DCE23 5th DOCTORAL CONGRESS IN ENGINEERING

Book of Abstracts

DCE23 - Symposium on Mechanical Engineering

U.PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

DCE 23 5th DOCTORAL CONGRESS IN ENGINEERING

Book of Abstracts

of the

Symposium on Mechanical Engineering

Editors:
Armando Oliveira, António Carneiro, Francisca Alves,
João Marafona, Jorge Gil, Mariana Carvalho

Porto
June 2023

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This volume contains the peer reviewed and accepted abstracts, presented at the Symposium on Mechanical Engineering, of the 5th Doctoral Congress in Engineering – DCE23, held at FEUP-U.Porto, Porto, Portugal, between June 15th and 16th, 2023.

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WELCOME

Welcome

This book contains the texts supporting the oral and poster communications that constituted the program of the Symposium on Mechanical Engineering, held on the 15th and 16th of june, 2023, at the Faculty of Engineering, University of Porto, Portugal, as part of DCE23 – 5th Doctoral Congress in Engineering. DCE23 was an opportunity for PhD students, in several areas of engineering, to discuss their on-going research with peers. MSc and BSc students were also welcome to participate.

The Symposium on Mechanical Engineering accepted works in a wide range of areas covered by mechanical engineering. The topics addressed included: adhesive joints, automation and control, biomechanics, computational mechanics, dynamic analysis, energy systems, experimental mechanics, fluid mechanics, friction and tribology, industrial design, materials and manufacturing processes, and mechanics of composite materials.

We are very grateful to the invited speaker, authors, members of the scientific committee, session chairs and organizers of DCE23 for their contributions to the colloquium.

Porto, June 2023

Symposium Organizing Committee

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PROGRAMME

Symposium Programme – June 15th

11:30 - 12:30	**Plenary Session (auditorium)**	**Moderators: João Pedro Pêgo**
12:00 - 12:15	#30: Artificial intelligence and simulation-based techniques to predict pelvic floor stresses during childbirth **Rita Moura**	
15:00 - 16:20	**Parallel Symposia (room B012)**	**Moderators: Armando Oliveira Francisca Alves**
15:00 - 15:05	**Symposium opening**	
15:05 - 15:35	**Keynote lecture** Eng. Carlos Alberto Sousa Duarte Neves (Sevenforma, Ordem dos Engenheiros)	
15:35 - 15:50	#202: Simulation of a green hydrogen production plant using python programming **Francisco Machado**	
15:50 - 16:05	#245: Multi-scale approaches for particle-laden viscoelastic flow modelling **Vicente Silva**	
16:05 - 16:20	#247: Simulation of flow conditions for natural gas and hydrogen blends for different points of the distribution natural gas network **Leonardo Fernandes**	
16:30 - 17:00	**Coffee-break**	
17:00 - 18:00	**Parallel Symposia (room B012)**	**Moderators: Pedro Leal Ribeiro António Carneiro**
17:00 - 17:15	#37: Numerical analysis of the impact of interface modeling on the behavior of PC/ABS blends **Alexandre C. Amaro**	
17:15 - 17:30	#246: On the multiscale modeling of advanced discontinuous fiber reinforced composites **José C. Nascimento**	
17:30 - 17:45	#51: Meshless analysis of fracture propagation in DCB adhesive joints **D.C. Gonçalves**	
17:45 - 18:00	#88: Radial Point Interpolation Methods in a Structural Dynamic Analysis **Luís D.C. Ramalho**	

Symposium Programme – June 16th

09:00 - 10:30	Parallel Symposia (room B012)	Moderators:	João Ferreira Mariana Carvalho
09:00 - 09:15	#248: Prediction of surface properties from Atomic Force Microscopy nanoindentations using Neural Networks **Luís Pacheco**		
09:15 - 09:30	#261: Recurrent Neural Networks and Three Point Bending Test on the Identification of Material Hardening Parameters **Daniel J. Cruz**		
09:30 - 09:45	#126: Surrogate modelling of the constitutive behaviour of hyperelastic materials based on artificial neural networks **Eduardo Carvalho**		
09:45 - 10:00	#101: Correlating Mechanical Properties with Relative Density in Multiscale Modeling of Triply Periodic Minimal Surfaces **Ana Pais**		
10:00 - 10:15	#254: Structuring the Industrial Maintenance Operation according to the Model of Hierarchical Complexity **Gonçalo Raposo**		
10:15 - 10:30	#203: Crashworthiness topology optimisation of a crash box to improve passive safety during a frontal impact **Christian J. G. Silva**		

09:00 - 10:30	Parallel Symposia (room B016)	Moderators:	Eduardo Marques João Marafona
09:00 - 09:15	#160: A review of injection-mould materials and their conventional and non-conventional machining processes **F. R. Nogueira**		
09:15 - 09:30	#216: A review of INCONEL® alloy's non-conventional machining processes **F. R. Nogueira**		
09:30 - 09:45	#50: Coefficient of friction predictions using an adaptative limiting yield shear stress model **Pedro C. Romio**		
09:45 - 10:00	#53: Influence of rolling speed, temperature, surface roughness and slide-to-roll ratio on the friction in a circular contact **Maria João Cortez**		
10:00 - 10:15	#33: Experimental validation of Fused Filament Fabrication (FFF) extrusion simulations **Tomás Schuller**		
10:15 - 10:30	#144: Design for large scale additive manufacturing **Henrique Brito**		

10:30 - 11:00	**Coffee-break**	
11:00 - 13:00	**Parallel Symposia (room B012)**	**Moderators: Carolina Furtado Francisca Alves**
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11:15 - 11:30	#48: Experimental characterization of self-healing composite structures to low and high-velocity impact applications **A. F. V. Pedroso**	
11:30 - 11:45	#49: Low and high-velocity impact evaluation of self-regenerating sandwich structures by FEM **A. F. V. Pedroso**	
11:45 - 12:00	#96: Study of thermal-optical properties of composite materials to support a Digital Twin model of an ATL process **André Soares**	
12:00 - 12:15	#240: Study of Processing Variables Regarding the Impregnation of Carbon Fibres With PET **Mariana Gonçalves**	
12:15 - 12:30	#241: Manufacturing and testing of a novel thermoplastic composite material **Pedro J. Silva Campos**	
12:30 - 12:45	#138: Development of a unified specimen for adhesive characterisation: Numerical and experimental study on the mode I (mDCB) fracture component **D.S. Correia**	
12:45 - 13:00	#155: Study of hybrid composite joints with thin-ply reinforced adherends **F. Ramezani**	
13:00 - 14:30	**Lunch break & Poster Session**	**Moderators: Pedro Leal Ribeiro Jorge Wolfs**
	#41: Big Data Collection for the Development of a Hybrid Digital Twin Model in the Maintenance Field of Leaf Springs Applied in Freight Wagons **V.M.G. Gomes**	
	#134: Creep Damage Laws and Cohesive Zone Modelling of Composite Bonded Joints under Pure Mode I and II Loadings **R.F.M. Couto**	
	#249: Impact of water uptake and microbial degradation on the lifetime of biopolymer-matrix composites **Rui Barreira-Pinto**	
	#250: Multi-scale 3D vision using robotic assistant **Fábio Silva**	

KEYNOTE SPEAKER

Eng. Carlos Neves

President of the National College of Mechanical Engineering of the Order of Engineers

Topic: Engineering and Development – The ecosystem approach

ORAL COMMUNICATIONS

Artificial intelligence and simulation-based techniques to predict pelvic floor stresses during childbirth

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The second stage of labor is widely associated with obstetric trauma, leading to long-term consequences such as incontinence or pelvic organ prolapse (Doumouchtsis, 2016). Although a widely dis-cussed topic, childbirth trauma remains unpredictable. Computational models and the finite element method (FEM) are commonly used to address problems that cannot be studied *in vivo*. However, since the FEM can be computationally expensive, researchers in the biomechanical field have been resorting to machine learning (ML) algorithms to replace the simulations (Phellan *et al.* 2021). This work aims to use ML models to predict the stresses on the pelvic floor muscles (PFM) during vaginal delivery, using different material parameters to characterize the muscles.

