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DOCTORAL CONGRESS in ENGINEERING

Book of Abstracts

3rd Symposium on Mechanical Engineering

U.PORTO
FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

3rd DOCTORAL CONGRESS IN ENGINEERING

Book of Abstracts

of the

3rd Symposium on Mechanical Engineering

Editors:

Abel D. Santos, José César de Sá, Rui L. Amaral, Carolina Furtado

Porto

July 2019

This volume contains the abstracts presented at the Symposium on Mechanical Engineering, within the 3rd Doctoral Congress in Engineering - DCE19, held in Porto, between June 27th and 28th, 2019.

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Edited by Abel D. Santos, José César de Sá, Rui L. Amaral, Carolina Furtado

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PREFACE

The Symposium on Mechanical Engineering was held within the Third Doctoral Congress in Engineering (DCE19), hosted at Faculty of Engineering of the University of Porto (FEUP), from June 27th to June 28th, 2019.

The scope of the Mechanical Symposium is focused on the science and practice of mechanical engineering. The presented proposals are quite broad and clearly reflect the multidisciplinarity of the area, its applications and recent developments.

This Book, which collects the abstracts or extended abstracts accepted for presentation at DCE, was reproduced directly from the files sent by the authors, having been compiled by the Organizing Committee of the Mechanical Engineering Symposium.

We use this opportunity to thank all the authors and the keynote speakers for sharing their research experience and also the members of the scientific committee for all their efforts and contribution to the success of this edition of Symposium on Mechanical Engineering.

Porto, July 2019

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PROGRAMME

Symposium on Mechanical Engineering

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Organizing Committee: Rui Amaral and Carolina Furtado
Location: room B023
Time for oral presentation: **10'** presentation + **5'** discussion

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ABSTRACTS

Materials and Manufacturing Processes

Computational Mechanics

Adhesive Joints

Dynamic Analysis, Fluids and Experimental Mechanics

MATERIALS AND MANUFACTURING PROCESSES

Identification of GTN model parameters for dual-phase steels under tensile loading conditions

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Abstract

Application of advanced high strength steels, such as dual-phase steels, has been received great significance in the automotive industry. This is related to the high ultimate yield strength values which improve the crash energy absorption performance. Furthermore, the advanced high strength steels allow manufacturing of structural components with reduced thickness, that is, lighter vehicles with reduction of fuel consumption and greenhouse gas emissions. In this work, the damage behavior of cold-rolled zinc coated dual-phase steel sheets DP600, and DP800 grades were evaluated using uniaxial tensile tests microstructural characterization and numerical modeling (Zhao 2016). The damage evolution in ductile metals arises from the growth of existing voids and nucleation of new voids by means of mechanisms of cracking or interface decohesions of inclusions and or precipitate particles (Saeidi 2014). The proposed procedure allowed identifying the parameters of the Gurson-Tvergaard-Needleman (GTN) damage model for these dual-phase steels (Santos 2018). The DP800 steel displayed improved strain-hardening and increased yield strength along with a lower critical strain to failure owing to higher martensite volume fraction. The resulting ductility effect can be attributed to the void nucleation sites which increase with the number of martensitic islands and ferrite-martensite interfaces.

Keywords. Dual-phase steel, Damage, GTN model, Tensile tests, Finite element modeling.

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Multi-objective design optimization for wide tapered multi-cell energy absorber made of aluminum

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Abstract

Due to the extensive use of cars, it has become necessary to design vehicles with higher levels of safety standards. Development of the computer aided design and analysis techniques has enabled employing well-developed commercial finite-element-based crash simulation computer codes, in recent years. The present study is an attempt to optimize behavior of the structural components of a passenger car in a full-frontal crash through including a proposed wide tapered multi-cell energy absorber. The optimization technique relies on the design of experimental (DOE) method to enables finding the absolute extremum solution through Gray Relational Grade (GRG). First, the car is modeled in PATRAN and meshed in ANSA software. Then, the full-scale car model is analyzed in ABAQUS/CAE software. The optimization has been accomplished through a multi-objective function to simultaneously, maximize the observed energy and minimize the passenger's deceleration. Results are verified by the experimental results.

Keywords: Multi-objective optimization, Crash safety, Design of experiment, Energy absorption, Design of Experiments

1. Introduction

Since the skin panels of the car body are chosen thinner to reduce the vehicle body weight and, consequently, reduce fuel consumption and increase the speed and acceleration in modern cars, investigation of the occupant safety in the frontal crashes has become a crucial issue more than before. Crashworthiness analysis of the passenger cars is generally conducted based on the theory of nonlinear finite element by means of special computer codes. Vehicle behavior determination techniques go through various stages before the model becomes ready for analysis (Kirkpatrick 2000).

2. Materials and Methods

In this study, damage criteria are used to obtain results that are comparable to the experimental results. These criteria include ductile damage for the steel (ρ =7800 (kg⁄m^3), E=210 (GPa), σ_y =776 (MPa), σu =953 (MPa), ϑ =0.3) used in the car body, as well as shear ductile damage and FLD damage for more detailed modeling of wide tapered multi-cell energy absorber made of aluminum 1060 (ρ =2700 (kg⁄m^3), E=68 (GPa), σ_y =113 (MPa), σ_u =147 (MPa), ϑ =0.3). Energy absorbent plays an important role in the energy absorption and reduction of acceleration force exerted on the occupants in frontal crashes. Therefore, the history of this component was investigated in the present study.

3. Discussion

Analysis of the proposed energy absorber in the ABAQUS/CAE and comparison of results with two other absorbers on the basis of SEA and CFE factors showed that a wide energy absorber behaves much better than two smalls energy absorber assembled between two panels. Based on the results obtained from this test, it is presented a completely new model to improve the energy absorbers behavior that finally led to development of the energy absorber geometry shown in (**Figure 1**). Wide energy absorber with length 1.125 (m) and width 0.08 (m) is embedded behind the bumper. The constituent materials and the wideness of this absorber have enabled it to behave much better than two small absorbers on both sides of the vehicle.

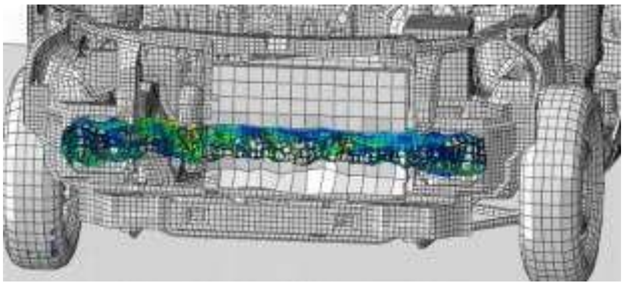

Figure 1: Energy absorber 64×4 cells status in time instants following the impact

Gray Relational Grade (GRG) was discovered by Deng in 1982 for working with incomplete information. Gray Relational Analysis can be used to solve complex inter-relationships among multi-objective. Gray normalized ranking for each level is calculated by averaging the coefficients of gray. Overall, in the GRD model if maximum or minimum quantities of objective are desired the output data is obtained using the eq. 1 or 2 respectively. **Table 1** shows the value of each factor that uses for the optimization problem.

$$X_i^{\circ}(k) = \frac{X_i^{(0)}(K) - \min. X_i^{(0)}(K)}{\max. X_i^{(0)}(K) - \min X_i^{(0)}(K)} \quad (1)$$

$$X_i^{\circ}(k) = \frac{\max. X_i^{(0)}(K) - X_i^{(0)}(K)}{\max. X_i^{(0)}(K) - \min X_i^{(0)}(K)} \quad (2)$$

Table *1*: Factor levels of the GRG optimization problem.

Factor	Variable	Level (1)	Level (2)	Level (3)
1	Number of Cells	8x2	64x4	128x8
2	Draft Angle	3	5	

4. Conclusions

The results represent a relative improvement in energy absorption and maximum acceleration responses in 64×4 Cells and 5 draft angle energy absorber. Application of the newly- introduced wide tapered multi-cell energy absorber has had a significant impact on energy absorption during full-frontal crash test.

Acknowledgments

The authors acknowledge the support from the projects POCI-01-0145-FEDER-032362, UID/EMS/00481/2013 and CENTRO-01-0145-FEDER-022083.

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Additively Manufactured AISI 316L Characterization for Metal Cutting Force Modelling

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Abstract
Despite the great deal of attention given to additive manufacturing (AM) of metallic components, functional parts obtained by that method are submitted to subtracting manufacturing finishing operations to ensure dimensional tolerances. The AM process nature results in parts with a distinct mechanical behaviour when compared to conventional equivalent materials (high anisotropy), putting emphasis on its characterization. This study focuses on the mechanical characterization of the AISI 316L stainless steel aiming the machining simulation. Distinct loading conditions and build orientations are explored for multiple specimen geometry fabricated with a fixed set of optimal parameters. Digital image correlation technique is used to validate the multiple applied loading conditions on the specimens. Experimental technological cutting tests are performed and the identification of constitutive laws is discussed.

Keywords. Additive Manufacturing; Metallic Materials; Material Characterization; Numerical Modelling.

1. Introduction

The distinct unconventional manner of additively fabricating parts has been gaining popularity due to the compelling design freedom and good mechanical behaviour, using minimum material resources. Such advantages make it suitable for a wide range of applications, from aeronautics to mould technology. Given that the main purpose of the fabricated parts is serving as functional components in system's assemblies (Wohlers 2017), surface quality as well as dimensional and geometrical tolerances need to be ensured. Subtractive methodologies (such as finishing metal cutting operations) are most often applied in the post-processing stages in order to meet those requirements (Kaynak et al. 2019). Despite the great focus given to the technology's parameters, little has been investigated regarding the material characterization that, due to the layer-by-layer manufacturing nature, reveals distinct properties from the conventionally manufactured materials and even less when it comes to characterization methodologies aiming to the metal cutting simulation (focusing on the characteristic high strain, strain rate and temperature conditions). The predictive control of the metal cutting operations can be of utmost importance in order not to jeopardize a highly valuable AM component but also in the way it can soften the effect of what is a major drawback in the additively fabricated parts – residual stresses. The large thermal gradients involved in the process result in compressive and tensile strains and stresses of the newly processed layers which contribute to the component's distortion when removed from the fabrication baseplate. The numerical simulation of the metal cutting process may allow to more accurately control the thermally induced state of stress, which goes in line with the current trends of smart manufacturing and process modelling.

