengthening configurations and the viability of using CFRP shear strengthened RAC beams compared to CFRP shear strengthened NAC beams.

Recent developments in understanding the mechanisms of hydrogen embrittlement and trapping behaviour in Al alloys

Masoud Moshtaghi

Chair of General and Analytical Chemistry, Montanuniversität Leoben, Franz-Josef-Strasse 18, 8700 Leoben, Austria

masoud.moshtaghi@unileoben.ac.at

Hydrogen embrittlement *Aluminium* *Failure mechanism*

Abstract The applicability of high-strength Al alloys with a good combination of low cost, light weight and mechanical properties make them as a potential candidate to use in different automotive products and aerospace systems. However, these alloys are involved with the severe loss in ductility and premature fracture when exposed to hydrogen, leading to a limit their usefulness. The environmentally assisted hydrogen embrittlement (HE) in high strength 7xxx series aluminum alloys, arising from the formation of atomic hydrogen through the reaction of the water vapor present in the atmosphere with the bare aluminum surface can lead to a low ductility and the catastrophic failure in primary and secondary structures of commercial aircraft.

The presence of hydrogen can increase the mobility of dislocations during plastic deformation which results in highly localized plastic deformation and faster failure. These observations led to the notion of hydrogen enhanced localized plasticity (HELP) mechanism. In addition to the HELP mechanism, another most-cited mechanism, namely hydrogen enhanced decohesion (HEDE) also has been proposed. HEDE considers a reduction in the cohesive bond strength between the metal atoms in the presence of hydrogen. High concentrations of hydrogen and the associated decohesion events could occur at a variety of locations, such as particle-matrix interfaces and grain boundaries. Despite the several suggested mechanisms to describe HE, there is no universally accepted HE mechanism. This is owing to different observed indications which have been attributed to different mechanisms of HE in different studies. A generally recognized common feature is that some critical concentrations of hydrogen must build-up at potential flaws, for failure to initiate. Thus, the partitioning of hydrogen inside the metal and its pattern of migration are of paramount importance for understanding the phenomena and designing alloys with improved HE behavior.

It was observed that hydrogen-induced decohesion is competing with hydrogen-induced softening on the strain required for void nucleation. HEDE mechanism leads to decrease in this strain, while HELP mechanism increases it, and the required strain is defined by the result of this competition. Hence, we explain the observed hydrogen effects on soluble particle/matrix interface on the basis of HEDE mechanism. Based on this mechanism high hydrogen concentrations at particle-matrix interfaces cause weakening of interatomic bonds. Thus, by increment of load during tensile test, the associated incremental opening of the soluble particle/matrix interface takes place. The interfacial amount of hydrogen increases continuously by the transport effect of dislocations which drive hydrogen from the environment to these areas during tensile test. The higher amount of trapped hydrogen can accelerate decohesion and separation of soluble particles from the matrix by weakening of the interatomic bonds, thus leading to failure at lower strains. It is well known that hydrogen-induced cracks in age- hardened Al alloys are nucleated at grain boundaries. However, the current studies showed that the accumulation of hydrogen and crack initiation at soluble particles are also possible.

Smart Light Bridge Monitoring

I. Poy, S. Arroniz

ipoy@grupoalava.com

Grupo Alava, Albasanz 16, 28035 Madrid, Spain

Structural health Monitoring *Bridge maintenance* *Operational Modal Analysis*

Abstract The current technological developments and the application of algorithms allow an intelligent and cost-effective bridges monitoring. Bridges pool in Europe are approaching their end of useful life and tools are needed to help decision-making during its maintenance and operation.

The new understanding of bridge monitoring is based on two fundamental aspects:

– -A new strategy of data treatment
– -Cost-effective, autonomous and easy-to-install sensors

The strategy to analyze structure monitoring data should be based on a dynamic structure characterization. This will subsequently become a model / reference to which compare monitoring data collated during use/life of the structure.

At the same time bridge monitoring should be based on similar dynamic parameters of automatic processing which must be easy for the manager to evaluate. With static parameters in order to confirm hypotheses.

If we want to see a widespread use of structural monitoring, it is important that expenses associated with the installation and purchase of the sensors as cost-effective as possible. Wireless technologies based on LORA communication systems greatly simplify significatively this aspect and make it possible for the democratization of bridge monitoring.

The role of hydrogen in the corrosion-induced reduction of plane-stress fracture toughness and strain-induced intergranular cracking of AA2024

C.C.E. Pretorius[1], R.J. Mostert[1], C-M. Charalampidou[2], N.D. Alexopoulos[2]

[1]*University of Pretoria, Department of Materials Science and Metallurgical Engineering, Lynnwood Road, Hatfield, Pretoria 0002, South Africa,*
cce.pretorius@gmail.com

[2]*Research Unit of Advanced Materials, Department of Financial Engineering, School of Engineering, University of the Aegean, 41 Kountouriotou str., 82132 Chios, Greece*

Hydrogen embrittlement *High-strength aluminum* *K_R-curves*

Abstract A reduction in plane-stress fracture toughness of the AA2024 alloy due to corrosion exposure and the associated manifestation of intergranular cracking have been reported before. In this work, the authors specifically focused on short-term exposure in the standard exfoliation corrosion test (EXCO test, ASTM G34) solution, and investigated the role of hydrogen on the embrittlement. In addition, the link between hydrogen and the formation of intergranular secondary surface cracks during plastic straining, as well as the influence of the secondary crack formation on the fracture toughness reduction, were investigated.

Slow strain rate K_R-curves were established utilizing the unloading compliance method as described in the ASTM E561 standard on 3.2 mm thick C(T) specimens. Four sets of samples were tested: **(i)** as-received (unexposed) samples, **(ii)** 2 h EXCO exposed samples, **(iii)** unexposed and heat-treated samples, and **(iv)** 2 h EXCO exposed and heat-treated samples. The heat treatments comprised of a solution heat treatment (520ºC for 2h), followed by an ageing heat-treatment (170 ºC for 48 h). The formation of secondary and primary intergranular cracks in the plastic zone of the C(T) samples, were studied using SEM. Thermal desorption mass spectroscopy, in which diffusible hydrogen was analyzed for the unexposed, 2 h EXCO exposed and heat treated material conditions, was utilized to evaluate the extent of hydrogen absorption due to the corrosive exposure, and the effect of subsequent heat treatment to remove it.