A dataset was generated using data retrieved from 1715 finite element childbirth simulations, which were conducted with different material properties of the Martins constitutive model to characterize the PFM. A dataset was created in which each node of the pelvic floor corresponds to an observation, and a set of 46 nodes located in the inferior portion of the PFM were selected from each simulation. Features such as node number and position, initial coordinates, and material parameters were used for training. Four models, namely Random Forest (RF), Extreme Gradient Boosting (XGBT), Support Vector Regression (SVR), and Neural Networks (NN), were chosen (Phellan *et al.* 2021). A training and test set were created with a 90/10 split, ensuring that the feature distribution was the same in both sets. Subsequently, hyperparameter optimization with cross-validation was performed, and the models' performance was evaluated using the mean absolute error (MAE).

In the FEM simulations, the stresses of the PFM varied between 0 and 30 MPa. Therefore, ML models must predict values within this range. The results showed that the ANN produced the best outcomes with a MAE of 0.191, while the SVR model had the highest error with a MAE of 0.356. Both tree-based algorithms performed reasonably well and were closer to the outcomes achieved by the ANN. The current work represents an advancement in the field of computational simulations for childbirth using artificial intelligence tools. The ability to predict stresses on the pelvic floor could aid in medical decision-making and in the identification of non-visible injuries.

Keywords. Childbirth biomechanics, Finite element method, Machine learning, Pelvic floor injuries.

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Doumouchtsis, S. 2016. *Childbirth Trauma*. Springer.

Phellan *et al.*, 2021. «Real-time Biomechanics Using the Finite Element Method and Machine Learning: Review and Perspective». *Medical Physics* 48 (1): 7–18.

Acknowledgments

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Simulation of a green hydrogen production plant using python programming

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Given the need for decarbonization of the most varied sectors, increasing reference is made to the need for projects whose main objective is the production of green hydrogen. At a national level, for example, according to the National Strategy for Hydrogen (EN-H2), the aim is to have an installed capacity of electrolysis systems between 2 and 2.5 GW in Portugal by 2030 ("Resolução Do Conselho de Ministros n.º 63/2020" 2020). Internationally the prospects are no different, with green hydrogen production facilities such as Puertollano (20 MW) already in operation, or several projects in earlier stages that aim for GW scale powers. Since the electrolysis process has an efficiency of around 65% (Buttler and Spliethoff 2018), it is important to investigate how to maximize its value. One possibility is the use of the by-products generated, of which heat is one. Waste heat, despite being at low temperatures - between 50 °C and 70 °C, according to studies consulted - represents about 25% of an electrolyser's input energy (Danish Energy Agency and Energinet 2022). It is therefore important to understand the technical and economic viability of its use. Therefore, and given the identification of the lack of this kind of solutions, a tool was developed that could represent the operation of the plant itself - Balance of Plant - and, in this way, be able to help and speed up preliminary feasibility studies. Furthermore, the tool has the advantage of not being fixed to a single layout, being able to cover several different situations. Finally, it is relevant to mention that the tool was made so that it could be improved, and it is expected that modules will be added to allow the analysis of ammonia production, liquefaction, among others.

Keywords. Hydrogen, Balance of Plant, Heat Recovery, Decarbonization, Renewable Energy.

References

Buttler, Alexander, and Hartmut Spliethoff. 2018. "Current Status of Water Electrolysis for Energy Storage, Grid Balancing and Sector Coupling via Power-to-Gas and Power-to-Liquids: A Review." Renewable and Sustainable Energy Reviews. Elsevier Ltd. https://doi.org/10.1016/j.rser.2017.09.003.

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Multi-scale approaches for particle-laden viscoelastic flow modelling

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Understanding the behavior of particle-laden viscoelastic fluids (PLVF), in which the continuous or matrix phase exhibits viscoelastic properties, is a crucial element of industrial operations. Simulating the dynamic response of PLVF is a significant challenge for computational mechanics (CM) due to the intricate rheology of the continuous phase and the nonlinear many-body interactions among the constituents.

Although Direct Numerical Simulations (DNS) offer a potential solution to these computational challenges, the significant computational effort required makes them impractical for many applications. As a result, a popular alternative for numerically simulating PLVF is to employ an unresolved Computational Fluid Dynamics-Discrete Element Method (CFD-DEM) coupling strategy. This work describes the implementation of an unresolved CFD-DEM coupling strategy using a dual-grid multiscale approach to numerically simulate particle-laden multiphase viscoelastic fluids, where the continuum phases (fluids) are solved using a fine grid and the dispersed phase (particles) are solved on a coarse grid. To assess the effectiveness of the dual-grid approach, a benchmark case study involving a multiphase newtonian-newtonian flow is performed using a volume-of-fluid (VOF) interface capturing solver. The benchmark case, known as "Dam Break" investigated the evolution of kinetic energy accumulation over time when using the VOF single-grid approach and the newly implemented dual-grid method. Subsequently, the capability of the dual-grid approach to study non-newtonian fluids is demonstrated and validated using a benchmark case study known as "Impacting Drop". This case involves a liquid drop composed of a viscoelastic fluid falling under gravity, and the width of the drop is monitored upon impact with a rigid plate for both the single-grid and dual-grid approaches.

Lastly, a novel unresolved Eulerian-Lagrangian multiphase CFD-DEM solver is developed, which can efficiently simulate particle-laden viscoelastic fluids at a much faster rate than the DNS method, while still maintaining a satisfactory level of accuracy in the obtained solutions.

Keywords. Multiphase flows, Volume-of-fluid, Particle-laden Viscoelastic Flows, Dual-grid, Computational Fluid Dynamics-Discrete Element Method.

Simulation of flow conditions for natural gas and hydrogen blends for different points of the distribution natural gas network

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The need to achieve carbon neutrality in Europe by 2050 requires a demanding international effort in order to operate the necessary technological and behavioural changes. One of the hardest sectors to decarbonize is the natural gas sector. From an economical point of view, it is unsustainable to immediately replace the actual natural gas infrastructure for a hydrogen infrastructure. So, as short-term goal, the idea is to inject small quantities of hydrogen in the actual natural gas grid and progressively increase the percentages of injection. Portugal's goal until 2030 is to have a percentage of 10-15% of hydrogen running in the national grid [1].
The main challenges to execute the plan are the material concerns, the hydrogen can induce corrosion and embrittlement in the pipe's material; different energetic densities, hydrogen is three times less energetic dense than natural gas; increased combustion temperature and laminar flame speed, which can be a safety threat; and the hydrogen leakage, being a very small molecule, the leakage rate is expected to be much higher [2].
Additionally, the mixing of the hydrogen and the natural gas is not easy or immediate. Being the hydrogen nine times less dense than the natural gas, a stratification phenomenon occurs often and the effective mixing of the two gases is delayed for a long distance, depending on the flow characteristics. To avoid this, it's proposed the introduction of a static mixer in the gas pipeline to provide an efficient mixing within a short distance without causing a significant flow pressure loss. The performance of an helicoidal mixer (KM) and a KVM mixer were analysed and compared to the standard T-junction without static mixer. The necessary distance needed to achieve a homogeneous mixture, using the COV as the measure criteria, in the different cases, was calculated and compared with the consequent pressure loss associated. The three cases were analysed for hydrogen injection percentages until 20% and for a gas pipeline connecting the transmission line to the distribution line (pressures around 18 bar). It is expected to see a faster homogenization of the mixture with the usage of the static mixers.