This work focuses the development of a material characterization methodology for the AISI 316L stainless steel, envisioning the numerical simulation of metal cutting operations. A batch with multiple specimen geometries was fabricated in order to cover the study of various loading conditions (such as compression, mixed shear/compression and shear/tension) as well as different building orientations. Digital image correlation is used in order to confirm the predicted loading conditions are ensured, allowing for the identification of the plastic behaviour under different states of stress, which goes in line with the current constitutive modelling trends (Baie t al. 2008). It is important to note that these loading conditions are selected due to being identified as prevailing in primary deformation zone of the orthogonal cutting model, illustrated in **Figure 1**.

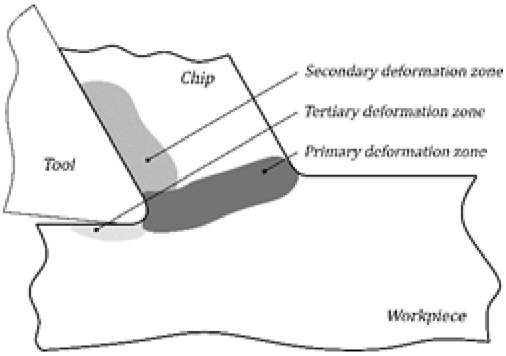

Figure 1: Orthogonal cutting model with the three deformation zones identified.

Since this study does not focus on the processing parameters selection, an already studied optimal configuration was chosen and a standard annealing heat treatment procedure was applied for residual stress relief. Since the material characterization in high ranges of strain, strain rate and temperature is a challenging and costly task, specimens destined to metal cutting experiments (orthogonal cutting and turning) were planned, enabling the discussion of using this experimental data to inversely identify constitutive laws capable of portraying the metal cutting plasticity and fracture phenomena.

Acknowledgments

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Chip Formation and Cutting Forces in Turning a Gamma Titanium Aluminide Alloy

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Abstract
The study of chip formation is a methodology commonly used for assessment the machinability of materials. This criterion identifies the main characteristics of chips and associates them with material properties, cutting parameters, cutting tools, process type and other factors involved in machining process (Astakhov 2010). γ-TiAl alloys are considered difficult to machining materials, mainly due to its low ductility and anisotropic microstructure. Consequently, the study of chip formation is not an easy task in this material. It is evident, that chip formation theories explained for metallic materials may not be appropriate to describe the mechanics of chip creation during machining γ-TiAl alloys (Priarone et al. 2012; Vargas Pérez 2005). The present research is focused on the comparative study of the chip formation in turning process of a gamma titanium aluminide alloy (Ti-48Al-2Nb-0.7Cr-0.3Si). Chip segmentation were study using a high-speed filming method. Experimental trials were conducted using cutting tools with PVD coated WC-Co inserts with round geometry, varying the cutting processing parameters (Vc: 45-70 m/min, and ap: 0.3-0.5 mm). Also, a cutting force were analyzed and discussed.

Keywords. Machinability, Titanium aluminide alloys, chip formation, cutting forces, round inserts.

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Mechanical behaviour of the AlSi9Cu3 aluminium alloy under combined stress fields

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Abstract

The paper investigates the plastic and fracture behaviours of the AlSi9Cu3 cast alloy covering low negative to high positive triaxialities, and exploring a recently proposed new testing specimen (so called Astakhov specimen) for intermediate negative-positive triaxialities. In addition, tensile tests of smooth and notched specimens were explored. The material revealed a pressure sensitive yield behaviour, as well as a fracture strain showing a cut-off limit for negative stress triaxialities, below which no failure is observed, and a sudden decrease of the facture strain with increasing stress triaxiality. A transition damage regime is expected for low positive stress triaxialities.

Keywords. AlSi9Cu3 cast alloy, Constitutive modelling, Drucker-Prager model, Damage, Fracture locus.

1. Introduction

Aluminium cast alloys (e.g. AlSi9Cu3) are very important for sustainable transports development. Despite an intensive research focus has been devoted to wrought aluminium allows, cast alloys have deserved less attention, despite their importance (Silva, 2019). Understanding the mechanical behaviour of cast aluminium alloys under combined multiaxial stress fields is fundamental, taking into account their applications in mechanical components. This is also important for the appropriate simulation of their processing such as by machining. Recently a new testing specimen (so called Astakhov specimen) has been proposed to allow the material behaviour characterization under combined stress fields: shear, shear+tensile and shear+compression loading. These tests were applied to investigate the plastic and fracture behaviours of the material. The experimental tests also included tensile and compression tests, which are presented and discussed, supported on numerical simulations using of Drucker-Prager constitutive material model.

2. Results and Conclusions

Tensile and compressive tests of smooth cylindrical specimens allowed identifying a significant strength-differential effect of the ALSi9Cu3 alloy, meaning a pressure sensitive yielding behaviour. The Drucker-Prager plasticity criterion was used to model the material plastic behaviour, the results being shown in **Figure 1**, left. The tensile tests were also performed for notched specimens allowing the evaluation of the material's ductility for high positive stress triaxialities. The compression tests on smooth cylindrical specimens did not revealed a clear failure mode.

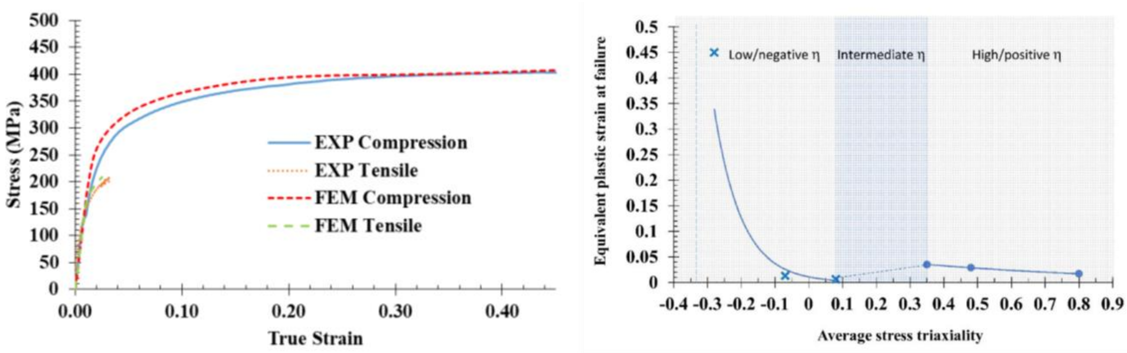

Figure 1: Smooth tensile and compressive behaviours – experimental vs. Drucker-Prager simulation results (left) and failure locus (right) for AlSi9Cu3 alloy.

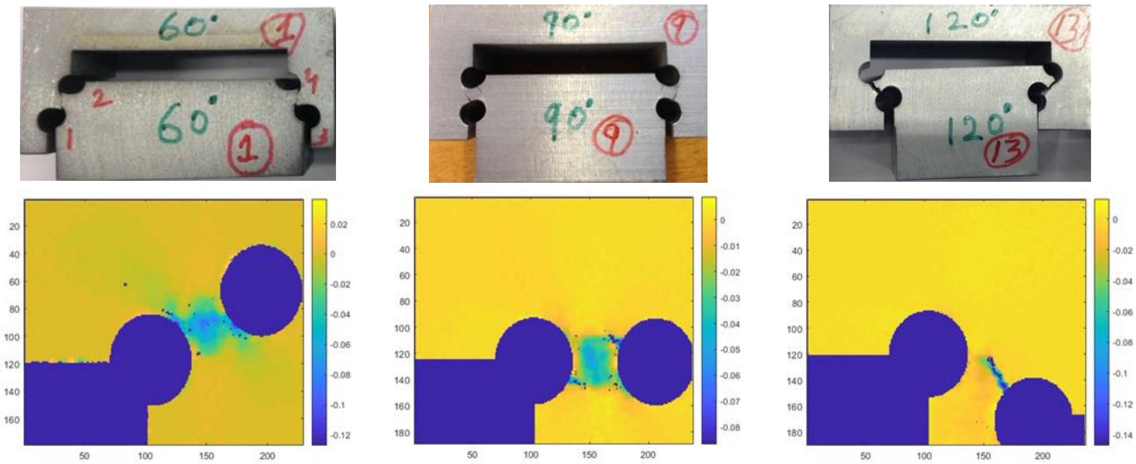

Figure 2: Astakhov fracture test results: failure appearance vs. DIC shear strain fields at failure instants.

A recently testing specimen was used to evaluate the material behaviour under combined stress fields: shear, shear+tensile and shear+compression loading. The tests were monitored using Digital Image Correlation (see **Figure 2**) and simulated using Drucker-Prager model. These tests allowed the material characterization between low negative triaxialities to low positive values. The resulting failure locus is presented in Figure 1 (right) for the cast alloy. The material revealed a pressure sensitive yield behaviour, as well as a fracture strain showing a cut-off limit for negative stress triaxialities, below which no failure is observed, and a sudden decrease of the facture strain with increasing stress triaxiality. A transition damage regime is expected for low positive stress triaxialities. Above triaxialities of -0.1, the material show very britle behaviour with failure strains bellow 0.05, which is due to the hard phases in α-Al matrix.

Acknowledgments

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Digital Fabrication, Engineering and Design: New ways of thinking, creating, acting, manufacturing and learning

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Abstract

This work discusses the interdisciplinary educational relationship between engineering and design in the context of digital fabricating. New social, cultural, economic and policy needs have demanded different educational approaches that stimulate creativity and inventiveness. The design can contribute in this context, demonstrating new ways to see, think, and act, centering in people needs, providing techniques and tools of project development and solution of complex problems based on design thinking principles like empathy, co-creation and experimentation as ways to integrate with other areas of knowledge such as engineering. The digital fabrication refers to processes that use the computer-controlled tools and the most important thing about design in this process is about to produce tangible objects on demand for business and education. The digital fabrication laboratories can be an environment where there is an opportunity to introduce more efficiently and naturally scientific and academic contents, necessary for the basic training of engineering.

Keywords. Digital fabrication, Engineering, Design Thinking, Higher Education.

1. Introduction

In engineering higher education, we have several questions to be answered: What needs are being generated? What competencies are required? What are the challenges proposed? What are the next steps that can turn the difficulties into possibilities? And we need a lot of actions necessary to attend these demands, such as: academic curriculum closer to professional practice, development of communication skills and teamwork, raising awareness of social, environmental, economic and legal issues, student-centered teaching and learning strategies, etc. (Mills & Treagust 2003). New social, cultural, economic, and policy needs have demanded different educational approaches that stimulate creativity and inventiveness (Imbernón 2000). The design can contribute in this context, demonstrating new ways to see, think, and act, putting people and their needs at the center of the process, providing techniques and tools of project development and solution of complex problems based on the design thinking principles like empathy, co-creation and experimentation as ways to integrate with other areas of knowledge such as engineering. The digital fabrication refers to processes that use the computer-controlled tools and the most important thing about design in this process is about to produce tangible objects on demand for business and education (Gershenfeld 2012). In this scenario, digital fabrication laboratories can be an environment where there is an opportunity to introduce more efficiently and naturally scientific and academic contents, necessary for the basic training of engineering.