It was hypothesized that, if corrosion-induced hydrogen embrittlement were the cause of the fracture toughness degradation and the formation of the intergranular cracking in the plastic zone, that heat-treatment would be able to reverse the two behaviors by removing the absorbed hydrogen through diffusion.

A significant degradation was observed in the effective slow-strain K_C toughness, determined from K_R-curves, after short-term exposure of the AA2024-T3 specimens to the EXCO solution. Post-exposure heat-treatments appear to have restored the plane-stress fracture toughness to its original values, indicating that the degradation in the crack growth resistance behaviour was caused by corrosion-induced (diffusible) hydrogen embrittlement rather than by the secondary cracking.

The presence of intergranular secondary surface cracks in the plastic zones of the C(T) samples was however not altered by the heat treatment, indicating that this cracking was not a result of the presence of diffusible hydrogen after short-term EXCO exposure. The secondary cracking, per se, furthermore did not influence the fracture toughness results. Alternate theories for the cause of the secondary cracking were proposed.

In-service failure of mechanically galvanized low alloy steel bolts of three 25,000 m3 bolted water tanks

Henrique Boschetti Pereira[1], Rafael Rocha Maia[1,2], Jiahao Shen[3], Qi Tong[3], Cesar Roberto de Farias Azevedo[1], André Paulo Tschiptschin[1]

[1]*Department of Metallurgical and Materials Engineering, University of São Paulo, São Paulo, Brazil,*
c.azevedo@usp.br

[2]*Department of Production Engineering, Faculdade de Tecnologia de São Paulo, FATEC, São Paulo, São Paulo, Brazil*

[3]*Department of Aeronautics and Astronautics, Fudan University, Shanghai, China*

Corrosion *Low alloy steel* *bolted joints*

Abstract Several single-lap bolted joints fastening the steel plates of three 25,000 m3 water tanks showed premature failure. Most fractured bolts were in the lower sector of the tanks. The tempered martensitic steel bolts were mechanically galvanised, and the poor quality of the galvanisation allowed the corroding agents (Cl− and SO4−2) to percolate through the Zn and Sn coating particles, finally reaching the steel surface of the bolts. Additionally, multiple 6 m deep intergranular pre-cracks were observed at the threads' roots of the new bolts.

During service, these pre-cracks accumulated the corrosive agents, creating numerous 10 m-deep corrosion pits, nucleating the bolts' environmentally assisted cracks. Microfractographic examination of the bolts featured stable growth of brittle cracks (intergranular and quasi-cleavage cracking) followed by mixed-mode cracking and a small region of ductile overload fracture. This failure sequence confirms that the fracture mechanism of the low alloy steel bolts is due to environmentally assisted cracking.

Finite elements analysis investigated the effect of the bolt diameter, bolted joint design and pre-load force on the tensile stress distribution. Improvements in the bolts' quality control and bolted joint design were discussed to prevent new failures.

Roadmaps to Sustainable Civil Engineering Infrastructure through Structural Health Monitoring

s.e.taylor@qub.ac.uk

Su Taylor[1], Kun Feng[1], Masoud Pedram[1], David Hester[1] and Myra Lydon[2]

[1]*Queen's University Belfast, UK*

[2]*University of Galway, Ireland*

Structural Health Monitoring *Vehicle Bridge Interaction* *Damage Detection*

Abstract The structural integrity of key civil engineering infrastructure, such as bridges, is a global strategic requirement. Projected spend on deficient UK civil engineering infrastructure is £600B and the challenges will intensify as climate change necessitates a net-zero carbon (NZC) future. As we move towards NZC, understanding the impact of loading has on our infrastructure is of key importance. Public transport offers particular opportunities for added value of structural health monitoring. By stimulating a digital transformation in the monitoring, processing and analysis of information about our infrastructure, we can predict how it will perform under changing vehicle loads, cycles of loading and environmental factors, and move towards Smart Infrastructure. The cost of repairing faults as they approach criticality is enormous, but if damage is prevented at an early stage, alongside accurate risk modelling, earlier interventions can be made. This SHM research used UNIX time stamp at microsecond accuracy applied to multiple vision sensors for bridge damage detection demonstrating synchronisation of multiple and different sensor types. However, a challenge is the requirement for a continuous power supply to structural health monitoring (SHM) systems.

Drive-by and fly-by systems can negate this, and the bus sector offers an interesting test case, with regular routes enabling continuous monitoring of critical infrastructure components. A drive-by inspection system can be capable of capturing damage by detecting changes in the mechanical properties. The proposed system uses computer vision (stereo and IRT) and acceleration measurements while a vehicle is traversing roads and bridges. The acceleration data can detect changes in frequencies. However, the detection of localised flaws is more challenging, further complicated by the dynamic response of the vehicle itself under highly variable loading conditions. Hence, bridge frequencies are isolated by implemented vehicular transfer functions from the measured bus accelerations for bridge condition assessment. Compared to conventional fleet monitoring, the bus network-based approach is proved to be more efficient because most of the mechanical properties of buses are identical, which further contributes more benefits in bridge information extraction. The proposed bus network-based fleet monitoring of drive-by SHM is validated with laboratory experiments of a scaled highway bridge. Further research using CV and IRT is also able to detect sub-surface damage in concrete structures and scour depths at bridge foundations under pressurised river flow.