Keywords. Power-to-gas, Hydrogen Blending, Static mixing, Natural gas grid, CFD

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Numerical analysis of the impact of interface modeling on the behavior of PC/ABS blends

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The PC/ABS ternary blend is one of the most successful commercial polymer blends, finding its main technological applications in the automotive sector and consumer electronics. Its success lies in the synergistic effect between its neat constituents, which enhances and combines their good characteristics: the excellent thermal and mechanical properties of polycarbonate (PC); and the toughness of acrylonitrile-butadiene-styrene (ABS) – itself a binary blend of styrene-acrylonitrile (SAN) and polybutadiene (rubber).

Different deformation mechanisms control the response of PC/ABS blends depending on the loading conditions and blend morphology. Among these deformation processes, one may emphasise the internal particle cavitation of the rubber particles and the debonding at the interface between the PC matrix and ABS particles (Seelig and Giessen 2007). Multi-scale models based on computational homogenisation are emerging as an effective way to predict the thermomechanical response of these blends, alternatively to the classic continuum mechanic models, which are often based on phenomenological assumptions. Besides the proper establishment of a representative volume element and the constitutive description of both material phases, it is expected that accounting for the explicit modelling of the PC/ABS interfaces is crucial to achieving accurate predictions.

In the present contribution, a microstructure generator software is developed to efficiently generate zero-thickness cohesive interface elements in preexisting discretised representative volume elements. This interface elements' behaviour is characterised by the PPR potential-based cohesive model (Park and Paulino 2012), and the homogenised thermomechanical response of the PC/ABS blends is inferred by first-order hierarchical multi-scale studies based on computational homogenisation. The impact of explicitly accounting for the interface phase on the blend's microstructure effective response is examined using several numerical simulations.

Keywords. PC/ABS polymer blends, Interfaces, Multi-scale modeling, Representative Volume Element, Finite element analyses

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On the multiscale modeling of advanced discontinuous fiber reinforced composites

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In recent years, a new class of fiber reinforced composites featuring unidirectional but discontinuous fibers has emerged as a promising material for high-performance structures, including aeronautical components. The performance of these materials is highly influenced by the fiber placement of the fibers, their orientation and arrangement. Despite their potential, these materials pose unique challenges in terms of modeling their complex behavior, which is highly dependent on these microscale phenomena.

To overcome the challenges associated with predicting the behavior of fiber reinforced composites, multiscale models based on computational homogenization have gained popularity as a means of interpreting the impact of heterogeneous microstructures on the macroscopic response of these materials. Moreover, it can also be employed to support the development of appropriate constitutive laws to predict the behavior of these materials at the meso and macroscales.

In the present contribution, the mechanical behavior of fiber reinforced composites is assessed to obtain a comprehensive understanding of the influence of the microscale phenomena, such as the interfacial properties and the gap length in the fibers. In this context, the mechanical behavior of a carbon fiber (CF) reinforced composite with discontinuous fibers and using Polyetherimide (PEI) as the matrix is analyzed with a fiber volume fraction content of 60%. A visco-elastic visco-plastic material model [1] is selected to predict the mechanical behavior of the polymeric matrix and a transversely isotropic Saint Venant Kirchhoff material model is used for the carbon fibers. Furthermore, the PPR potential-based cohesive zone model [2] is selected to characterize the behavior of the interface elements.

Keywords: Multiscale modeling, CF/PEI Composite, Discontinuous fibers, Microstructure generation, Finite element analyses

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Meshless analysis of fracture propagation in DCB adhesive joints

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Today, adhesively bonded joints are commonly used over traditional joining techniques due to their inherent advantages, such as lightweight materials, reduced stress concentration, fatigue resistance, or ability to join dissimilar materials. However, the numerical simulation of such structures currently represents an engineering challenge, and new computational tools are currently being developed to predict the intricate behaviour of adhesive joints. In this work, a meshless radial point interpolation method (RPIM) is combined with a crack propagation algorithm to simulate fracture propagation in double cantilever beam adhesive joints. Using the RPIM allows a flexible discretization of the joint in a set of independent nodes and numerical integration is obtained using a background integration mesh. The numerical simulation accurately predicts the experimental data, thus validating the developed meshless methodology.

Keywords. Adhesive Joints, Fracture Propagation, Meshless Methods, Radial Point Interpolation

Radial Point Interpolation Methods in a Structural Dynamic Analysis

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Meshless methods are an advanced type of numerical method that can be used as an alternative to the common Finite Element Method (FEM) to solve continuum mechanics problems. These methods have been used in many types of structural analysis, but mainly static. Some works are also focused on dynamic analysis. An example of this is the work of Mendonça et al. [1] where the Integrated Local Mesh Free Model (ILMF) to study forced vibrations in a cantilever beam. The current work aims at using two different meshless methods, the Radial Point Interpolation Method (RPIM) and the Natural Neighbours RPIM (NNRPIM), in a forced vibrations problem to assess the validity of these methods when applied to dynamic problems. Since this problem requires time integration three different time integration methods have been tested, namely: the Central Difference Method (CDM), the Wilson method and the Newmark method. The CDM is an explicit method, while the other two are implicit. Furthermore, three different loading conditions have also been tested, namely: a constant load, a transient load and a harmonic load. The results include a discretization study to identify the ideal refinement level for this problem, and a study of the ideal time step length for the two implicit time integration methods. Finally, the two meshless methods are compared with the FEM with the three different loading conditions and time integration methods previously mentioned, and damping. The comparison between the meshless methods and the FEM in all these cases showed minimal differences, thus proving the validity of the meshless methods.

Keywords. Damping, Forced vibrations, Meshless methods, Radial Point Interpolation Method.

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Prediction of surface properties from Atomic Force Microscopy nanoindentations using Neural Networks

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The study of mechanical properties has been trending towards the nanoscale, as material properties are fundamentally defined by the atomic structure. Atomic Force Microscopy (AFM) is one of the main methods when it comes to imaging a sample, but it is also a powerful technique to study the nanomechanical properties of a wide range of materials, as well as to characterize interactions at the piconewton level. With AFM nanoindentations, fitting the force-displacement curve obtained for each sample with a suitable contact model, allows to acquire the properties of interest. Given the high number of points in each curve and the typical need to analyse thousands of curves, the process of selecting a contact model and applying it to fit the data, can be a challenging and time-consuming task. As a result, alternatives to this procedure are being explored and it has been shown that an approach based on Machine Learning (ML) models can be of great use to predict relevant material properties, from AFM analysis [1,2].
In this work, two regression models using Artificial Neural Networks (ANN) were created, to predict Young's modulus and surface energy from AFM nanoindentations, which were divided into approach and withdraw curves. For learning purposes, synthetic data was generated, using two contact models. Approach curves were created with Hertz contact and used to train ANN forecasting the Young's modulus, while JKR contact was the support for producing withdraw curves, that trained a second ANN model, that not only predicted the Young's modulus, but also the surface energy.
Synthetic data was split into training, validation and test sets, always accounting for target stratification. Employing the *PyTorch* framework to build and train the model, we set and optimised key parameters such as the learning rate, layer width and ANN depth, number of epochs, loss function and weight optimiser. At last, the model was successfully tested with experimental data from AFM nanoindentations.
Our framework provided accurate predictions, in a computationally efficient way, thus validating the potential of a ML approach to explore AFM nanoindentations and motivating the further development of the presented work.