2. Materials and Methods

The research was based on a theoretical referential survey based on the following topics: the current scenario in engineering and design higher education, aspects of engineering design, "soft skills" currently required in the formation of the engineer, the industry 4.0, the maker movement and digital fabrication, the (r)evolution of design/fabrication process and the aspects of the maker education.

3. Discussion

The main discussion here is about how is the process of project development, teaching and learning in a digital fabrication mode, what is the characteristics of a digital fabrication educational lab and what is the contribution of design in this context. Some case studies will be presented to show some applications of digital manufacturing in both industry and engineering academic scopes.

4. Conclusions

This paper is part of a larger project in progress, a doctoral research, that addresses the teaching of design in the engineering courses in a transdisciplinary way and analyzes how this relationship happens more specifically in the prototyping laboratories like the Fab Labs.

Acknowledgments

This study was financed in part by the Coordination of Improvement of Higher Education Personnel (CAPES - Brazil) - Finance Code 001, Anhembi Morumbi University (UAM – Brazil) and Mauá Institute of Technology (IMT - Brazil).

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Influence of the infill shape and orientation on mechanical properties of PLA 3D parts

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Abstract
The use of low-cost Fused Filament Fabrication (FFF) machines has been growing in the last years. However, it is also necessary to have parts with better quality and mechanical properties. Recent studies about gyroid models produced by Additive Manufacturing have shown that this geometry is very resistant due to its isotropic mechanical behavior. This work aims to study the influence of this inner infill geometry on the mechanical properties of PLA parts. Samples for tensile, compression and bending were printed in a Ender3 and Creality CR10s were produced with 100% infill and orientations: 0° ,45°,+-45°,90° and with the gyroid infill, 20%,50%,80% density. The specimens were tested on a universal testing machine.

Keywords. Gyroid models, low cost machines, Fused Filament Fabrication, Infill

1. Introduction

Fused Filament Fabrication (FFF) is one of the most used Additive Manufacturing technologies due to low cost machines and materials. It is accessible to everyone, regardless of their technic know-how. The main difference between FFF and Fused Deposition Modelling (FDM) concerns more in the legal aspects than in the technological one. FDM is the designation for a technology and commercial brand patented by Stratasys. The designation FFF was adopted later and boosted by the open source concept, RepRap, as a more generic way to present the additive material extrusion manufacturing through the material deposition passing by a nozzle (Wohlers et al. 2018).

The biggest barriers for FFF machines being widely used in the industry is its low repeatability and the difficulty to predict quantitatively the influence of the printing parameters on the printed parts.

The Gyroid is a porous complex structure. It was experimentally discovered by Alan Schoen in 1960 and its main interest is due to the combination of local and global homogeneity, so it presents equal resistance to compression regardless of the solicitation direction. This structure is only possible to be produced by additive technologies because of its complex surface, which is even more important than the material itself. The use of this structure to build a repetitive foam will allow to achieve enhanced properties with PLA, making it a stronger and lighter part (Khaderi, Deshpande and Fleck 2014; Monkova et al. 2017).

Thus, this work aims to study the influence of the infill geometry on the mechanical properties of the parts.

2. Materials and Methods

The study was divided in two stages. First, the specimens were printed with 100% and orientations of :45º, +-45º, 90º, 0º. Hence, they were tested in tensile, bending and compression. 10 specimens were printed for each orientation and test, generating a total of 160 samples.

The second stage was designed to test the gyroid infill. Samples were printed with three different densities: 20%, 50%, 80% and characterized under the same standards (10 samples for each density). Cubic specimens (2 x 2 x 2 mm) were also printed to evaluate the isotropy (15 samples). So, generating in total 135 samples.

3. Discussion

The mechanical properties of the PLA parts were determined by tensile, compression and bending tests. The bonding morphology of the layer on fracture surfaces of the tested samples were evaluated by optical an electronic microscopy.

4. Conclusions

The experimental results indicate that the infill used is very important on the mechanical properties obtained, being the gyroid infill the best option, because of the combination of the mechanical properties gained, the speed of the process and weight. The best combination of properties for a 100% infill orientation is, as expected, gained with the +/-45º orientation.

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Development of a miniature testing for sheet metal mechanical characterization

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Abstract

The miniature tensile testing is a simple yet powerful method to characterize the behavior of a material (Sousa, 2017). Based on this technique, an experimental system was developed aiming the determination of sheet metal mechanical properties. A tensile-compression loading device was designed capable to achieve a strain rate of about 10 -3 s-1at the gage section level. Being the buckling behavior an important phenomenon, a miniature sample geometry was studied and optimized to minimize and to avoid such effect (Boger, 2005). The sample has an uniform section of 2x2 mm. The device includes custom-made clamps that guarantee the alignment of the sample with respect to the loading axis, guided by linear bearings; it also includes a recirculating roller screw actuated by a step-motor that ensure a continuous and accurate motion. To measure the force during the test an "S"- type load cell is used while the evaluation of the surface strain fields is performed by digital image correlation technique. Following these measurements, hardening curves are evaluated and plotted. Additionally, numerical simulations are performed for the different loading conditions and the obtained results are compared with experimental data, thus being possible to study phenomena such as the Bauschinger and stress differential effects of metallic sheets.

Keywords. tensile test, material mechanical characterization, Bauschinger effect, stress differential.

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Development of a Mechanical Sheet Metal Characterization System

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Abstract

Tensile machines are commonly used in mechanical labs to perform tensile, compression or bending tests (Callister, 2007). This work presents the development of a LabVIEW software application to control and acquire the data of a tensile testing machine. This device is meant to perform experimental mechanical tests in metallic sheet specimens with the main goal of promoting the development and study of plastic forming processes. The device can be controlled either through a GPIB (General Purpose Interface Bus) communication protocol, using a GPIB to USB-B converter or by the local HMI (Human Machine Interface) attached to the machine load frame. The acquisition of the force and displacement is performed using a *National Instruments* data acquisition board, and a LabVIEW application that is able to read, process, display and record the data, as well as, to interact with the tensile testing using the GPIB for status check and commands (Mihura, 2001). Two cameras were installed in the machine, a Microsoft HD webcam for overall scene record, and a professional Ethernet camera equipped with a 75x zoom to evaluate the deformation of the specimen. Thus, the software includes also a module for artificial vision, which is able to process the images and extract the deformation. The interface includes the most common tests and default settings for the respective parameters, making the user interface friendly and easy to use, even for non-specialized professionals.

Keywords: LabVIEW, Tensile Tester, INSTRON 4466, IEEE-488, GPIB, Data Acquisition, Computer Control

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Development of a Control Unit and Data Acquisition System for a Sheet Metal Universal Testing Machine

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Abstract

A sheet metal universal testing machine is a fundamental need to material formability characterization. This type of machine is flexible enough to perform various tests, which include formability testing such as Nakajima, Fukui, Marciniak and Swift tests, in addition to Hole Expansion tests. The failure prediction of formability behaviour during analysis of sheet metal forming helps the optimization of process and the tool design, by evaluating the manufacturability of a designed part and the selection of materials, based on the complexity and strength requirements (Altan and Tekkaya 2012). The upgrade and new developments in the universal testing machine are divided into three main tasks: (i) collected the machine information and characteristics; (ii) replacement of old components, adding current automation and control capabilities, namely a new programmable logic controller (PLC) and human machine interface (HMI) with updated specifications; (iii) experimental mechanical tests and comparison with the numerical results. The PLC is linked to a Matlab application for real-time data acquisition using the app designer (Matworks) add-on using Ethernet communication. The PLC implements the standard tests, control position and displacement of the Punch. Results of developments will bring a better understanding and validation of numerical results and will provide flexibility to future developments, in order to improve control and data analysis, in addition to allowing diverse mechanical tests with up-to-date technological components. The connectivity and flexibility commonly used in Industry 4.0 will be conceivable to use for web control or remote data acquisition (Ortelt et al. 2014).

Keywords. Universal testing machine, sheet metal forming, formability, automation.

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Sheet metal forming simulation and experimental validation using defined benchmarks

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Abstract

Stamping is a plastic forming process, starting from a sheet of metal in which the main objective is to obtain a part by plastic deformation. Nowadays, numerical simulation is a key point in the design phase of a product, aiming to predict, validate and optimize the results of the manufacturing process. However, accuracy of forming and springback predictions represents a key point on finite element analysis of sheet metal forming processes (Barros et al. 2016), especially when using high strength steels and aluminum alloys. In this contribution case studies are presented, aiming to test and validate numerical results and corresponding model definitions of process conditions and material descriptions. One application is the prediction of forming and springback for an aluminum panel of a car component. This part has been defined and proposed as a benchmark at NUMISHEET 2016 series of conferences. Results are compared with experiments, as well as other numerical results, submitted by benchmark participants. Another application is a deep drawing cylindrical cup test and the objectives include the study and the influence of different yield criteria in the finite element (FE) results (Amaral et al. 2019). Dual-phase steel sheets containing different amounts of martensite are considered. Results for this kind of advanced high strength steels include punch force evolution and the earing height profiles. Experimental tests are also being carried out, thus being possible to compare and validate obtained numerical results.