Effect of post-production heat treatment on SLM-produced AlSi10Mg components tested at high strain rates

G.P. Cipriano[1], G. Monteiro[2], D.F.O. Braga[1], H. Lopes[2], J. Jesus[3], L.P. Borrego[3], P.M.G. Moreira[1]

[1]INEGI, Rua Dr. Roberto Frias 400, 4200-465 Porto, Portugal

gcipriano@inegi.up.pt

[2]Department of Mechanical Engineering, ISEP, Instituto Politécnico do Porto, Rua Dr. António Bernardino de Almeida 431, 4249-015 Porto, Portugal

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

High Strain Rate *Selective Laser Melting* *Digital Image Correlation*

Abstract The effect a post-production heat treatment has on the mechanical performance of specimens produced by selective laser melting, from an aluminium alloy powder (AlSi10Mg), was investigated in this work. The specimens were tested, as produced, at high strain rates using a Split-Hopkinson pressure bar setup. The localized failures were assessed by applying digital image correlation to the instances recorded during testing. Significant differences were observed between the three distinct build directions studied. Moreover, the results observed evidenced distinct levels of variability within each build detection and the effect the heat treatment applied influenced the performance of those specimens.

Acknowledgements

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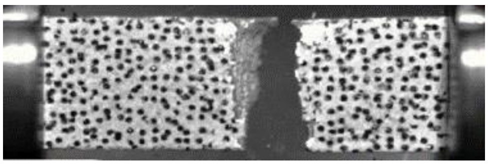

Figure 1 *– Failure after tensile testing at high strain rate of specimen built in the vertical direction*

Experimental characterization of apple skin

Rafael Araújo[1], Fábio Pereira[1], José Xavier[2,3], Nuno Dourado[4], José Morais[1]

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

famp@utad.pt

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

[3] *LASI, Intelligent Systems Associate Laboratory, 4800-058 Guimarães, Portugal*

[4] *CMEMS-UMINHO, Universidade do Minho, Guimarães, 4800-058, Portugal*

Apple skin Mechanical behaviour Hyper viscoelastic

Abstract In this work, monotonic and cyclic tensile tests were performed on apple peel specimens from three apple cultivars: Golden, Reineta, and Starking. These tests were carried out in two anatomical directions under displacement control. A comparison was made between the behaviour of the apple skin in puncture tests, commonly used to characterize biological fields, and tensile tests. This approach allowed for establishing a correlation between the mechanical parameters obtained from the puncture test and the mechanical properties resulting from the tensile test.

The digital image correlation technique (DIC) was employed to measure the displacement field during the monotonic tests, allowing the identification of the elastic modulus and Poisson ratio. The results from both cyclic and monotonic tests indicated that the material exhibited an isotropic hyper-viscoelastic behaviour, with noticeable material heterogeneity at the specimen scale. Inverse methods were utilized to identify appropriate constitutive models for the numerical analysis of this material.

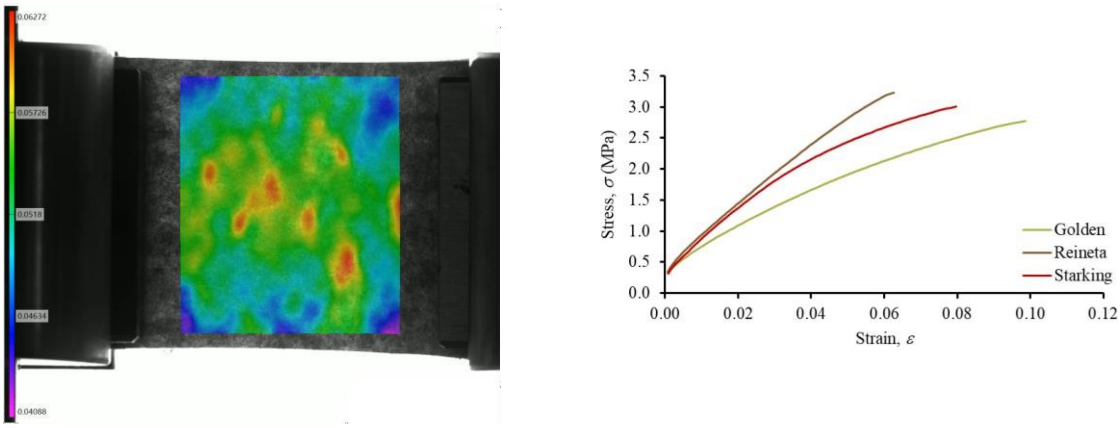

Figure 1 – (a) *Strain field* (b) *Average stress-strain curves by cultivar.*

Probabilistic Fatigue Resistance Curves for Structural Steel Based on Dislocation Density

António M. Mourão[1*], Iara G. Oliveira[1,2], J.A.F.O. Correia[1], Túlio Bittencourt[3], Rui Calçada[1]

amourao@fe.up.pt

[1]CONSTRUCT, Faculty of Engineering, University of Porto, Portugal

[2]Federal Fluminense University, Rio de Janeiro, Brasil

[3]Polytechnic School, University of São Paulo, São Paulo, Brasil

Fatigue *Structural Steel* *Dislocation density* *Monte Carlo*

Abstract Albeit subject of study for over century, continued deterioration of the material’s properties attributed to fatigue continues to pose a hurdle pertaining to a structure/component operational service life. Fatigue resistance curves constitute an important tool to gauge the performance of a structural component under cyclical load conditions when aiming to design and/or estimate the remaining life. Despite being advocated in standards and recommended practices, these fatigue resistance curves are frequently associated with global fatigue approaches that tend to be insensitive to both the geometry of complex components along with the material's properties throughout the detail. Local fatigue methodologies, on the other hand, provide an alternative for predicting the remaining life of a detail by taking into consideration the localized stress-strain fields alongside the material's cyclic elasto-plastic properties. A local approach based on the material's dislocation density is put forward in this study in order to obtain the fatigue resistance curves and associated probabilistic scatter bands for a structural steel (St52) used in the Trezoi bridge, that exhibits an identical composition and microstructure to current S355 steel. The fatigue resistance curves were derived using the Huffman damage model, which ties together the dislocation strain-energy density to the fatigue damage parameter. A Monte Carlo simulation was implemented to generate the probabilistic bands, whereby taking into consideration the variability of the material's features. The results showed that the proposed approach is capable of providing accurate and reliable forecasts of structural steel fatigue life and fatigue limit compared to global approaches.