Keywords. Atomic Force Microscopy, Contact Mechanics, Machine Learning, Deep Learning.

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Recurrent Neural Networks and Three Point Bending Test on the Identification of Material Hardening Parameters

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Phenomenological constitutive models are mathematical expressions used to accurately describe the various fundamental properties and behavior of materials under different loading conditions. Phenomenological models require a calibration procedure to fit the constitutive parameters with experimental data. In this context, machine learning (ML) methodologies can be used to take a step forward in material constitutive modeling, contributing to improve the material parameter calibration procedure. Recurrent neural networks (RNNs), among the various types of learning algorithms, are especially interesting due to their ability to process sequential data and overcome limitations imposed by nonlinearities and multiple parameters involved in phenomenological models.

This study explores the modeling capabilities of RNNs in predicting the hardening behavior of a sheet metal material using standardized experimental test results. The developed neural networks are based on shallow artificial neural networks and long short-term memory (LSTM) structures. These networks take the punch force-displacement curve obtained in a three-point bending test as input and provide the characteristic parameters of the adequate hardening laws, e.g. Swift or Voce, as output. The required data for designing the neural network solutions are collected from numerical simulation using finite element methodology (FEM), which in turn is validated by experiments. A total of 91 curves were generated, considering different values for the K and n parameters of a Swift hardening law.

The results demonstrate that the proposed RNN-based approach outperforms traditional identification techniques in predicting the material hardening parameters indicating that the developed procedure can be successfully applied to characterize different materials, mainly those widely used in industrial applications, ranging from mild steels to advanced high-strength steels.

Keywords. Machine Learning, Material Parameter Identification, Three-Point Bending, Recurrent Neural Networks (RNNs), Long Short-Term Memory (LSTM)

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Surrogate modelling of the constitutive behaviour of hyperelastic materials based on artificial neural networks

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The Finite Element Method (FEM) is a powerful tool that enables the simulation of many complex engineering problems. In complex analysis, such as in the modelling of biological and biomechanical phenomena, it is necessary to specify the constitutive equations that describe the biomechanical behaviour of such materials.

Soft tissues and other biological materials subjected to large deformations present an extremely nonlinear behaviour, which makes the constitutive modelling of such materials a complex task and expensive in terms of time and computational resources. Alternatively, it is possible to use surrogate models, which consist of models that replace the traditional and expensive main models to overcome some computational limitations.

Such surrogates can learn the behaviour of the soft tissue when trained on previously acquired data and then replace the expensive numerical models. To develop the surrogates, Artificial Neural Networks (ANNs) will be trained from a large dataset with the deformations (inputs) and the corresponding stresses (outputs). Then, the weights and biases of the trained model will be used to write the forward pass equations in Fortran to implement a general user material subroutine (UMAT) for the Finite Element software ABAQUS. The surrogate models will be tested under homogeneous deformation cases and for some more complex models to compare and validate the obtained results.

Keywords. Machine Learning, Surrogate Model, Constitutive Behaviour, Hyperelasticity

Correlating Mechanical Properties with Relative Density in Multiscale Modeling of Triply Periodic Minimal Surfaces

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Multiscale modeling involves analyzing materials at one length scale and relating the results to properties at another length scale. To reduce computational time, numerical homogenization techniques are often used in composites by modeling a representative region instead of the entire structure. This approach can also be applied to lattice materials, where a simplified assumption is made and the lattice is modeled with only one solid phase and a void phase. The mechanical properties of the lattice material are then determined by relative density.

Two cellular structures based on TPMS, the gyroid and primitive surface, were evaluated to determine their elastic and plastic properties. The study found correlations between the relative Young's modulus and relative yield stress and the relative density, which aligned well with experimental data found in the literature.

Additionally, since cellular materials are suitable to reduce stress shielding in bioengineering applications, a study on a femoral stem is presented where it was shown that using the gyroid TI-6Al-4V foam as the porous part of the femoral stem presents adequate properties of stiffness and strength to replace human bone.

Keywords. Cellular materials, Homogenization, TPMS, Gyroid, Primitive, Femoral stem

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Structuring the Industrial Maintenance Operation according to the Model of Hierarchical Complexity

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The incorporation of new technologies into traditional manufacturing processes has been a notable development over the last two decades. The goal is to reshape the industrial environment. The industry 4.0 agenda created a digital change that impacts specific production assets and the labour involved. This change should be centred on the operators and the engineering should provide them with the necessary tools to improve their productivity. All of this can be accomplished through improved and tailored visual information techniques. Advancements in robotics, automation, and digitalization have facilitated agile manufacturing, reduced lot sizes, and accelerated modifications to products and production processes. Nevertheless, workers need to swiftly learn new roles and adjust to frequent changes, highlighting the crucial role of learning in industrial operations [1]. This study specifically looks at the Model of Hierarchical Complexity (MHC), a quantitative behavioural developmental theory [2]. Using the MHC model, this work proposes a methodology to create digital work instructions that are adapted to the worker's profile. According to the concept, tasks may be categorized into different levels of complexity and digital work instructions can be produced with varying levels of information based on the worker's profile and the procedure's complexity. With this, it is possible to develop a flowchart that can adapt to any type of maintenance procedure, and anyone can be doing it by placing tasks to different levels of hierarchical complexity. According to this research, digital work instructions based on the MHC model may improve quality, reduce errors, and increase efficiency in maintenance activities, reducing down-times and increasing reliability.

Keywords. Industry 4.0, Digitalization, Model of Hierarchical Complexity, Digital Work Instructions

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Crashworthiness topology optimisation of a crash box to improve passive safety during a frontal impact

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When referring to passive safety in the automotive industry, the concept of crashworthiness design needs to be addressed. It seeks to enhance passenger safety by developing structures designed for maximum energy absorption while minimizing the intrusion into the driver's operating area. While the constraint on energy absorption requires compliance and flexibility, the structure must retain rigidity to satisfy the penetration constraint. If so, crashworthiness design deals with conflicting objectives and a compromise between these parameters can be found by applying optimisation methods [1].

In this research, attention is targeted towards optimising a coach structure under frontal impact. In that condition, most of the energy is absorbed by the vehicle's frontal structure, posing a risk to the driver and passengers, and increasing the chance of fatalities [2]. Still, the existing literature on crashworthiness improvement of structures for passenger buses is limited.

Structural optimisation can be applied to improve the current design of heavy passenger vehicles. Most specifically, this research aims to employ topology optimisation algorithms to determine the best arrangement of material to minimize compliance while satisfying a volume constraint.

The nonlinear nature of crash simulation constitutes a challenge to the implementation of topological optimisation, which is typically established for linear static problems and resorts to sensitivity information [3]. Crashworthiness simulation yields high computation costs thus, the optimisation process will be carried out on a single component, namely, a crash box. The iterative optimisation process is materialized through a MATLAB code linked to Abaqus® where the crash simulation is performed.

This study aims to incorporate the optimised component into the chassis baseline of the coach to be tested according to the ECE R29 regulation. Iteratively, an energy absorption increase in the structure is intended, ensuring the physical integrity of the driver.

Keywords. Topological Optimisation, Crashworthiness, Passive Safety, Transportation, ECE R29.