Keywords. Springback Prediction, Finite Element Method, Sheet Metal Forming

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Overview about the Application of Driven Tools for Turning Operations

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Abstract

In this modern age full of various kinds of products most of the companies are pushed to create and manufacture a lot of products requested by the market with maintaining their quality and accuracy. This process is necessary in the mechanical engineering. Companies focused on mechanical engineering must addere to this situation if they want to stay in competition. Mechanical engineering companies are willing to apply the system this development process to get better their machinery, manufacturing processes and tools as well. Workers in development field develop these things in addiction to what the market needs and what will help with making their productions easier. These facts are very important from an economic perspective, because when companies need to create some products and their nowadays machines that are not able to create requested options. They have an option to buy new equipments. This decision is in many cases not ideal from the economic perspective and development field can create solution like upgrading already used machines or tools, which can save a lot of money. This work solves the situation with upgrading machining center for turning. For machining center will be designed new rotary tool with external drive. Contraction solution have to count on spatial restriction and required stiffness. Whole construction needs to be reliable and resist vibrations and overcome resistance when the tool is cutting metal. Tool will be designed to make angular adjustment possible as well. This adjustment cause deflection from cutting position and will needed to return to his origin position. To return to its original position it will be necessary for construction to provide linear guidance with setting position. This whole upgrade of the machine provides new possibilities for turning, because of adding for machining another driven axis. Big advantage is in possibilities for machining very hard materials, for example titanium alloys because tools with his own rotation cause that the heat is dissipated from the cut place. Tools like that have longer lives, better performance and bigger effectivity. Main reason is good cooling of the tool, which is done by rotation draining the heat from the cutting place. Big advantages are that you can modify your machine cheaper and create machine with another driven axis and create better technology. Also, you can create more complex products, practically in one clamp. In turning area are already rotary tools used, but mainly those so-called autorotation tools. It means that main rotary movement is caused by the friction between workpiece surface and surface of the cutting part of the tool. Tools like that were testing for example in past at University of Zilina by professor Pilc. Turning with rotary tool which is driven externally are not tested that frequently and this work will provide research regarding that tools and provide new possibilities of usage these tools in practical manufacture. The research could possibility solve the quality requirements of the surface after machining by changing the directions in rotary movements and rotary speed as well. Another possibility is the changing of the tool angle and check its impact on machining quality. Final part of the research is focused on chip control.

Keywords. Driven tools, machining, turning, develop, materials

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Residual stresses in PMO material during the production of tools

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Abstract

The process of multi-axis machining and the change of technological production operations ensure significantly shortening manufacturing times in the production of moulds. This is an inseparable part of the efficiency improvement in moulding tools production. Another major factor in the production of these tools is the required surface quality. The surface quality is affected by many factors like, fatigue strength, wear rate, corrosion resistance and so on. Steel components go through different temperature phases during production. Therefore, it is necessary to examine the integrity of the surface in the production of moulding tools. They are introduced in heat processing and machining. The residual stress values that are included in each operation are diametrically different, so it is crucial to choose the most appropriate operations. In the experimental part we will examine if we are able to maintain the required precision and quality of the tool when we change the production technology from grinding to hard milling. Subsequently, we will examine if the introduced residual stresses have a positive or negative impact on tool longetivity. During experimental measurements of tools that were made by grinding technology, we found residual stresses that had a negative impact on durability. The goal of this work is to analyse the residual stress induced by the designed prototype of the moulding tools with X-ray diffractometer and also to evaluate and review if the residual stresses under the surface have the required values and if it is possible to make moulding tools of the demanded quality by using selected materials and production technologies or if it is vital to make some changes in production technology. There is an acceptable occurrence of pressure stresses in moulding tools, then atoms tend to be grouped and counteract the cracks in the workpiece. Whereas no one dealt with a similar solution in certain material and certain production conditions, it is appropriate to publish these experimental measurements and results to further progress.

Keywords. Tools, production, residual stress, materials.

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Flexural test for specimen with different size and shape of inner structures created by 3D printing.

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Abstract
The paper is focused to size and shape influence analysis of inner structures from flexural test. Aim this paper will mechanical properties from flexural test. Specimens are created by 3D printing. Material for specimens is composite material Onyx. Flexural test measures stress from the force required to bend a beam under three points loading conditions. Aim this paper is to find out the data, which will used to select choice size and shape of the inner structure dimensions for parts that will loads with flexing. Flexural modulus is used as an indication of a material's stiffness when flexed. By optimizing the size and shape of the inner structure to ensure the choice of the right structure for a given issue with regard to material consumption. The samples are sized according to ISO 178. The test is carried out according to ASTM D790 and next ISO 178. Test will measure the force required to bend the specimen he test is stopped when the specimen reaches 5% deflection or the specimen breaks before 5%. If the sample can withstand the desired deflection, the test will continue by norm ISO 178 and the test is stopped when the specimen breaks. These data will processed in tables and graphs and compared with boundary values. The lower limit or value will be a hollow sample. The upper limit will be a solid sample where the highest stiffness is expected.

Keywords. Flexural test, Size, Shape, Inner Structure, Specimen, Onyx, Optimization.

1. Introduction

The flexural test measures the force required to bend a beam under three point loading conditions. The data is often used to select materials for parts that will support loads without flexing. Flexural modulus is used as an indication of a material's stiffness when flexed.

The specimen lies on a support span and the load is applied to the center by the loading nose producing three point bending at a specified rate. The parameters for this test are the support span, the speed of the loading, and the maximum deflection for the test. By optimizing the size and shape of the inner structure to ensure the choice of the right structure for a given issue with regard to material consumption. The samples are sized according to ISO 178. The test is carried out according to ASTM D790 and next ISO 178. Test will measure the force required to bend the specimenhe test is stopped when the specimen reaches 5% deflection or the specimen breaks before 5%. If the sample can withstand the desired deflection, the test will continue by norm ISO 178 and the test is stopped when the specimen breaks. For the Specimen shape will used size from norm ISO 178. It is 10mm x 4mm x 80mm.

2. Material and method

2.1. Composite material Onyx

Onyx is a composite filament for Mark Two Enterprise 3D printers. A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. Onyx is not just only another plastic material, it’s actually a fusion of engineering nylon and chopped carbon fiber. This chopped carbon fiber filament adds stiffness to 3D printed parts, not only providing micro-carbon reinforcement to keep parts true to their dimensions, but also giving parts a smooth, matte black finish. Onyx have properties, where are valued in 3D printing: hardness, nice surface finish, and good adhesion so parts don’t split along layer seams. Onyx is about 3.5 times stiffer than standard nylon because of the micro-carbon reinforcement. Because it also contains nylon, the engineering toughness and wear resistance is comparable as well, and the material has a heat deflection temperature of 145 °C. Onyx is can use it with high-strength fibers – carbon fiber, Kevlar, fiberglass, or HSHT fiberglass, to even further strengthen parts.

Table *1*: Datasheet of Onyx by norm ASTM D790

Materials	Flexural Strength (MPa)	Flexural Modulus (GPa)	Specific Weight (g/cm^3)
Onyx	81	2,9	1,18
Nylon	32	0,84	1,10

2.2. Specimens

Specimens will created from material Onyx with additive technology Fused Filament fabrication. Specimens will have 80mm x 10mm x 4mm dimensions. Their differents will in inner structure. Final number of specimens will created 10 types. This Specimens have differents size and shape inner structure. First group will have shape square, second group is hexagonal and third group is triangles. This shapes have others sizes 2, 4 and 6 mm. Thickness fringes and wall between shapes is 0,8 mm. Settings by 3D printing are 2 layers by 0,4mm and 4 roof and floor layers.

3. Conclusions

Results will datas from flexural test. Aim will comparing different shape and size between each other. From these results, can conclude which structure at a given size can best transmit the bending load and maximum load size. This results will comparing on the volume consumed material. All results will writing in tables and graphically comparing each other in the graph. The lower limit will be an empty specimen and the upper limit will be a full specimen.

Acknowledgments

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Effect of Mechanical Properties Variability of an Advance High Strength Steel in Sheet Metal Forming Processes

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Abstract

The sheet metal material properties can vary between suppliers, as well as, between different batches and coils (Lazarescu 2013). Being the design phase of a sheet metal component an important topic for the forming industry, the scatter of the mechanical properties needs to be lower in order to guarantee the robustness of the process (Prates 2018). This paper presents a study on the variability of sheet metal material properties and associated scattering, considering different suppliers. An Advanced High Strength Steel grade was selected for this analysis, namely a dual-phase steel (DP600). Uniaxial tensile test are performed to obtain the material fundamental properties and the corresponding stress-strain hardening curves, for different loading angles relative to the sheet rolling direction. Additionally, standard hole expansion tests (HET) and Erichsen tests are performed, in order to identify and to observe the effect in material formability of the scatter between the different sheet samples. Numerical simulations were taken into consideration, using the obtained mechanical characterization and evaluating corresponding influence on results.

Keywords. Sheet metal forming, material scattering, numerical simulation, hole expansion test, erichsen test, dual-phase steel.

Acknowledgments

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Numerical Analysis Based on Non-associated Flow for Forming of Anisotropic Sheet Metals

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Abstract

A numerical analysis based on non-associated flow rule is presented and applied to forming of anisotropic sheet metals. This model is defined in the quadratic form of the Hill's48 anisotropic function under a general three-dimensional stress condition. The anisotropic parameters for the yield function are identified using the directional planar yield stresses, bulge yield stress and shear yield stress, while those for the plastic potential function are identified using the directional r-values. A full expression related to the non-associated flow rule is applied and the model was implemented into the finite element code ABAQUS, using a dynamic-explicit analysis (Wang *et al.*, 2014; Cvitanić and Kovačić, 2017). Capabilities of developed model for predicting the anisotropic behavior of sheet metal are investigated by considering cup heights and through-thickness strain distributions obtained from the simulations (Wu, 2019). Numerical results were compared with experimental data. Results demonstrate that the developed material model considering 3D condition can improve accuracy of predicting the anisotropic behavior. Furthermore, the simple formulations are efficient and user-friendly for computational analyses and to solve common industrial sheet metal forming problems (Ming and Pantalé, 2018).

Keywords. Sheet metal forming, Non-associated Flow, Anisotropic material, Constitutive behavior, Finite element.

Acknowledgments

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Drawability and formability numerical and experimental analysis of dual-phase steels using a deep drawing test

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Abstract

This paper presents a drawability and formability analysis of dual-phase steel sheets using a deep drawing cylindrical cup test. Finite element simulations have been performed, considering different anisotropic yield criteria to describe the material behaviour, as well as, experimental tests in order to compare and evaluate the acquired results. Force vs. displacement curves and thickness distribution along the cup wall were obtained, in addition to height evolution of cup earing.

Keywords. Dual-phase steels, sheet metal forming, deep drawing cylindrical cup, FE simulation.

1. Introduction

Advanced High Strength Steels (AHSS) are among the materials which are currently seeing increased usage and implementation in weight reduction efforts, due to their high strength-to-weight ratio. Dual Phase (DP) steel sheets, as the most common type of AHSS, have been used in automotive industry for lightweight design, due to the combination of unique mechanical properties such as high tensile strength and high work hardening rate at early stages of plastic deformation.

One of the widely used sheet metal forming processes in the automotive industry to produce most of the necessary components of a vehicle body is the deep drawing. Although extensive research on drawability of sheet metal materials has been published, taking into account the application of numerical methods (Hilditch et al. 2015, Bandyopadhyay et al. 2015), the drawing and formability behaviour of DP steels has still many questions to be solved.

2. Materials and experimental setup

Different grades of dual-phase steels were selected (DP500 and DP780) with the same initial thickness (0.8 mm), which contributes to a better comparison, as well as, a more adequate and more accurate material characterization and analysis. The anisotropic behaviour is modelled by the Hill 48', Yld'91 and CPB06 yield criteria.