Acknowledgements

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Investigating the use of CFRP retrofitting techniques to extend the lifespan of existing metallic railway bridges

João Arrojado[1*], Anis Mohabeddine[2], José A. F. O. Correia[1], Diogo Ribeiro[3], Anna Rakoczy[4]
up201606508@fe.up.pt

[1]CONSTRUCT, Faculty of Engineering, University of Porto, Portugal, Rua Dr. Roberto Frias, 4200-465, Porto

[2]Faculty of Civil Engineering and Geosciences, Delft University of Technology, Netherlands

[3]CONSTRUCT, School of Engineering, Polytechnic of Porto, Portugal

[4]Institute of Roads and Bridges, Department of Civil Engineering, Warsaw University of Technology, Poland

Metallic bridges *Retrofitting* *CFRP*

Abstract Fatigue damage is a critical cause of structural collapse on old metallic bridges. The need to ensure the safety, efficiency, and environmental friendliness of freight transport and people's mobility has become a top priority for the European Union. Due to economic factors, existing bridges may require the extension of their operational life. To achieve this, it is essential to thoroughly characterize the monotonic and fatigue behavior of structural elements, both bare and reinforced with CFRP retrofitting techniques, to use in existing metallic railway bridges in the national and European contexts. In this study, elements representative of the Luiz I Bridge were subjected to preliminary experimental and numerical studies. The findings and data obtained from these studies demonstrate a marked improvement in both the static resistance and fatigue performance of the studied details with CFRP reinforcement. Therefore, the remaining lifespan of the reinforced bridges can be extended. The results of this study have important implications for the design and rehabilitation of metallic railway bridges. The use of CFRP reinforcement can significantly improve the fatigue performance of bridges, extending their operational life and reducing the risk of structural collapse.

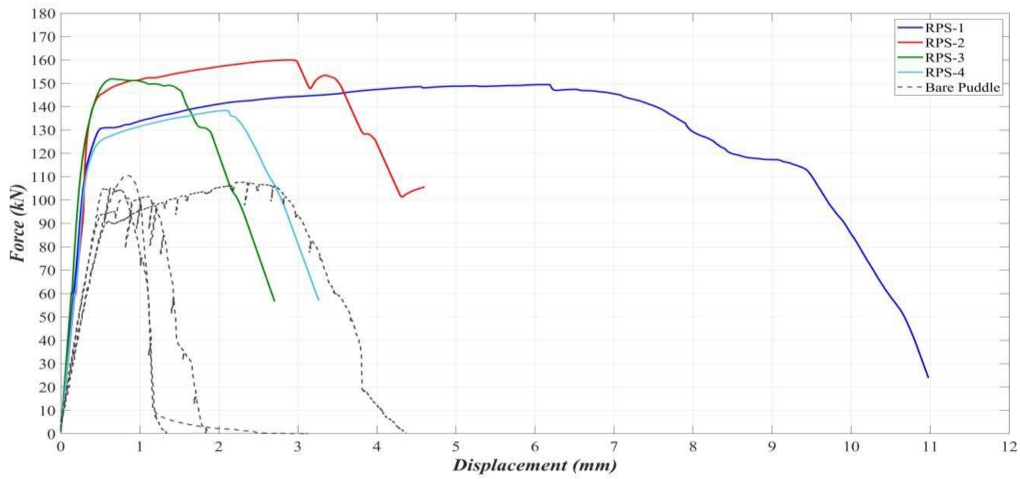

***Figure 1** – comparison between bare and reinforced specimens under tensile static loading*

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Probabilistic Fatigue Analysis of Riveted Bridge Connections: Evaluating the Effect of Fatigue Accumulation Rules

João Nuno Silva, António Mourão, Cláudio Horas, J.A.F.O. Correia, Rui Calçada

up201705111@fe.up.pt

[1]*CONSTRUCT, Faculty of Engineering, University of Porto, Portugal, Rua Dr. Roberto Frias, 4200-465, Porto*

Riveted Connections *Probabilistic Modelling* *Fatigue Accumulation*

Abstract Fatigue is a critical phenomenon in engineering, particularly in the context of bridges, and has been a major factor in recent collapses attributed to neglect, inadequate maintenance strategies, increased traffic demands, and exposure to environmental factors. Throughout Europe, some 200 000 metal bridges have been identified to be at risk, a figure which pales in comparison to the threefold increase in the United States. Consequently, accurate and reliable fatigue assessments are essential. Therefore, accurate and reliable fatigue assessments are crucial. Several models can be implemented to determine fatigue life; however the reliability of these methodologies depends not only on the concentration of stress/strain, multiaxiality, size effects, but also on the model's ability to understand the behavior of the joints under multiple levels of loading. As such, this work focuses on the compound effect of the chosen probabilistic analysis, used to derive design fatigue strength curves for metallic riveted bridge connections as well as the fatigue accumulation rules used to compute the structure's fatigue performance. Multiple probabilistic methodologies were employed, including the standardized approach (ISO12107), the probabilistic method based on the two-parameter Weibull probability density function, all of whom fitted using classic and total least squares methods. Additionally, the Castillo and Fernández-Canteli based on the three-parameter Weibull distribution as well as the Markov-Chain Monte Carlo were used. Finally, both linear and non-linear damage accumulation rules, namely the Sequential Law and Huffman models were taken into consideration, the latter of which took into account the effects of loading sequence.