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A review of injection-mould materials and their conventional and non-conventional machining processes

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Injection moulds are crucial for producing plastic and very ductile metal components. One of the primary challenges associated with them is that they may suffer from wear, such as cracking, due to the extreme temperatures and pressures involved in the production process. Manufacturing processes can be conventional or non-conventional, according to the pretend geometry and respective needs. This article focuses on three foremost alloys: AMPCO® (Copper-Beryllium alloy, CuBe), Invar-36 (Iron-Nickel alloys, Fe-Ni36), and heat-treated steels. An insight into the manufacturing processes' limitations of this kind of materials will be made, and solutions for more effective ways to machine them will be presented by reviewing others authors' remarks.The main objective is to improve the advantages of these alloys and solve the machinability disadvantages, discovering the prospects for future works. Research sources of information have been used to establish this article, like ScienceDirect, Springer, MDPI, ASTM, and ISO. Books and papers from ASM International, Academic Press, Wiley, and Butterworth Heinemann publications were also research sources. Many keywords have been used during the development of this article to get the intended information, namely: "injection moulds", "manufacturing processes", "Copper-Beryllium alloys", "Iron-Nickel alloys", and "heat-treated steels", and the possible combinations between those words. Noticeably, there's much work to investigate for some alloys and respective manufacturing processes.

Keywords. Injection-Molds, Manufacturing Processes, Copper-Beryllium alloys, Iron-Nickel alloys, Heat-treated steels

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A review of INCONEL® alloy's non-conventional machining processes

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The increased usage of difficult-to-machine materials for high-temperature applications brought to light problems such as high-temperature machining, build-up-edge (BUE), and tool wear (TW), significantly contributing to high-cost manufacturing and poor tool-life management. This article intends to present a detailed review of non-conventional machining processes that may facilitate the machinability of INCONEL®, lower manufacturing costs, and moderate production problems. The primary objective aims to provide and analyse the progress taken within the field of INCONEL® non-conventional processes from 2018 to 2023 and present the most recent solutions found in the industry and the prospects from researchers. To undertake this article, ScienceDirect, Springer, Taylor & Francis, Wiley, ASME, ASTM, and ISO have been used as sources of information due to excellent fidelity knowledge. Books from Woodhead Publishing Series, CRC Press, and Academic Press have also been used. The main keywords used in searching information were: "non-conventional manufacturing", "hybrid manufacturing", "high-temperature machining", "INCONEL® 718", and "INCONEL® 625". Combining these keywords was crucial to seeking information about the evolution of INCONEL® non-conventional machining technologies. In subsequent research, it becomes quickly noticeable that some techniques are yet to be intensely exploited. Moreover, the characteristics of non-conventional processes, without tool-workpiece contact pair, pose significant advantages over traditional ones.

Keywords. Non-conventional manufacturing, hybrid manufacturing, high-temperature machining, INCONEL® 718, INCONEL® 625.

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Coefficient of friction predictions using an adaptative limiting yield shear stress model

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Rolling element bearings, gears, and cam-followers are examples of mechanical components that transmit power and motion via surfaces interacting with each other and with a lubricant [1]. Under these circumstances, the mechanical components are subjected to friction forces that may affect their performance, namely failure occurrence and efficiency. In this sense, understanding and modelling the coefficient of friction (CoF) can benefit the design process.
This work uses a thermal elastohydrodynamic lubrication (TEHL) model [2] to predict the CoF in a rough circular contact for a commercial ISO VG150 polyalphaolefin oil under different operational conditions [3].
The main goal of this research is to present an adaption of Bair and Winer's [4] linear relations for lubricant limiting yield shear stress (τ_L) and the lubricant limiting elastic shear modulus (G_∞) in order to better predict experimental values in different lubricantion regimes. The results show that an improvement in traction curves predictions can be made by introducing the slide-to-roll ratio (SRR), entrainment velocity, dynamic viscosity and maximum Hertz pressure in the limiting yield shear stress. In addition, this work also presents maps for the coefficient of friction in each operational condition, which allows one to use the CoF point by point instead of a single global value.

Keywords. Thermal elastohydrodynamic lubrication (TEHL) model, Coefficient of Friction and Numerical modelling

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Influence of rolling speed, temperature, surface roughness and slide-to-roll ratio on the friction in a circular contact

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The friction in lubricated contacts, such as in gears and rolling bearings, has an influence on the contact's performance (Björling et al. 2011). The Stribeck curve is useful in showing the frictional behaviour of such contacts (He et al. 2017). Thus, it is important to determine how different parameters of the contact conditions, such as rolling speed, temperature, surface roughness and slide-to-roll ratio (SRR), affect the friction behaviour in the contact.
A commercial ISO VG150 polyalphaolefin gear oil was fully characterized with measurements of the film thickness and friction coefficient (CoF) using an EHD2-Ultra Thin Film Measurement System (PCS Instruments, England, 2014), which applies optical interferometry to measure the film thickness at the centre of the contact and a load cell to measure the total CoF. The film thickness was measured in a normally loaded ball-on-disk contact, using a sapphire disc and a steel sphere, with a roughness of Ra=0.02μm, for three temperatures and three slide-to-roll ratios (SRR) in the rolling speed range from 2.5m/s to 0.05m/s with a load of 50N. The CoF measurements were done for contacts with composite roughness of Ra=0.02μm, Ra=0.16μm, and Ra=0.30μm under the same loading, temperature, and speed conditions.
The results were analysed using the analysis of variance (ANOVA) method to determine the influence of the temperature, SRR, and surface roughness on the friction coefficient. It was observed that all three factors (temperature, SRR, and composite roughness) influence the Stribeck curve, with slight interaction between the temperature and the SRR, that remained constant in the rolling speed range of the measurements, and significant interaction between the temperature and the roughness, that decreased with the decrease in rolling speed. No interaction was observed between the roughness and the SRR.

Keywords. Stribeck curve, lubrication, slide-to-roll ratio, ANOVA.

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Experimental validation of Fused Filament Fabrication (FFF) extrusion simulations

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Fused filament fabrication (FFF) is one of the most used material extrusion additive manufacturing techniques. In a typical process, a thermoplastic filament is fed into the extrusion-head via a pinch roller mechanism. The filament is melted in a heated liquefier with the solid portion of the filament acting as a piston to push the melt through a nozzle. Movement of the print head allows to deposit the material in specific locations thereby layer-by-layer building of custom 3D geometries is realized [1]. Recently, the need for building functional prototypes and tools is pushing the development of 3D printers with higher performances. However, gaps in knowledge still need to be overcome to develop the next generation of printers. For instance, research on the extrusion process and its influence on the properties of 3D printed parts is paramount for improving the printing process. This work presents an experimental and numerical study on FFF 3D printing. The goal is to experimentally validate numerical simulations of nozzle flow with viscoelastic multi-mode models and analyze the performance of commercially available nozzle shape designs regarding printing speed and required relative extrusion force. The experimental setup consisted of an UltiMaker® feeder equipped with a sintered metal nozzle produced by additive manufacturing. The total pressure drop in the system is calculated numerically and measured by a load cell. The die-swell exhibited by the polymer melts at the exit of the print head is measured with a high-speed camera. Results are compared with numerical simulations, giving insight on the role of the extensional viscosity, and conclusions are drawn on the pressure drop gap, considering the differences between these two methods, mainly the simplifications made in the simulations and non-ideal conditions that occur in the experimental method.

Keywords. 3D printing, Additive manufacturing, Pressure drop, Computational fluid dynamics, Annular backflow

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Design for large scale additive manufacturing

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Introduction: One of the most fascinating aspects of 3D printing is figuring out how big it can be printed, hence the term LFAM (Large Additive Manufacturing) was born. However, it has some difficulties that do not exist in "conventional" 3D printing of small parts. Even so, currently, this branch of 3D printing has been experiencing high growth rates.

Together with Solidtech (a company specialized in additive manufacturing), it was possible to systematically study some inherent difficulties of LFAM, using a robotic arm coupled with an extruder head for pellets (MEX process).