The cylindrical cup test tool setup is composed by a die, a cylindrical punch, a blank holder and a stopper (Amaral et al. 2018). The die diameter is 62.4 mm and its radius 10 mm, while the punch has a diameter of 60 mm. The uniqueness of this experimental tool setup are features that allow to reduce and avoid the pinching effect at the end of the drawing stage and also to minimize any misalignment of circular blank relative to the tools.

2.1. Results and discussion

The obtained force vs. displacement curves using the implemented yield criteria are shown in **Figure 1**, as well as, the wall thickness distribution of the cup along the rolling direction of the steel sheet.

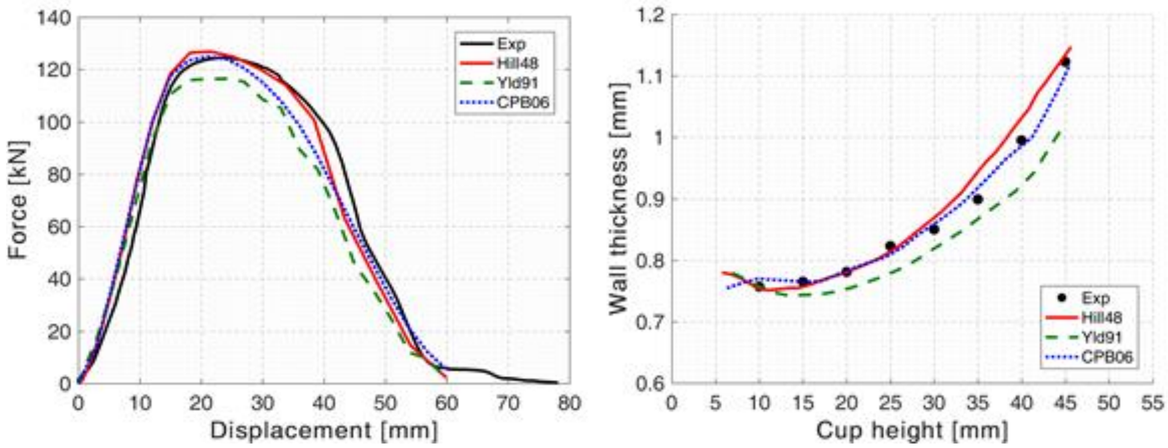

Figure 1: Numerical and experimental results comparison for the dual-phase steel DP780 using an initial blank diameter of 125 mm: force vs. displacement curves (left) and wall thickness distribution along rolling direction (right)

As seen, the experimental punch force vs. displacement evolution is well predicted by the FE simulation for all the selected yield criteria. On the other hand, the Yld'91 wall thickness show a lower tendency when compared to the experimental measured points.

3. Conclusions

In this paper, a numerical analysis of a deep drawing cylindrical cup was performed, considering the Hill'48, Yld'91 and CPB06 yield criteria to describe the anisotropic mechanical behaviour of the two dual-phase steel sheets grades (DP500 and DP780). Experimental tests were carried out to evaluate and validate the numerical predictions. The obtained force vs. displacement curves from numerical simulation show not be very sensitive to the implemented yield criteria, being very close to the experimental data. Regarding the thickness distribution along the cup wall, Hill48' and CPB06 show a similar tendency and a good agreement with measured experimental points.

Acknowledgments

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COMPUTATIONAL MECHANICS

Application of phase-field diffusive crack approach in a ductile damage model

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Abstract
The present contribution addresses a novel methodology to couple an existing ductile damage law with the phase-field diffusive crack approach. In this modeling, the phase-field crack order parameter is driven by the accumulation of damage through a crack driving force defined via a state function in the post-critical range, which is characterized by a crack initiation criterion. The application of the approach is validated and compared with a known benchmark under a tensile test.

Keywords. Ductile damage law, Phase-field approach, Crack driving force, Crack initiation.

1. Introduction

For decades it has been of increasing interest in engineering communities to study the material degradation to prevent catastrophic failures in industrial and non-industrial applications. Recent variational-based phase-field diffusive approach in fracture has gained an enormous popularity due to its superior features in various fracture situations such as crack branching and bifurcation, whereby it has ability to be verified on a single mesh discretisation with a relatively straight-forward computational implementation. Although it has been well-developed in brittle fracture context, to name a few (Borden et al. 2012; C. Miehe, Welschinger, and Hofacker 2010), there is an ongoing research on its application on ductile materials (Aldakheel, Wriggers, and Miehe 2017; Christian Miehe et al. 2015). This study utilizes the predictive capability of the phase-field approach in initiation and propagation of macro-cracks in an inelastic material framework, whereby the Rousselier ductile damage law is employed to model the internal material degradation.

2. Materials and Methods

The Rousselier ductile damage law can be defined based on the following plastic potential:

$$\phi = \frac{\sigma_{eq}}{\rho} - R(\alpha) + \sigma_1 f\, D \exp\left(\frac{-p}{\rho\sigma_1}\right) \tag{1}$$

where σ_{eq} is the effective stress, $R(\alpha)$ is the hardening function, ρ is the density of the voids, f is the void volume fraction, p is the pressure and σ_1 and D are the model parameters. The coupling is made using a phase-field driving force based on the energy of damage, reads:

$$\mathcal{H} = \max_{\tau\in[0,t]}\{F_D\} \quad ; \quad F_D = \eta\sigma_1 f\, D \exp\left(\frac{p}{\rho\sigma_1}\right) \tag{2}$$

which appears in the strong form of the boundary value problem defined on the body Ω as:

$$\begin{aligned} \nabla\boldsymbol{\sigma} - \boldsymbol{b} &= 0 \quad in \quad \Omega \\ \frac{g_c}{l}(d - l^2\Delta d) &= 2(1-d)\mathcal{H} \quad in \quad \Omega \end{aligned} \tag{3}$$

being g_c the critical energy release, d and l the phase-field crack and length scale respectively.

3. Discussion

The above problem is treated with finite element method and is implemented via a staggered integration algorithm using a user material interface (UMAT) and a parallel solver embedded in user element interface (UEL) in ABAQUS/Standard. The results are verified through analysis of a notched round bar tensile test with the notch radius of $4\ mm$ and the sequence of the void volume fraction and the phase-field crack are visualized in Fig. 1. Accordingly, the damage is initiated from notches and localized on the central part, where crack starts to propagate after a certain point characterizes by the critical void volume fraction value $f_c = 0.02$.

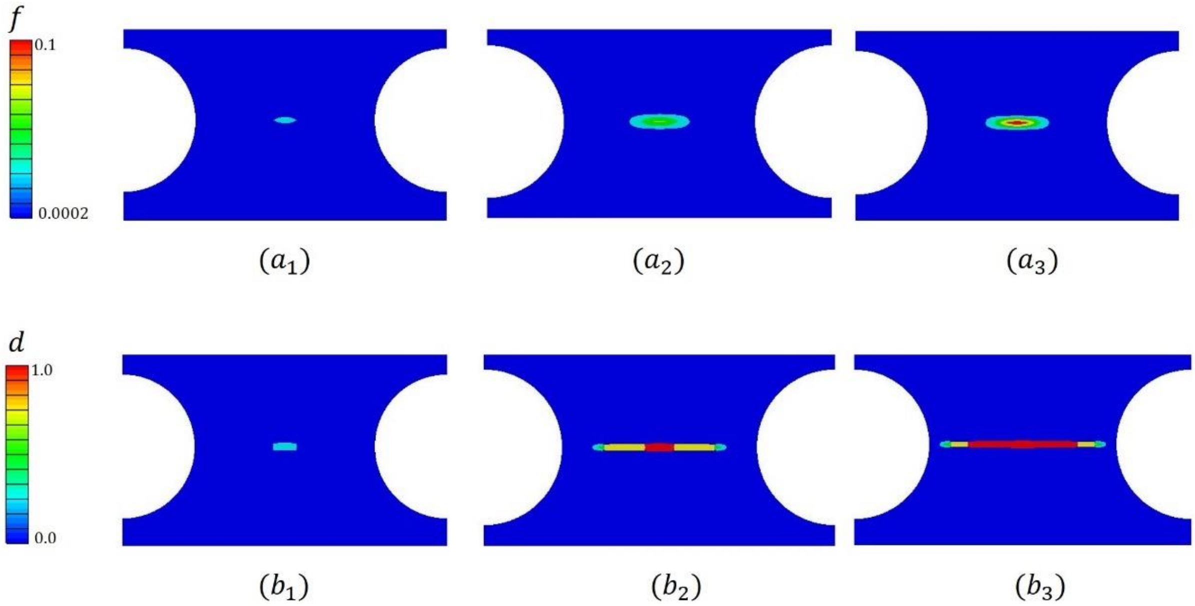

Figure 1: Contour plots showing distributions of void volume fraction (a_1-a_3) and phase field (b_1-b_3) in notched round bar tensile test

4. Conclusions

In this study, the crack development including initiation and propagation was investigated using the phase-field approach within the ductile damage context. The qualitative result on a tensile test showed a promising predictive capability of the implemented methodology.

Acknowledgments

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Simulation of failure in laminated polymer composites: building-block validation

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Abstract

The development of numerical tools to complement the experimental determination of structural design parameters is of key importance to hasten the certification process of new materials and structures. A methodology to simulate elastic and inelastic deformation of composite laminates at the subcomponent level based on finite element analysis is proposed. A modified version of a continuum damage model proposed in the literature combined with a frictional cohesive zone model is used to capture the intralaminar and interlaminar damage and failure of composite laminates in general loading conditions. The methodology is validated for three aerospace-grade carbon fibre reinforced (epoxy) polymer composite material systems and coupon configurations with increasing level of complexity. The predictions obtained are in good agreement with the experimental results for all the test cases, with maximum relative error of 13%.

Keywords. Composite laminates, Continuum damage mechanics, Finite element analysis

1. Introduction

The design of composite structures is based on testing and simulation of composite coupons that represent structural details under simple loading scenarios, following an approach known as the building block approach. This process ensures that a deep understanding of the structural behaviour under simple loading conditions is gained at the early stages of the design process, consequently mitigating the risk associated with the design of complex structures. The experimental determination of these design parameters is an inherently costly and time-consuming process, and consequently delays both the introduction of new materials and the design of new structures, two aspects that are critical for the competitiveness of the aeronautical industry. The development of numerical models to complement, or potentially replace, the purely experimental determination of the design parameters is, therefore, of key importance. The objective of this work is to develop and implement a methodology to simulate composite laminates at coupon level compatible with industrial requirements.