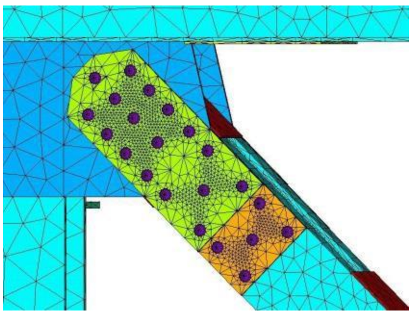

Figure 1 *– Critical riveted connection sub-model.*

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Promoting multiscale fatigue to design reliable and sustainable structures

José A.F.O. Correia[1]

[1]INEGI & CONSTRUCT, Faculty of Engineering, University of Porto, Rua Dr. Roberto Frias, Campus FEUP, 4200-465 Porto, Portugal and jacorreia@fe.up.pt

Fatigue phenomenon *Scale of physics* *Components and structures*

Abstract This document presents the experience of the author in experimental research, numerical modelling and in the development of models related to the characterization of the fatigue behaviour of metallic materials, from the material-detail to the detail-structure, where advances have been made in fatigue characterization of materials for various physical scales ranging from the micro-scale to the macro-scale.

In structural fatigue design, due to time and cost considerations, as well as constraints on test equipment, the assessment of the fatigue behaviour of structural components and large-scale engineering structures is often derived from the mechanical properties of normalised small-scale specimens. Therefore, probabilistic approaches and modelling at various physical scales must be used to overcome this problem and establish practical solutions to analyse the obtained data.

Design code approaches generally derive a predicted structural component life from the average lives of the most stressed points on the component, plus safety factors that account for dispersion bands, size effects, stress field uncertainties, and different environments. However, this method may not be accurate enough, which may result in designs that are too conservative or too optimistic.

Currently, achieving the transformation between the fatigue properties of small-scale samples for the strength of structural components through modelling at various physical scales, taking into account the loading effects, environmental effects, and probabilistic analysis, become an increasingly urgent task in fatigue design to make structures reliable and sustainable.

For these reasons, the keynote begins with the experience of the author in the characterization of the fatigue behaviour of metallic materials, more specifically, the experimental characterization and modelling of the fatigue resistance, followed by the experimental characterization and modelling of the fatigue crack propagation, but also, the development of probabilistic fatigue models. The second topic, to be addressed in this keynote, to be presented by the author, addresses the characterization of the fatigue behaviour of structural components and connections, where the themes are addressed in the following order: - integrated fatigue approach applied to structural components; - modelling of fatigue behaviour based on fracture mechanics; - experimental characterization and modelling of the behaviour of structural connections; and, - probabilistic fatigue modelling of structural components and connections. Finally, in the third and last topic, the fatigue damage assessment of components and engineering structures, the author addresses the themes in the following order: - linear and non-linear fatigue damage assessment; - riveted and bolted metallic bridges; - welded bridges; and, - wind towers and offshore platforms. Additionally, two technical-scientific works, related to the fatigue damage assessment of engineering structures (e.g. riveted bridge, welded bridge), requested by a government entity and a structural engineering consultant, are presented.

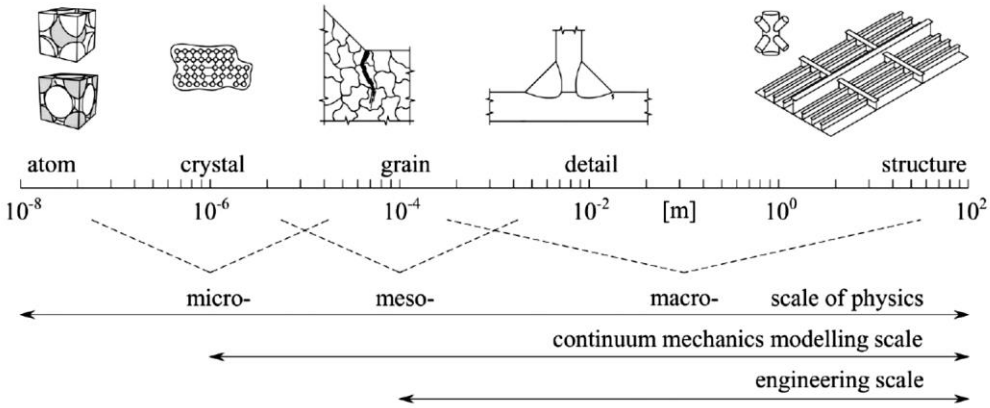

***Figure 1** – Fatigue physics in a range of scales*

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References

[1] José A.F.O. Correia, P. Raposo, M. Calvente, S. Blasón, G. Lesiuk, A.M.P. De Jesus, P.M.G.P. Moreira, R.A.B. Calçada, A. Fernández-Canteli, "A generalization of the fatigue Kohout-Věchet model for several fatigue damage parameters". Engineering Fracture Mechanics, Volume 185, 2017, Pages 284-300. {http://dx.doi.org/10.1016/j.engfracmech.2017.06.009}

[2] Joelton Fonseca Barbosa, José A.F.O. Correia, R.C.S. Freire Júnior, Abílio M.P. De Jesus, "Fatigue life prediction of metallic materials considering mean stress effects by means of an artificial neural network", International Journal of Fatigue, 2020, vol. 135, 105527. {https://doi.org/10.1016/j.ijfatigue.2020.105527}

[3] Ribeiro, V., Correia, J., Mourão, A., Lesiuk, G., Gonçalves, A., De Jesus, A. & Berto, F. 2021, "Low-cycle fatigue modelling supported by strain energy density-based Huffman model considering the variability of dislocation density", Engineering Failure Analysis, vol. 128, 105608. {https://doi.org/10.1016/j.engfailanal.2021.105608}

[4] Rita Dantas, José A.F.O. Correia, Grzegorz Lesiuk, Dariusz Rozumek, Abílio M. P. de Jesus, Shun-Peng Zhu, Luca Susmel, Filippo Berto, "Evaluation of multiaxial high-cycle fatigue criteria under proportional loading for S355 steel". Engineering Failure Analysis, 2021 vol. 120, 105037.