Material shrinkage, construction paths, raster angles, path radius, surface finish, adhesion to the construction platform, among others, were studied to be able to print parts with adequate properties.

Objective: Stablish a set of adequate parameters for LFAM, especially in terms of design and final quality of the printed parts.

Methodology: The work was divided into two steps: a first part, where materials, equipment, techniques and solutions used in this technology were investigated; and a second part, of experimental work, which involved carrying out several printing tests with different thermoplastic materials, to make parts with the best parameters.

Results: The results obtained allowed to conclude that PP with 30 % GF, PETG and PLA can be used to print large format parts, depending the chosen material on the part requirements (cost, resistance, lightness, finishing, among others). The data obtained allowed creating fundamental strategies (especially for the design) that relates the line thickness as a function of the extrusion and robot speeds, as well as identifying the different types of defects that can be obtained in the parts, it´s respective cause and solution. In addition, it was also possible to identify the limitations of the materials in terms of construction angles, speeds, layer heights (Lh), temperatures, etc., which was fundamental to make the technical sheet of the material to build large parts.

Conclusion: This work allowed to conclude that design for additive manufacturing (DFAM) is critical when the objective is to manufacture large parts. This study demonstrated that sometimes is necessary to change the design of a part to be feasible to be build, but also that using the right material, equipment and parameters it is possible to make parts that would otherwise take much longer, or even be impossible to print.

Keywords: LFAM; DFAM; MEX; Polymers; Printing parameters; Defects; Large Format.

Compaction analysis in composite material processing by the vacuum infusion process

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Vacuum infusion is a closed-mold manufacturing process that belongs to the family of liquid composite molding (Hammami and Gebart 2000). In vacuum infusion, fibrous reinforcements are placed between a rigid mold and a flexible bag, and vacuum is drawn inside the mold to generate a pressure gradient that will drive the resin into the mold, impregnating the reinforcement (Miracle and Donaldson 2001). One limitation of this process is the low compaction pressure that can be exerted on the reinforcement, which cannot exceed the atmospheric pressure (Hammami, Gebart, and Nilsson 1999), and thus hinders the manufacturing of parts with high fiber volume fraction. A deeper understanding of the reinforcement compaction is thus of extreme importance because it will enable designing the manufacturing process (Robitaille and Gauvin 1998) taking full advantage of the limitations inherent to the process. Studies indicate that imposing cyclic compaction on the dry reinforcement prior to resin impregnation increases the final fiber volume fraction of the part, by taking advantage of the hysteretic behavior of fibrous reinforcements. However, there is still lack of knowledge regarding the compaction process of fibrous reinforcements, by which a detailed procedure for reinforcement compaction prior to impregnation in vacuum infusion is yet to be proposed. This study addresses more efficient methodologies inducing the increase of fiber volume fraction of a non-crimp fabric (NCF), processed by the vacuum infusion process. The aim is to improve the mechanical properties of the part in vacuum infused laminates, which are requirements imposed by the aeronautical industry. The authors intend to analyse different pressure curves imposing cyclic compaction as a function of time aiming to find out which would be the best procedure to increase the fiber volume fraction of the laminates. They observed that the number of cycles imposed on the reinforcement, the type and the period of the chosen function have a significant influence on the fiber volume fraction results. This is an interesting and relevant research topic with promising interesting conclusions. It is recommended that a correlation between material properties and parameters inherent to vacuum process is established and presented.

Keywords. Vacuum infusion, fiber reinforcements, atmospheric pressure, compaction behavior, fiber volume fraction.

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Experimental characterization of self-healing composite structures to low and high-velocity impact applications

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The high demand and use of composite materials have been noticed in recent decades. One of the most significant applications throughout industries involves sandwich structures in aeronautics. Thanks to their low apparent density core and subsequent bending-resistant properties, sandwich composites are vital to the aircraft fuselage. Still posing significant challenges, not only by its heterogeneous nature but also due to skin stacking, composite materials have complex damage mechanisms, leading to the need to employ specific failure criteria for evaluating and designing these structures. For aircraft applications, a significant problem is a collision with birds in low-flight, take-off, and landing, resulting in irreversible damage and consequent repairing of the sandwich composites. In this paper, a solution to drastically reduce the lack of residual strength of composite materials is carried out, combining hybrid fabrics of carbon fibre with Dyneema® laminates, a NOMEX® honeycomb core and a self-healing elastomeric material called Reverlink™. A comparison with a more traditional approach that considers the epoxy Araldite® 2015 adhesive is undertaken, allowing the evaluation of the difference in mechanical properties during the experimental tests of a low and high-velocity impact (LVI and HVI, respectively). The quantifiable results made it possible to infer that Reverlink™ has an improved impact behaviour and can be considered instead of traditional sandwich joining with epoxy adhesives. Moreover, thanks to its self-healing property, the regeneration of mechanical properties after the first impact is accomplished.

Keywords. High-velocity impact, Low-velocity impact, Hybrid composites, Sandwich, Self-healing.

Funding: The work is developed under the “MOSHO — Advanced solutions for impact materials, repairing of composite structures and its monitoring” research project, within the “Portugal2020” program scope.

Conflicts of Interest: The authors declare no conflict of interest.

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Low and high-velocity impact evaluation of self-regenerating sandwich structures by FEM

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Nowadays, composite materials, due to their high cost and the reduced recycling ability, require an initial digital test to determine their behaviour to the imposed demands. To lower costs and predict the behaviour of composite structures, the finite element method (FEM) is applied. Due to the heterogeneous nature and staking sequence, the challenge is increased when moving from static to dynamic analyses. With the computational and complex mechanisms for predicting the damage of composite materials evolution in recent years, dynamic FEM analyses have become more suitable to calculate and predict the behaviour of sandwich structures subjected to low and high-velocity impacts (LVI and HVI, respectively) with greater accuracy. Composite sandwiches for aircraft applications have collision damage problems with birds in low-flight, take-off, and landing, developing irreversible damage and consequent repairing of the sandwich composites. This article intends to present a numerical solution to predict the mechanical behaviour of a sandwich structure subjected to LVI and HVI. Those sandwich structures are composed of hybrid fabrics of carbon fibre with Dyneema® laminates, a NOMEX® honeycomb core and a self-healing elastomeric material called Reverlink™. A comparison between numerical models with epoxy Araldite® 2015 adhesive and Reverlink™ elastomer is undertaken, enabling the *in-loco* comparison of mechanical properties by finite element analysis (FEA). The results demonstrated the destruction caused by LVI and HVI events in sandwich structures joined with Araldite® 2015 and Reverlink™. After a brief comparison with the analogous experimental analysis, the numerical model agrees with the actual event.

Keywords. High-velocity impact, Low-velocity impact, Hybrid composites, Sandwich, Self-healing.

Funding: The work is developed under the “MOSHO — Advanced solutions for impact materials, repairing of composite structures and its monitoring” research project within the “Portugal2020” program scope.