2. Modeling strategy and numerical results

A methodology to simulate composite laminates at the coupon level based on modifications implemented in the continuum damage model proposed by Maimí et al. (Maimí 2007) and in the cohesive zone models based on the work of Turon et al. (Turon et al. 2018) and Alfano et al. (Alfano and Sacco 2006) was proposed. The continuum damage model proposed by Maimí et al. (Maimí 2007) was enriched with a bilinear cohesive law for longitudinal compression more suitable to represent kinking failure. Additionally, a damage activation function for longitudinal compression that accounts for the effect of though-thickness stresses based on the 3D failure criteria proposed by Camanho et al. (Camanho et al. 2015) and engineering solutions to account for the effect of pressure on the longitudinal compression and in-plane shear fracture toughness were proposed. A frictional cohesive model was used in this work to more accurately represent delamination propagation and load carrying capability in test cases where the effect of through-thickness pressure cannot be neglected. The methodology was thoroughly validated for various material systems and coupons with increasing level of complexity: from unnotched tension and compression, open-hole tension and compression and filled-hole compression of both soft and hard laminates. A good agreement was found between the predictions and the experimental ultimate strengths for all the test cases, with maximum relative error of 13%.

3. Conclusions

The models developed follow the requirements typically used by the aeronautical industry, in terms of element size and mesh structure. Additionally, all the predictions were obtained using a common set of material properties and material models. These facts indicate that the work presented is a step towards the simulation of failure of composite structures using a standard modelling strategy. The work serves as basis for modelling more complex geometries and can potentially be used for the generation of statistically-based design allowables.

Acknowledgments

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An assessment of a micromechanical damage model for porous solids exhibiting tension–compression asymmetry

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Abstract
The Cazacu and Stewart (2009) yield criterion is assessed regarding the damage process of porous solids exhibiting tension-compression asymmetry. It is shown that, under tensile axisymmetric loadings, the model will predict two distinct behaviours for the damage evolution, depending on the sign of the third deviatoric stress invariant. It is highlighted that for negative values of this invariant, the criterion will not account for Strength Differential (SD) effects on the direction of the plastic strain increment and, eventually, on the porosity evolution.

Keywords. Ductile damage, Porous materials, Micromechanical damage model, CPB06, SD Effects

1. Introduction

Cazacu and Stewart (2009) derived a plastic potential for porous aggregates containing randomly distributed spherical voids. The SD effects are accounted by the isotropic form of the CPB06 yield criterion (Cazacu, Plunkett, and Barlat 2006). Assuming the associated plastic flow rule, the Cazacu and Stewart (2009) yield criterion, φ is of the form:

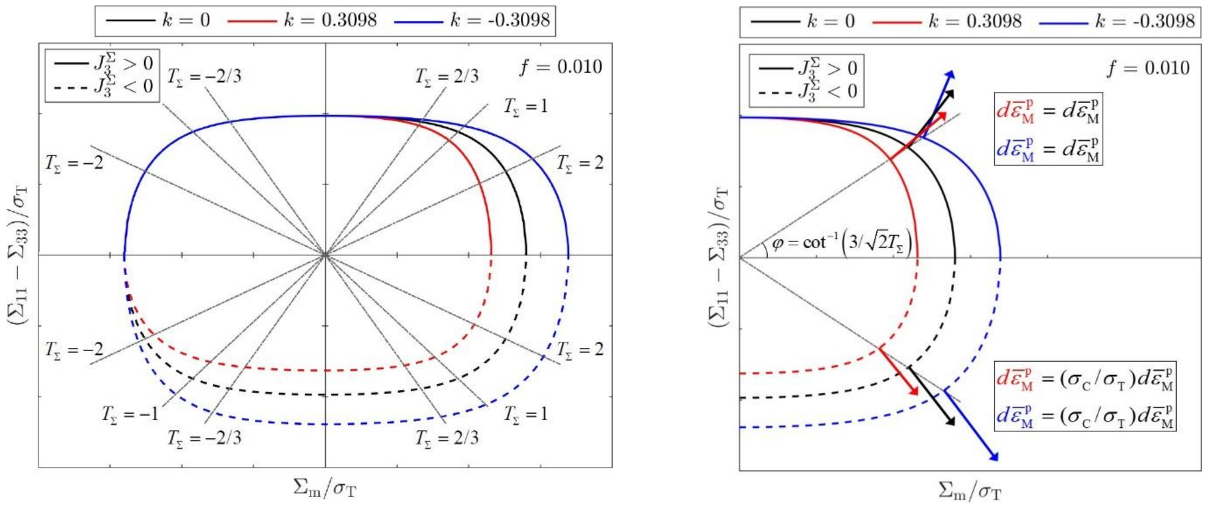
$$\varphi(\Sigma', k, \sigma_T, f) = \left(\frac{m\sqrt{\sum_{i=1}^{3}\left(|\Sigma_i'| - k\Sigma_i'\right)^2}}{\sigma_T}\right)^2 + 2q_1 f \cosh\left(z_s \frac{3q_2\Sigma_m}{2\sigma_T}\right) - q_3 f^2 - 1 = 0 \quad (1)$$

where Σ_i', $i = 1,2,3$ are the principal values of the deviatoric Cauchy stress tensor; Σ_m is the macroscopic mean stress; f is the void volume fraction; q_i, $i = 1,2,3$ are fitting parameters; and k and z_s are parameters that depend on the tension-compression asymmetry ratio, σ_T/σ_C where σ_T and σ_C are the uniaxial yield in tension and in compression, respectively. z_s also depends on the sign of the mean stress.

The main goal of this work is to study the Cazacu and Stewart (2009) yield loci for porous aggregates displaying different levels of tension-compression asymmetry, in order to understand the role played by the SD effects on the plasticity and damage evolution with respect to the imposed stress state, particularly for axisymmetric tensile loadings.

2. Cazacu and Stewart (2009) criterion under macroscopic axisymmetric stress states

In order to illustrate the dependence of the studied yield criterion on the third invariant of the stress deviator, $J_3^\Sigma = \Sigma_1'\Sigma_2'\Sigma_3'$, let $(\mathbf{e}_1, \mathbf{e}_2, \mathbf{e}_3)$ denote the reference frame. An axisymmetric loading about the $\mathbf{e}_3$ axis is characterized by Σ_{11}=Σ_{22}, such that $\mathbf{\Sigma} = \Sigma_{11}(\mathbf{e}_1 \otimes \mathbf{e}_1 + \mathbf{e}_2 \otimes \mathbf{e}_2) + \Sigma_{33}(\mathbf{e}_3 \otimes \mathbf{e}_3)$, with Σ_{11} and Σ_{33} denoting the imposed macroscopic lateral and axial stress, respectively. For such loadings the mean stress is $\Sigma_m = (2\Sigma_{11} + \Sigma_{33})/3$ and the von Mises equivalent stress is $\Sigma_e = \sqrt{3J_2^\Sigma} = |\Sigma_{11} - \Sigma_{33}|$. **Figure *1*** (a) illustrates the yield surfaces for three porous solids displaying different SD effects. The yield loci are intercepted by straight lines through the origin, representing different stress triaxialities, $T_\Sigma = \Sigma_m / \Sigma_e$. In this projection, positive values of (Σ_{11}–Σ_{33}) correspond to positive values of J_3^Σ and vice versa. **Figure *1*** (b) details the case of tensile axisymmetric loadings, i.e. $\Sigma_m \geq 0$. Note that the yield curves for $J_3^\Sigma \leq 0$ are obtained through homothetic transformations of each other, unlike for loadings with $J_3^\Sigma \geq 0$. Indeed, the yield criterion in the fourth quadrant of **Figure *1*** (a) is a homogenous function with degree of homogeneity $\alpha = 1$ and a scale factor σ_C/σ_T. Thus, according to the normality principle, at the point of intersection with a given stress triaxiality, the direction of the matrix/local plastic strain increment, $d\bar{\varepsilon}_M^p$, is independent of the SD effects, for loadings with $J_3^\Sigma \leq 0$. This ultimately leads to a porosity evolution that is strikingly different regarding the sign of J_3^Σ Indeed, from the mass conservation principle, it would be possible to prove that for, and only for, tensile loadings with $J_3^\Sigma \leq 0$ the porosity evolution is equally independent of the matrix SD effects.



(a) (b)

Figure *1*: Axisymmetric deviatoric plane projections: (a) intersection with stress triaxiality values; (b) direction and magnitude of the plastic strain increment for tensile loadings (first and fourth quadrant of Figure 1a).

3. Conclusions

The results show that under axisymmetric tensile loadings the Cazacu and Stewart (2009) yield criterion predicts two distinct plasticity behaviours regarding the sign of the third invariant of the stress deviator. This is due to the homogeneous characteristics of the yield function in the fourth quadrant of the axisymmetric plane projections, implying that the direction of the plastic strain increment, and consequently the porosity evolution, are independent of tension-compression asymmetry of the porous solid.

Acknowledgments

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Hole Expansion Tests of Metal Sheets: Numerical Study

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Abstract

A numerical analysis of the hole expansion test is presented. It focuses on the impact that different values of initial blank hole diameter have on the maximum values achieved for the principal strains, during the test. This analysis considers a case in full conformity with the ISO 16630 standard. The remaining cases studied differ from this, changing only the initial value of the blank hole. The results show that a smaller blank hole allows the test to reach higher values of major strain.

Keywords. Sheet metal forming, hole expansion test, plastic strain, numerical analysis.

1. Introduction

Advanced high-strength steels (AHSS) have been increasingly used in the automotive industry due to their good strength-to-weight ratio. However, forming of AHSS steel sheets can lead to cracks at the edge of a flange, submitted to tensile stress states. The hole expansion test is commonly used to evaluate the occurrence of edge cracking during flanging. This test consists of expanding a circular hole by the action of a conical punch. The minimum displacement of the punch required to cause a crack is measured. The hole expansion test is generally performed according to ISO 16630 standard (2017), however, there are studies in the literature that propose deviations in some geometrical features, namely the initial blank hole diameter (Uthaisangsuk et al. 2008). In this work, a numerical study is carried out to evaluate the impact of the initial blank hole diameter on the maximum values achieved for the principal strains.

2. Numerical Model and Procedure

The numerical model consists of a circular blank with a diameter of 120 mm and a thickness of 2 mm, a conical punch with a tip-angle of 60º, and a die with an inner diameter of 70 mm. Due to material and geometry symmetries, only one fourth of the blank is simulated, resulting in a finite element mesh with 13860, 8-node hexahedral solid elements. The numerical simulations were carried out with the in-house finite element code DD3IMP (Menezes et al. 2000). The material considered consists of a S460MC high-strength low-alloy steel. For each case studied, the evolution of the major in-plane principal strain (ε_1) with the punch displacement (Δl) is evaluated.