{https://doi.org/10.1016/j.engfailanal.2020.105037}
[5] G. Lesiuk, J.A.F.O. Correia, M. Duda, J. Rabiega, A.M.P. De Jesus, M. Katkowski, "Fatigue crack growth rate in CFRP reinforced constructional old steel". International Journal of Structural Integrity, vol. 9 (3), 2018, pages 381-395. {https://doi.org/10.1108/IJSI-10-2017-0050}
[6] G. Lesiuk, José A.F.O. Correia, M. Smolnicki, Abílio M.P. De Jesus, M. Duda, P. Montenegro, R.A.B. Calcada, "Fatigue Crack Growth Rate of the Long Term Operated Puddle Iron from Eiffel Bridge". Metals (MDPI), 2019, 9(1), 53, 13 pages. {https://doi.org/10.3390/met9010053}
[7] José A.F.O. Correia, Abílio M.P. de Jesus, Hermes Carvalho, Grzegorz Lesiuk, António Mourão, Lucas F. Grilo, Rui A.B. Calçada, "Fatigue crack growth modelling of Fão Bridge puddle iron under variable amplitude loading", International Journal of Fatigue, 2020, vol. 136, 105588. {https://doi.org/10.1016/j.ijfatigue.2020.105588}
[8] Anis Mohabeddine, José A.F.O. Correia, Pedro Aires Montenegro, José Miguel Castro, "Fatigue crack growth modelling for cracked small scale structural details repaired with CFRP", Thin-Walled Structures, 2021, vol. 161, 107525. {https://doi.org/10.1016/j.tws.2021.107525}
[9] José A.F.O. Correia, Sergio Blasón, Attilio Arcari, M. Muñiz-Calvente, Nicole Apetre, Pedro M.G.P. Moreira, Abílio M.P. De Jesus, Alfonso Fernández-Canteli, "Modified CCS fatigue crack growth model for the AA2019-T851 based on plasticity-induced crack closure". Theoretical and Applied Fracture Mechanics, Volume 85, Part A, October 2016, Pages 26–36. {http://dx.doi.org/10.1016/j.tafmec.2016.08.024}
[10] José A.F.O. Correia, Abílio M.P. De Jesus, Pedro M.G.P. Moreira, Paulo J.S. Tavares, "Crack closure effects on fatigue crack propagation rates: application of a proposed theoretical model". Advances in Materials Science and Engineering, vol. 2016, Article ID 3026745, 11 pages, 2016. {http://dx.doi.org/10.1155/2016/3026745}
[11] Victor Hugo Ribeiro, José Correia, Grzegorz Lesiuk, Aparecido Gonçalves, Abílio De Jesus, Filippo Berto, "Application and discussion of various crack closure models to predict fatigue crack growth in 6061-T651 aluminium alloy", International Journal of Fatigue, 2021, vol. 153, 106472. {https://doi.org/10.1016/j.ijfatigue.2021.106472}
[12] Haohui Xin, José A.F.O. Correia, Milan Veljkovic, "Three-dimensional Fatigue Crack Propagation Simulation Using Extended Finite Element Methods for Steel Grades S355 and S690 Considering Mean Stress Effects", Engineering Structures, 2021, vol. 227, 111414. {https://doi.org/10.1016/j.engstruct.2020.111414}
[13] Ribeiro, V., Correia, J., Mourão, A., Lesiuk, G., Gonçalves, A., De Jesus, A., & Berto, F. (2022). Fatigue crack growth modelling by means of the strain energy density-based Huffman model considering the residual stress effect. Engineering Failure Analysis, 140, 106543. {https://doi.org/10.1016/j.engfailanal.2022.106543}
[14] Pedrosa, B., Correia, J., Lesiuk, G., Rebelo, C., & Veljkovic, M. (2022). Fatigue crack growth modelling for S355 structural steel considering plasticity-induced crack-closure by means of UniGrow model. International Journal of Fatigue, 164, 107120. {https://doi.org/10.1016/j.ijfatigue.2022.107120}
[15] José A.F.O. Correia, Nicole Apetre, Attilio Arcari, Abílio M.P. De Jesus, Miguel Muñiz-Calvente, Rui Calçada, Filippo Berto, Alfonso Fernández-Canteli, "Generalized probabilistic model allowing for various fatigue damage variables". International Journal of Fatigue, Volume 100, Part 1, (2017), Pages 187-194. {http://doi.org/10.1016/j.ijfatigue.2017.03.031}
[16] Joelton F. Barbosa, José A.F.O. Correia, R.C.S. Freire Júnior, Shun-Peng Zhu, Abıílio M.P. De Jesus, "Probabilistic S-N fields based on statistical distributions applied to metallic and composite materials: State of the art", Advances in Mechanical Engineering, 2019, Vol. 11(8), pp. 1–22. {https://doi.org/10.1177/1687814019870395}
[17] J.A.F.O. Correia, P. Huffman, A.M.P. De Jesus, G. Lesiuk, J.M. Castro, R. Calçada, F. Berto – "Probabilistic fatigue crack initiation and propagation fields using the strain energy density". Strength of Materials, Volume 50, Issue 4, 2018, Pages 620-635. {https://doi.org/10.1007/s11223-018-0007-5}
[18] Haohui Xin, José A.F.O. Correia, Milan Veljkovic, Youyou Zhang, Filippo Berto, Abílio M.P. de Jesus, "Probabilistic strain-fatigue life performance based on stochastic analysis of structural and WAAM-stainless steels", Engineering Failure Analysis, 2021, vol. 127, 105495. {https://doi.org/10.1016/j.engfailanal.2021.105495}
[19] Fernández Canteli, A., Castillo, E., Blasón, S., Correia, J.A.F.O., & de Jesus, A.M.P. (2022). Generalization of the weibull probabilistic compatible model to assess fatigue data into three domains: LCF, HCF and VHCF. International Journal of Fatigue, 159, 106771. {https://doi.org/10.1016/j.ijfatigue.2022.106771}