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Study of thermal-optical properties of composite materials to support a Digital Twin model of an ATL process

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Composite materials play a crucial role in the development and innovation in various areas, such as renewable energy, healthcare, mobility, and infrastructure. Those areas are requesting structures with even more performance, in that sense, composites have earned relevance in researching for more effective manufacturing processes. A composite manufacturing process that gained relevance in the last years is the Automated Tape Laying (ATL) process. In this process, a composite tape is heated by a radiation heat source, which allows the composite matrix to melt and weld to a previously laid material or on top of a mould. For this type of manufacturing process, it is mandatory to understand the heat transfer phenomena to control it and ensure the structure quality. Recent studies conducted in order to determine the thermo-optical properties of composites, namely emissivity and reflectivity, have shown interesting results, by evaluating the microscale effects of radiation, and how it may influence the overall heating process [1]. This work aims to determine those thermal-optical properties, as a function of the composite material temperature by an in-house developed procedure, to support a Digital Twin-based model for an ATL process [2]. The proposed procedure is based on placing a pyrometer and PT100 sensors measuring the temperature of the composite material. In fact, the pyrometer was set to read a material with the emissivity of a blackbody. In light of this, it is possible to calculate the material's emissivity through an equation that considers the difference between the optical temperature (pyrometer) and the real temperature (PT100 sensor). Another goal is to determine the temperature measurement of an optical sensor as a function of the incidence angle of measurement and the orientation of the fibers. In fact, the orientation of the fibers may deflect the incident radiation and then reflect some of the energy, which combined with the view factor may minimize the measurement uncertainty. Regardless of the material's orientation, the positioning of the fibers along the composite material is random, which contributes to the reflection uncertainty. The results present a slight emissivity variation as a function of the fibre's orientation and a significant variation as a function of the incidence angle.

Keywords. Composite material, Digital Twin, Radiation heat, Thermo-optical properties, Fibres orientation

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Study of Processing Variables Regarding the Impregnation of Carbon Fibres with PET

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Over the last decades thermoset composites have gradually been replaced by the thermoplastic ones. Such replacement occurred due to the thermoplastic composites' characteristics, which can offer, for example, increased toughness, higher damage tolerance and durability. On the other hand, by being reprocessable and contributing to eliminate styrene emissions, these materials have proven to be more advantageous [1,2]. Moreover, they allow greater industrial productivity as they present short processing cycle times [1,3].

Nevertheless, the processing of thermoplastic matrices is a demanding step concerning the manufacture of composites. As it requires high temperatures and pressures, and since these materials present a superior viscosity than thermoset composites, new technological and scientific challenges have emerged to produce them. Those challenges are also applied to other obstacles, such as the difficulty and complexity to impregnate continuous reinforcements into thermoplastics, as well as to consolidate the obtained composite [1,3].

Despite of the previous challenges, prepregs of thermoplastic matrix have already been manufactured by using some innovating processes to deposit the polymer on the reinforcement phase [1-3]. Thermoplastics such as PP and PET are the most used ones to produce these pre-impregnated components. Furthermore, when such polymer matrices are associated with continuous carbon fibres it is possible to obtain composites that present the highest specific stiffness as well as excellent specific strength and exceptional fatigue resistance [4]. These composites are then important since they fulfil the requirements of the aeronautic, aerospace, automotive and military defense industries [5].

This article intends to follow up the study that has been carried out concerning the thermoplastic matrix composites. With this purpose, and using a recent developed manufacturing technique, thermoplastic matrix prepregs were produced by impregnating continuous carbon fibres in PET. Thus, composite tapes whose production process was carried out varying the temperature and speed processing parameters were obtained.

Keywords. Thermoplastic matrix composites, PET, Carbon fibres, Processing parameters.

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Manufacturing and testing of a novel thermoplastic composite material

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The aeronautical and aerospace fields are in constant demand for innovation towards more lightweight and sustainable materials. New materials are featured prominently in the research and development taken by academic institutions and industrial companies. Among other classes of materials, composites featuring a thermoplastic matrix have been a subject of interest recently due to relevant properties in this field.

This work aims at analysing state-of-art carbon fibre-reinforced thermoplastic (CFRTPs), including the relationship between manufacturing processes and its mechanical performance.

In this contribution, the finishing operations and their parameters are studied in detail for a novel thermoplastic-based composite. A comprehensive assessment of three milling bits is performed to study their performance. The machined surfaces were subjected to mapping on a 3D scanner to inspect the surfaces more closely. The milling bit catalogued for machining of composite systems showed the best performance. The cut surfaces presented adequate quality independently of the set of parameters defined in this study. In addition, the most adequate hole drilling parameters are identified, with the aid of X-ray analyses to ensure that no delamination appears at the hole free edges. Having identified the ideal trimming and machining tooling and parameters, several lamina and laminate tests were performed, to characterise, among others, the inelastic deformation under off-axis compressive loads, the intralaminar fracture toughness in tension and in compression, ply size effects and the strength of bolted joints. Post-mortem macro-photography, micrography and X-ray analyses are conducted to identify failure modes and compare with state-of-art thermoset-based composites. Despite the different processing conditions, which lead, for example, to different levels of residual stresses, preliminary comparisons between the aerospace-grade thermoplastic and a state-of-art thermoset-based composite show that the former, which exhibits greater potential for recyclability, can also be a potential alternative to the latter for primary structural applications.

Keywords. Thermoplastic composites, Manufacturing, Machining, Process-property relationships.

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Development of a unified specimen for adhesive characterisation: Numerical and experimental study on the mode I (mDCB) fracture component

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These days, many major industrial players feel that faster mechanical characterisation procedures are required due to the rapidly expanding use of adhesive bonding in industrial applications. The currently existing methods are exceedingly time-consuming, costly, and sophisticated, removing them as an option for many industries. Given this, the development of a more agile unified method, which can significantly reduce development times and costs, has the potential to be a disruptive technology for a variety of users, including adhesive manufacturers and the electronic, automotive, and aerospace industries, among many others.

The present work displays part of the development of this fully integrated adhesive characterization tool [1] that can load specimens in several different conditions during a single test. The resulting data must then be processed with custom advanced algorithms, reducing the amount of manual effort necessary, and enabling the direct generation of cohesive zone laws.

To this extent a novel mode I test was designed, the modified double cantilever beam – mDCB – specimen, as a result of the need to combine a mode I (DCB) and mode II (end-loaded split - ELS) tests. Where the DCB test usually presents two solid cantilever beams, the mDCB now uses a full-fledged ELS specimen as the upper beam. To consider the particularities of this composed specimen a new linear elastic fracture mechanics based custom data reduction method [2] was also devised.

Two different adhesives were numerically and experimentally characterised, comparing the performance of the novel specimen against standard mode I adhesive characterisation techniques.

Numerical and experimental results presented good correlation between each other, and overall showed comparable characterisation performance in relation to the standard methods presenting errors smaller than 5%. As such, it was possible to develop a robust specimen and custom data reduction method to characterise adhesives under mode I loading.

Keywords. structural adhesives, adhesive characterisation, fracture toughness, fracture process zone, unified specimen.

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Study of hybrid composite joints with thin-ply reinforced adherends

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The use of carbon fibre reinforced polymer (CFRP) materials is continuously increasing due to their advantages [1]. However, delamination, which is still an issue in composite materials, can lead to rapid degradation of the mechanical performance of the structure and cause premature failure [2]. It has been demonstrated that a possible solution to reduce delamination in a unidirectional composite laminate lies in the replacement of conventional carbon fibre reinforced polymer layers with optimized thin-ply layers, creating hybrid laminates [3]. This leads to an increase to the transverse tensile strength of the hybrid composite laminate. This study investigates the performance of hybrid composite laminate reinforced by thin-plies when used as adherends in bonded single lap joints. Two different composites with the commercial reference "Texipreg HS 160 T700" and "NTPT-TP415" were used as the conventional and thin-ply respectively. Three configurations were considered in this study, two reference single lap joints with conventional composite or thin-ply used as the adhrends and a hybrid single lap joint. Numerical models of the joints were also created, allowing to better understand the underlying failure mechanisms and identify the damage initiation sites. The results show a significant increase in tensile strength for the hybrid joints compared to the conventional ones, driven by changes in the damage initiation sites, the level of delamination present in the joint and the final failure mode.