3. Results and Discussion

Four cases were defined for this analysis, considering the initial blank hole diameters equal to 10 mm, 20 mm, 30 mm and 40 mm. The results are presented in (**Figure *1***). It is clear from these results that lower values of the initial blank hole diameter lead to higher values of ε_1.

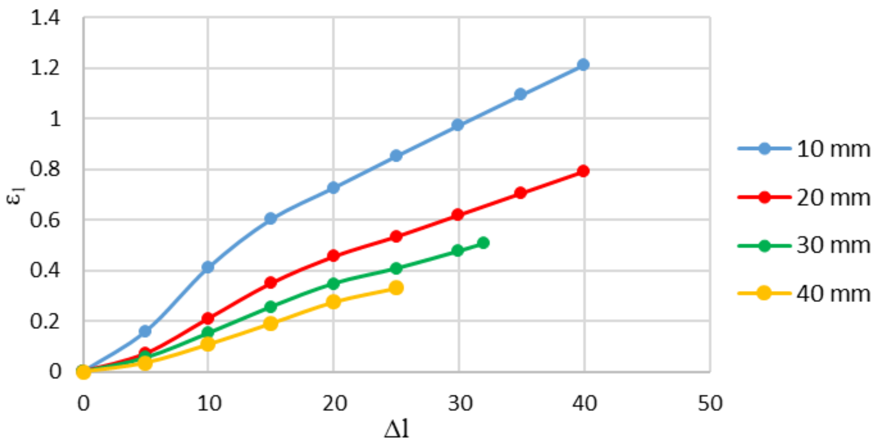

Figure *1*: Influence of the initial blank hole diameter on the major principal strain values achieved during the hole expansion test.

The 30 mm and 40 mm cases studied had their tests ended before the punch displacement value was equal to the other two cases (40 mm). This is due to the fact that the punch displacement measurement starts at the instant that it contacts with the blank. For higher values of blank hole diameter, this instant occurs for a lower position of the punch, and the tests are considered finished when the cylindrical portion of the punch contacts with the blank, which happens for these two cases before Δl reaches 40 mm.

4. Conclusions

A numerical study was performed on the influence of the initial blank hole diameter on the major strain values achieved during a hole expansion test. This test shows that lower values of the initial hole diameter allow the test to achieve higher values of major strain. Future studies will focus on the effect of the die diameter and sheet thickness, as well as material hardening behaviour.

Acknowledgments

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Mechanical characterization of a polyurethane using a hyper-viscoelastic constitutive model

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Abstract

The main objective of this study is to calibrate the material parameters of a hyper-viscoelastic constitutive model of a polyurethane used in rubber pad forming. Uniaxial compression, stress relaxation and free vibration tests are carried out experimentally. The hyperelastic behavior is described by the Mooney-Rivlin model, while the viscoelasticity is modelled by a series of Maxwell elements. The results show that the identified material parameters can accurately predict the mechanical behavior of the polyurethane in all tests performed.

Keywords. Rubber pad forming, hyper-viscoelastic behavior, Mooney-Rivlin model, Maxwell elements

1. Introduction

Increasing attention has been given to fuel cell technology in order to replace the internal combustion engines in transport applications. Since the bipolar plates (BPPs) are the primary component of the proton-exchange membrane fuel cells, comprising most of the cost, special attention is given to their manufacturing process. Rubber pad forming is one of the processes applied to manufacture BPPs (Liu and Hua 2010). The simulation of the rubber pad forming requires the accurate modelling of the mechanical behavior of the rubber material, which is both elastic and viscous (Andrade et al. 2019). In order to identify the material parameters of the constitutive model it is necessary to perform different experimental tests.

2. Experimental procedure and constitutive model

Three different mechanical tests were adopted to characterize the hyper-viscoelastic behavior of the polyurethane (PUR): (i) loading/unloading uniaxial compression tests, with three different grip velocities (0.05 mm/s, 0.5 mm/s and 5 mm/s); (ii) stress relaxation tests and (iii) free vibration tests. The PUR analyzed presents a hardness value of 70 Shore A; thus, it will be referred as PUR70. The specimen used is cylindrical (25 mm of height and 18 mm of diameter). The hyper-viscoelastic behavior was represented by the generalized Maxwell model, which is defined by an elastic spring (hyperelasticity) in parallel with *m* Maxwell elements (visco elasticity), where each of this elements is composed by an elastic spring and a viscous Newton-element in series. There are two material parameters, C_{10} and C_{01}, associated to the Mooney-Rivlin hyperelastic model as well as for each Maxwell element considered, *ak* and *τ*.

3. Calibration of material parameters

The nonlinear least square fitting was adopted to calibrate the material parameters, comparing the experimental and the numerical first Piola-Kirchhoff stress evolutions. The identified material parameters are listed in **Table *1***, showing that four Maxwell elements had to be considered to accurately capture the viscous effect. The comparison between the experimental and the calibrated curves is shown in **Figure *1***.

Table *1*: Material parameters obtained by curve fitting for the PUR70.

C_{10}	C_{01}	ak_1	ak_2	ak_3	ak_4	τ_1	τ_2	τ_3	τ_4
1,19882	0	10^{-5}	0,069804	0,64690	0,09290	12763,88	9,38	0,00437	726,02

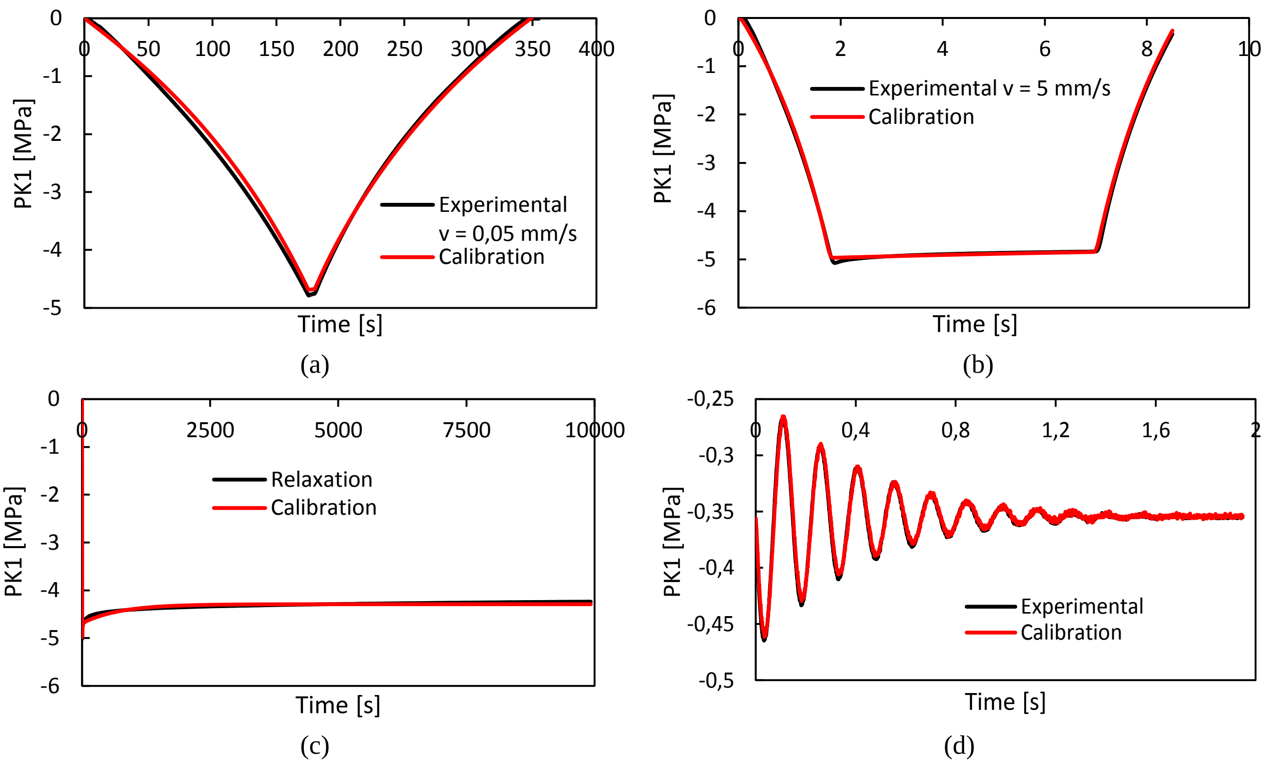

Figure *1*: Comparison between the experimental and numerical first Piola-Kirchhoff stress for the PUR70: (a) uniaxial compression test v = 0.05 mm/s; (b) uniaxial compression test v = 5 mm/s; (c) stress relaxation test; (d) free vibration test.

4. Conclusions

The results show that the identified material parameters can predict very accurately the mechanical behavior of the polyurethane in all tests performed. This model will be applied in the numerical simulation of rubber pad forming of thin BPPs.

Acknowledgments

The authors gratefully acknowledge the financial support of the Portuguese Foundation for Science and Technology (FCT) under the projects with reference PTDC/EMS-TEC/0702/2014 and PTDC/EMS-TEC/6400/2014 and by UE/FEDER through the program COMPETE2020 under the project MATIS (CENTRO-01-0145-FEDER-000014).

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Residual stresses in a casting component by multiscale analysis

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Abstract

Residual stresses can be generated in a part as it is manufactured by a casting process. These stresses directly affect the useful life of the part when it is subjected to fatigue, limiting also the loads that can be applied to it. Therefore, the correct prediction of how such stresses are formed in the part is of great importance when designing parts and structures. Several methodologies have been developed that allow considering the changes in microstructure that the material undergoes throughout the process, as well as the evaluation of the properties and field values at a macrostructural level (Fish 2014). This multi-scale approach, when evaluating residual stresses, has the potential to accelerate and optimize the design and manufacturing processes of parts and structures, allowing developers to characterize a geometry with a given material, without the need to resort to mechanical tests, which are often impractical due to the dimensions and costs of the structure or because they need highly expensive destructive tests. This study is based on the implementation of several thermo-mechanical models by finite element analysis, in order to determine the residual stresses in a manufactured product by casting process (Song 2011). It was considered a part made of duplex stainless-steel grade 2205, with a specific geometry known as C-Ring (Sousa 2019), which is widely used in research as a benchmark for validation of numerical results, by comparing them with experimental data for residual stresses and geometrical distortions. Different analyses were carried out on a microscopic scale, based on a real image of the microstructure of the proposed material, obtaining field values for the stresses and strains generated during the solidification and cooling of the multiphasic material (Figure 1). Additionally, based on the chemical composition of the material, homogenized mechanical properties were obtained, with the aim of applying such properties in the macroscopic analysis of the casting process and partially considering the microstructural changes in the process when performing macroscopic simulations (Pietrini 2019). For the macroscopic study (C-Ring geometry) several simulations were carried out and sensitivity analyses were performed by changing simulation parameters and assembly variables of the process, with the objective of analyzing and discussing the results, weighing their influence and relevance. Results were obtained for the final field values (**Figure 1**) and for their evolution in a certain section of the part during the casting process, as seen in **Figure 2** and **Figure 3** (Pietrini 2019). The results obtained for the field values by the computational simulations were later compared with experimental results, allowing the improvement of simulations and a better understanding of the influence of parameters and corresponding accuracy on their evaluation.