[20] J.A.F.O. Correia, P. Huffman, A.M.P. De Jesus, S. Cicero, A. Fernández-Canteli, F. Berto, G. Glinka – "Unified two-stage fatigue methodology based on a probabilistic damage model applied to structural details". Theoretical and Applied Fracture Mechanics, vol. 92, 2017, pages 252-265. {https://doi.org/10.1016/j.tafmec.2017.09.004}
[21] P. Raposo, J.A.F.O. Correia, A.M.P. De Jesus, R.A.B. Calçada, G. Lesiuk, M. Hebdon, A. Fernández-Canteli, "Probabilistic fatigue S-N curves derivation for notched components". Frattura ed Integrita Strutturale, 42, (2017), pages 105-118. {https://doi.org/10.3221/IGF-ESIS.42.12}
[22] J.A.F.O. Correia, S. Blasón, A.M.P. De Jesus, A. Fernández-Canteli, P.M.G.P. Moreira, P.J.S. Tavares, "Fatigue life prediction based on an equivalent initial flaw size approach and a new normalized fatigue crack growth model". Engineering Failure Analysis, Volume 69, November 2016, Pages 15–28. {http://dx.doi.org/10.1016/j.engfailanal.2016.04.003}
[23] Bruno Pedrosa, José A.F.O. Correia, Carlos Rebelo, Grzegorz Lesiuk, Abílio M.P. De Jesus, António A. Fernandes, Rui Calçada, Milan Veljkovic, "Fatigue resistance curves for single and double shear riveted joints from old portuguese metallic bridges". Engineering Failure Analysis, Volume 96, 2019, Pages 255-273. {https://doi.org/10.1016/j.engfailanal.2018.10.009}
[24] A.L.L. Silva, José A.F.O. Correia, HaoHui Xin, Grzegorz Lesiuk, Abílio M. P. de Jesus, A.A. Fernandes, Filippo Berto, "Fatigue strength assessment of riveted details in railway metallic bridges". Engineering Failure Analysis, 2021, vol. 121, 105120. {https://doi.org/10.1016/j.engfailanal.2020.105120}
[25] Bruno Pedrosa, José A.F.O. Correia, Carlos Rebelo, Milan Veljkovic, Helena Gervásio, "Fatigue experimental characterization of preloaded injection bolts in a metallic bridge strengthening scenario", Engineering Structures, 2021, vol. 234, 112005. {https://doi.org/10.1016/j.engstruct.2021.112005}
[26] José A.F.O. Correia, Abílio M.P. De Jesus, A.L.L. Silva, B. Pedrosa, Carlos Rebelo, Rui Calçada, "FE simulation of S-N curves for a riveted connection using two-stage fatigue models". Advances in Computational Design, an International Journal, vol. 2 (4), 2017, pages 333-348. {https://doi.org/ 10.12989/acd.2017.2.4.333}
[27] A.L.L. da Silva, José A.F.O. Correia, Abílio M.P. de Jesus, M.A.V. Figueiredo, B. Pedrosa, A.A. Fernandes, C. Rebelo, Filippo Berto, "Fatigue characterization of a beam-to-column riveted joint". Engineering Failure Analysis, Volume 103, 2019, Pages 95-123. {https://doi.org/10.1016/j.engfailanal.2019.04.073}
[28] António L.L. da Silva, José A.F.O. Correia, Abílio M.P. de Jesus, Grzegorz Lesiuk, António A. Fernandes, Rui Calçada, Filippo Berto, "Influence of fillet end geometry on fatigue behaviour of welded joints". International Journal of Fatigue, 2019 Volume 123, June 2019, Pages 196-212. {https://doi.org/10.1016/j.ijfatigue.2019.02.025}
[29] Mohabeddine, A., Correia, J., Montenegro, P.A., De Jesus, A., Castro, J.M., Calçada, R., & Berto, F. (2022). An approach for predicting fatigue life of CFRP retrofitted metallic structural details. International Journal of Fatigue, 154, 106557. {https://doi.org/10.1016/j.ijfatigue.2021.106557}
[30] José A.F.O. Correia, B. Pedrosa, P. Raposo, A.M.P. De Jesus, H. Gervásio, G. Lesiuk, C. Rebelo, R.A.B. Calçada, L. Simões da Silva, "Fatigue strength evaluation of resin-injected bolted connections using statistical analysis". Engineering, Research Bridge Engineering, vol. 3 (6), 2017, Pages 795-805. {https://doi.org/10.1016/j.eng.2017.12.001}.
[31] B. Pedrosa, J.A.F.O. Correia, C. Rebelo, M. Veljkovic, "Reliability of Fatigue Strength Curves for Riveted Connections Using Normal and Weibull Distribution Functions". ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering, 2020, 6(3), 4020034. {https://doi.org/10.1061/AJRUA6.0001081}
[32] Anis Mohabeddine, José A.F.O. Correia, Pedro Aires Montenegro, Abílio De Jesus, José Miguel Castro, Filippo Berto, "Probabilistic S-N curves for CFRP retrofitted steel details", International Journal of Fatigue, 2021, vol. 148, 106205. {https://doi.org/10.1016/j.ijfatigue.2021.106205}
[33] Correia, J., Mourão, A., Xin, H., De Jesus, A., Bittencourt, T., Calçada, R., & Berto, F. (2023). Fatigue strength assessment of riveted railway bridge details based on regression analyses combined with probabilistic models. Journal of Materials Research and Technology, 23, 3257-3271. {https://doi.org/10.1016/j.jmrt.2023.01.193}
[34] José A.F.O. Correia, António L.L. da Silva, Haohui Xin, Grzegorz Lesiuk, Shun-Peng Zhu, Abílio M.P. de Jesus, António A. Fernandes, "Fatigue Performance Prediction of S235 Base Steel Plates in the Riveted Connections". Structures, 2021, vol. 30, 745-755. {https://doi.org/10.1016/j.istruc.2020.11.082}
[35] S. Balsón, J.A.F.O. Correia, A.M.P. De Jesus, A. Fernandez-Canteli, R.A.B. Calçada, "A probabilistic analysis of Miner's law for different loading conditions". Structural Engineering and Mechanics, An