Keywords. composite joints, thin-ply, single lap joints

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POSTERS

Big Data Collection for the Development of a Hybrid Digital Twin Model in the Maintenance Field of Leaf Springs Applied in Freight Wagons

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In recent decades, the Portuguese railway sector has suffered significant funding cuts, which have led to disinvestment in the development of this sector. With environmental concerns gaining prominence in recent years, the railway sector has been seen as one of the key points for the development of a sustainable economy. In the freight sector, the rail vehicle has been in the industry's exportation planning. However, the dynamics of sales have required the logistics sector's efficient management and maintenance of their resources to respond efficiently to customer demand. For this to be possible, the knowledge of the health state of the components must be well-known. This knowledge is even more important in components with a high degree of risk. One of these elements is the leaf springs that constitute the suspension of freight wagons. Leaf spring fracture normally occurs due to fatigue phenomena and its failure can lead to vehicle derailment (DETEC, 2016). With the aim of knowing the health state of the leaf springs, a real-time monitoring campaign of the stress magnitudes applied on the leaf springs is carried out. of leaves. Electric strain gauges are used to monitor the surface deformations in the leaf springs. Additionally, linear potentiometers are installed to gather the variation of the relative displacement between the wagon frame and axle. Since the vertical displacement and longitudinal stresses are collected, the numerical model of a full-scale leaf spring can be posteriorly calibrated. After, a response surface relating the maximum stress on the leaf spring and the vertical displacement can be modeled e assumed as a reduced-order model for future predictions. The reduced-order model and the instrumentation layout may be combined with a data-driven modeling system in order to develop a hybrid digital twin model for predictions. This hybrid digital twin model features itself as a tool for maintenance practices in leaf spring suspensions, and then avoiding the fatigue occurrence in the leaf springs.

Keywords. Leaf Springs, Maintenance, Fatigue Prediction, Hybrid Digital Twin, Railway.

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Creep Damage Laws and Cohesive Zone Modelling of Composite Bonded Joints under Pure Mode I and II Loadings

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Adhesively bonded joints have been investigated in several industries: automotive, electrical, maritime and shipbuilding, packaging, and even medicine, however the aviation sector is the main contributor. Research has been presented, where the mechanical behavior of composite bonded joints under quasi-static loading is well established. Developments on fatigue loading have recently been presented, whose proceedings constitute the starting point for the investigation of other mechanical phenomena such as creep. Crack growth has been predicted in metallic structures in the last decades, even using cohesive zone modelling (CZM). This study presents an adaptation, of the presented creep damage in the state-of-art, for applications in ductile polymers such as adhesives. In this way, Kachanov-Rabotnov [1] and Liu-Murakami [2] damage models, including rheological parameters by using Maxwell, Voigt-Kelvin, and Burgers constitutive equations, are considered, whose numerical formulations take into account viscoelastic effects. Stress degradation due to creep phenomena is considered, incorporating power law and sin-hyperbolic based models. Twelve damage models are derived: Kachanov-Rabotnov-Maxwell (KRM), Kachanov-Rabotnov-Voigt-Kelvin (KRVK), Kachanov-Rabotnov-Burgers (KRB), Kachanov-Rabotnov-Maxwell-Sun (KRMS), Kachanov-Rabotnov-Voigt-Kelvin-Sun (KRVKS), Kachanov-Rabotnov-Burgers-Sun (KRBS), Liu-Murakami-Maxwell (LMM), Liu-Murakami-Voigt-Kelvin (LMVK), Liu-Murakami-Burgers (LMB), Liu-Murakami-Maxwell-Hyperbolic (LMMH), Liu-Murakami-Voigt-Kelvin-Hyperbolic (LMVKH), and Liu-Murakami-Burgers-Hyperbolic (LMBH). The implementation of the derived laws in CZM is demonstrated, being capable of predicting primary, secondary, and tertiary creep phases under pure mode loading (I and II). A parametric analysis is presented, investigating the influence of the different laws on the creep damage rate. The numerical curve shape, characterizing the creep response, is analyzed considering different parameters. The creep behavior of double-cantilever-beam (DCB) and end-notched-flexural (ENF) specimens are evaluated with experimental validation. A theoretical basis is then established in this study for further analysis of several creep loaded adhesively bonded joints and repairs using CZM, where mixed-mode I+II loading can be considered in the near future.

Keywords. bonded joints, cohesive zone modeling, creep, damage, viscoelasticity

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Impact of water uptake and microbial degradation on the lifetime of biopolymer-matrix composites

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Polymer-matrix composites are nowadays employed in several engineering applications, with biopolymers gaining more and more relevance, due to sustainability concerns. Nevertheless, their performance over time is still affected by several environmental factors, in ways yet to be understood. This study gathers data on the vulnerability to environmental factors of the most relevant biopolymers today: poly-lactic acid (PLA), thermoplastic starch (TPS) and polyhydroxyalkanoates (PHAs, of which polyhydroxybutyrate (PHB) is the most common one), focusing on the published studies in the last fifteen years on Scopus. Water uptake is shown to stiffen matrices for temperatures below freezing and, if above the glass transition temperature, to have a plasticizing effect, leading ultimately to hydrolysis, happening at the filler-matrix interface in composites, e.g., in PLA/TiO2 composites tested at 37 ºC over one year [1]. Seawater, besides contributing to hydrolysis, due to its high salinity and currents, promotes mechanical break-down and surface erosion, leading, e.g., to a weight loss of up to 60% after 35 days in tropical waters for PHB samples [2], while PLA featured a negligible mass loss in fresh and seawater over 365 days [3]. The microbial and/or enzymatic degradation acts through the stages of fragmentation, hydrolysis and assimilation, metabolising some polymers and natural fillers and altering their structure/composition. The obtained products accelerate the loss of integrity, which affects predominantly amorphous domains and is particularly relevant for natural fibres and/or biodegradable composites, e.g., with PLA and TPS matrices under tensile fatigue/creep loads which increase the exposed area. Specifically, TPS is reported to fully disintegrate over 30 days of soil burial at 30 ºC [4], nevertheless, contrasting results are also reported [5,6]. As we move towards biopolymers, the assessment of the mechanical properties of these polymer matrices, beyond pure degradation tests, is due, namely via (high and low-cycle) fatigue and creep tests.

Keywords: polymer-matrix composites, environmental fatigue, microbial degradation

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Multi-scale 3D vision using robotic assistant

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The theme of "Multi-scale 3D vision with robotic assistant" is a cutting-edge research area that combines the fields of computer vision, robotics, and machine learning. Multi-scale 3D vision is done by taking pictures of objects in different angles and distances. However, the development of efficient multi-scale 3D vision systems incorporating robotic assistance faces several obstacles despite the potential advantages, such as existing shadows and occlusions in the industrial environment [1].

Most objects are complicated by nature, therefore three-dimensional vision systems have a problem with shadow regions that can be fixed. The camera or the base that the object is standing on must then be moved [2].

In this project the object is going to rotate with the aid of one rotary table and a grip system, and the camera only need to zoom out or zoom in, as needed. It can be easier and more effective to move the object to get rid of the shadows, as the camera need be static to capture a sharp image.

Beyond this, after taking several pictures it is possible to make a 3D reconstruction of the object. MATLAB is going to be used to make the vision system and the 3D reconstruction algorithms.

Due to the results obtained with these types of systems, the capabilities of robotic assistants have increased in recent years because of the development of multi-scale 3D vision systems, which combine high-resolution vision with the capacity to detect objects at various scales. It provides the user extreme precision and accuracy, as needed in surgical operations or the inspection of sophisticated structures [3].

Keywords: Multi-scale, 3D vision, Shadows, 3D reconstruction, MATLAB

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