International Journal, Vol. 60, No. 1, 71-90, 2016. {http://dx.doi.org/10.12989/sem.2016.60.1.071}
[36] José A.F.O. Correia, Abílio M. P. de Jesus, S. Blasón, Miguel Calvente, A. Fernández-Canteli – "Probabilistic nonlinear cumulative fatigue damage of the P355NL1 pressure vessel steel". ASME 2016 Pressure Vessels & Piping Conference (PVP2016), Vancouver, British Columbia, Canada, July 17–21, 2016; Pressure Vessels and Piping Division, Volume 6A: Materials and Fabrication, Paper No. PVP2016-63920, pp. V06AT06A034; 8 pages. {https://doi.org/10.1115/PVP2016-63920}
[37] Shun-Peng Zhu, Yong-Zhen Hao, José Correia, Grzegorz Lesiuk, Abílio M.P. de Jesus, "Nonlinear fatigue damage accumulation of P355NL1 steel: A comparative study". Fatigue and Fracture of Engineering Materials and Structures, 2019, 42(6), Pages 1271-1282. {https://doi.org/10.1111/ffe.12937}
[38] Zhongxiang Liu, M.H. Hebdon, J.A.F.O. Correia, H. Carvalho, P.M.L. Vilela, A.M.P. De Jesus, R.A.B. Calçada, "Fatigue assessment of critical connections in a historic eye-bar suspension bridge". Journal of Performance of Constructed Facilities - ASCE, Volume 33, Issue 1, 2019, Article number 04018091. {https://doi.org/10.1061/(ASCE)CF.1943-5509.0001236}
[39] Zhongxiang Liu, José Correia, Hermes de Carvalho, Patrícia Raposo, Abílio de Jesus, Rui Calçada, Filippo Berto, "Global-local fatigue assessment of an ancient riveted metallic bridge based on sub-modelling of the critical detail". Fatigue and Fracture of Engineering Materials and Structures, 2019; 42: 546–560. {https://doi.org/10.1111/ffe.12930}
[40] Abílio M.P. de Jesus, Cláudio S. Horas, José A.F.O. Correia, Pedro A. Montenegro, Rui A.B. Calçada, Metodologia de Avaliação da Vida Útil Remanescente em Pontes Ferroviárias - Parte 1: Definição da Metodologia, Faculdade de Engenharia da Universidade do Porto, 77 páginas. (in Portuguese)
[41] Abílio M.P. de Jesus, Cláudio S. Horas, José A.F.O. Correia, Pedro A. Montenegro, Rui A.B. Calçada, Metodologia de Avaliação da Vida Útil Remanescente em Pontes Ferroviárias - Parte 2: Exemplo de Cálculo, Faculdade de Engenharia da Universidade do Porto, 122 páginas.
[42] Cristiane Viana, Hermes Carvalho, José A.F.O. Correia, Pedro Montenegro, Raphael Heleno, Guilherme Alencar, Abílio M.P. Jesus, Rui Calçada, "Fatigue assessment based on hot-spot stresses obtained from the global dynamic analysis and local static sub-model", International Journal of Structural Integrity, 2021, 12(1), 31-47. {https://doi.org/10.1108/IJSI-03-2019-0021}
[43] Bruno Pedrosa, António Mourão, Rita Dantas, José A.F.O. Correia, Ponte rodoferroviária sobre o rio Tocantins: Avaliação à Fadiga, Faculdade de Engenharia da Universidade do Porto & Instituto da Construção, 93 páginas. (in Portuguese)
[44] Muhammad Farhan, Mohammad Reza Shah Mohammadi, José A.F.O. Correia, Carlos Rebelo, "Transition Piece Design for an Onshore Hybrid Wind Turbine with Multi-Axial Fatigue Life Estimation". Wind Engineering, vol. 42 (4), 2018, pages 286-303. {https://doi.org/10.1177/0309524X18777322}
[45] P. Mendes, J.A.F.O. Correia, A. Mourão, R. Pereira, N. Fantuzzi, A.M.P. De Jesus, R. Calçada, "Fatigue Assessments of a Jacket-type Offshore Structure based on Static and Dynamic Analyses". Practice Periodical on Structural Design and Construction - ASCE, 2021, Vol. 26, Issue 1, 04020054. {https://doi.org/10.1061/(ASCE)SC.1943-5576.0000533}
[46] António Mourão, José A.F.O. Correia, Bianca V. Áliva, Camila C. Oliveira, Tiago Ferradosa, Hermes Carvalho, José M. Castro, Abílio M.P. De Jesus, "A fatigue damage evaluation using local damage parameters for an offshore structure". Maritime Engineering (ICE), 2020, 173 (2), pp. 43-57. {https://doi.org/10.1680/jmaen.2019.24}
[47] Heo, T., Liu, D.-P., Manuel, L., Correia, J.A.F.O., Mendes, P. (2023). Assessing Fatigue Damage in the Reuse of a Decommissioned Offshore Jacket Platform to Support a Wind Turbine. J. Offshore Mech. Arct. Eng. Aug 2023, 145(4): 042002 (8 pages). {https://doi.org/10.1115/1.4056943}
[48] Liao, D., Zhu, S.-., Correia, J.A.F.O., De Jesus, A.M.P., Veljkovic, M., & Berto, F. (2022). Fatigue reliability of wind turbines: Historical perspectives, recent developments and future prospects. Renewable Energy, 200, 724-742. {https://doi.org/10.1016/j.renene.2022.09.093}
[49] Haselibozchaloee, D., Correia, J., Mendes, P., de Jesus, A., & Berto, F. (2022). A review of fatigue damage assessment in offshore wind turbine support structure. International Journal of Fatigue, 164, 107145. {https://doi.org/10.1016/j.ijfatigue.2022.107145}