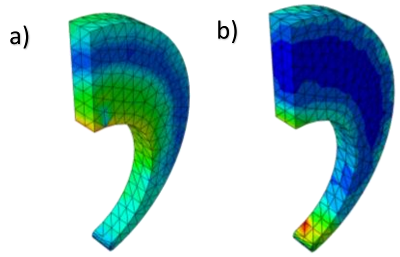

Figure *1*: Field map at the end of the casting process: **(a)** Stress (v. Mises); **(b)** Equivalent plastic strain.

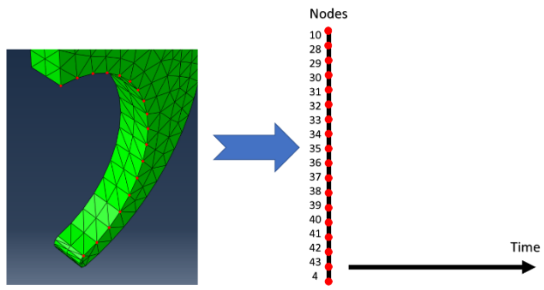

Figure 2 - Inner curve nodes considered in order to evaluate the evolution of results over time.

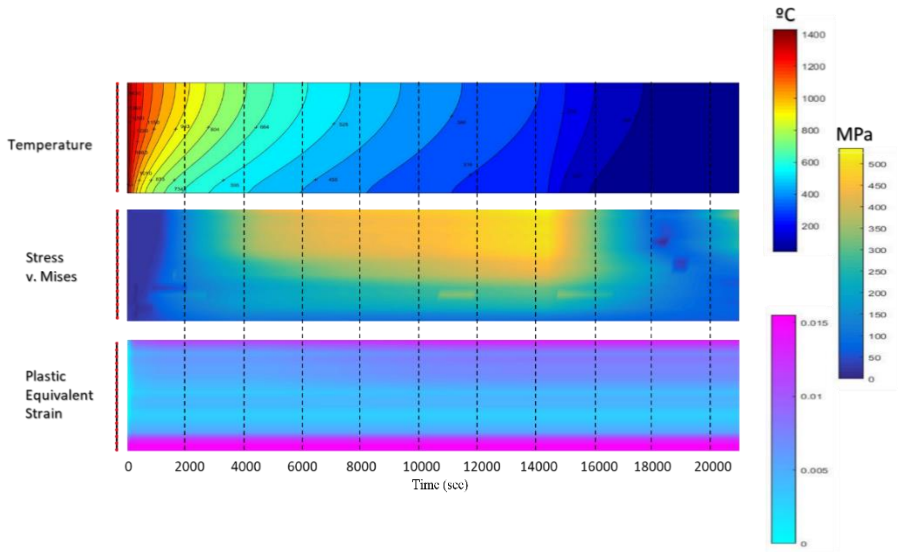

Figure 3: Evolution of temperature, stress (v. Mises) and equivalent plastic strain on the inner curve of the part over time, presented on a chromatic scale.

Keywords. Multiscale, Residual Stress, FEM, Casting, Simulation, Thermal analysis, Stress analysis.

Acknowledgments

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A modified Hill yield criterion combined with meshless methods formulation for the elasto-plastic analysis of FFF printed thermoplastics

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Abstract

This work proposes a non-linear computational framework capable to analyze the elasto-plastic response of ductile materials showing distinct compressive and tensile responses. The elasto-plastic algorithm proposed uses meshless methods (Belinha 2014) as the numeric discretization technique. In the elasto-plastic model, a modified version of the Hill yield surface is implemented. This yield criterion allows to analyze, at the same time, the behavior of materials exhibiting different mechanical properties under tension and compression – which is the case of the Fused Filament Fabrication 3D printed material. In those conditions, specimens are tested experimentally and numerically to validate the numerical methodology and the accuracy of the yield criterion.

Keywords. Modified Hill yield criterion, meshless methods, Fused Filament Fabrication (FFF)

1. Introduction

Fused Filament Fabrication (FFF) is a low-cost Additive Manufacturing technology that allows the production of components and structures using filaments of thermoplastic materials. The FFF process uses a RepRap machine (Jones et al. 2011; Salinas 2014), incorporated in an open-source software, and produces prototypes by extruding a filament through a heated nozzle onto a platform. The material is deposited and it cools, solidifies, and bonds with the already deposited material. The formation of the bonding in the FFF process is driven by the thermal energy. The quality of the bond formed between filaments depends on the growth of the neck formed between adjacent filaments and on the molecular diffusion and randomization at the interface (Bellehumeur and Li 2004). Nonetheless, this additive technique is not extensively used in high-value industrial sectors mainly due to parts' anisotropy, related to deposition strategy, and residual stresses, caused by successive heating cycles. These features have a significant influence on the mechanical performance of 3D printed parts, in particular thermoplastics with nonlinear behavior (such as PLA or PA). Thus, engineering approaches to predict these elasto-plastic responses are demanded. This work intends to generate a numerical tool, using meshless methods, for the simulation of the FFF process and the prediction of the structural behavior of printed parts. This work is focused on the constitutive model of the printed thermoplastics.

2. Materials and Methods

Materials, such as thermoplastics, often exhibit different behaviors depending on their loading conditions. Thus, yield criterions have to be appropriately chosen in order to capture those different material behaviors. In this work, the tensile and compression behaviors of FFF thermoplastics are investigated using a yield criterion that accounts, simultaneously, the presence of tensile and compressive loads applied on the material (a modified Hill yield criterion). The developed elasto-plastic algorithm, which uses the incremental-iterative Newton-Raphson method, is implemented within the formulation of meshless methods. Despite the use of the Finite Element Method (FEM) for engineering applications have become widespread, new accurate and efficient discrete advanced numerical techniques - such as the meshless method – can handle the same kind of problems as the FEM and being, in some cases, even more efficient. In order to discretize the problem domain, meshless methods only require an unstructured nodal distribution. The numerical integration of the Galerkin weak form is performed using a background integration mesh, the nodal connectivity is enforced using the influence-domain concept and then the interpolation shape functions are obtained.

Printed specimens of PLA are tested using standardized mechanical tests (compression, tensile and three-point bending tests), and then modelled using the FEMAS software (cmech.webs.com) running in MATLAB® environment. The mechanical properties extracted from the experimental stress-strain curves are input variables for the elasto-plastic algorithm, which uses two meshless methods (the Radial Point Interpolation Method (RPIM) and the Natural Neighbor Radial Point Interpolation Method (NNRPIM)), as well as the FEM, for comparison purposes. Thus, the specimens are tested both experimentally and numerically.

3. Conclusions and Discussion

In this work, experimental data was collected from standard mechanical tests in order to validate a computer algorithm using meshless methods and a modified Hill yield criterion to predict the structural elasto-plastic behavior of FFF printed parts. The proposed algorithm revealed to be a robust and accurate numerical tool, since the numerical stress-strain curves matched the experimental ones, not only for the tensile and compression tests, but also for the three-point bending test, in which there are, simultaneously, compressive and tensile loads. Both experimental and numerical stress-strain curves highlight the importance of characterizing polymeric materials in different stress states since the stress levels under compression can be largely higher than the ones observed in the case of the specimens under tensile loads. Additionally, from the studied numerical approaches, NNRPIM was the most accurate, a fact that it is intrinsically related to the higher nodal connectivity imposed within its formulation.

Acknowledgments

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A Numerical Study on Distortions Prediction of an Additive Manufactured Component and Experimental Validation

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Abstract

The Additive Manufacturing (AM) has drastically changed the manufacturing industry, this process is able to produce components with very high stiffness to weight ratio and allows the design of complex geometries. It has also changed the way engineers think about a component project. However, there are some intrinsic characteristics of the process, like thermal gradients, which results on residual stresses and distortion and are usually bad for the process. Distortions are bad for the manufacturing process, it generates non-conforming workpieces and risk of failure of the process during the building process. The aim of the present work is to, based on the manufacturing process parameters (like workpiece orientation, scanning strategies and layer thickness, for example), estimate the distortions of a simple part. The results of the numerical simulation will be compared with measurements performed on the built workpiece, produced by the Powder Bed Fusion (PBF) technology.

Keywords. Additive Manufacturing, Powder Bed Fusion, Residual Stress, Distortion

1. Introduction

Additive Manufacturing (AM) is a process capable of producing high complexity components with very high stiffness to weight ratio. In recent years, the metallic additive manufacturing has been consolidated in the market, standing out in the aeronautical, tooling (e.g. moulds) and prosthesis sectors, for example. An intrinsic characteristic of the AM is the large thermal gradients. These thermal gradients generate residual stresses, distortions and microstructural heterogeneities after part cooling

Patterson et al. review the few works published about residual stress in the selective laser melting based processes, pointing out that most of the studies are numerical without experimental validation. Babu et al. emphasize the necessity to validate the numerical models experimentally under multiple process conditions. Luzin et. al. performed an analytical and experimental study about the stresses on a thin-walled structure, built via Wire-Arc Additive Manufacturing using Ti-6Al-4V.

The main objective of this work is to predict, through a numerical model, the residual stresses and distortions originated during the AM process. The distortions are relatively easier to measure than the residual stress. Therefore, the present study will have the distortions as the only parameter in experimental results. Some preliminarily work will be showed on the present document. **Figure *1*** shows some preliminarily results from simulations of the residual stress field of a parallelogram on two different build stages, after the building process (left) and after the removal of the base plate (right). The simulations were performed on the software ESI Additive Manufacturing and will be later validated with experimental results (distortions). There is an ongoing work about the mesh refinement and solution convergence of this problem. In order to gain confidence on the numerical model, simple geometries will be simulated and built.

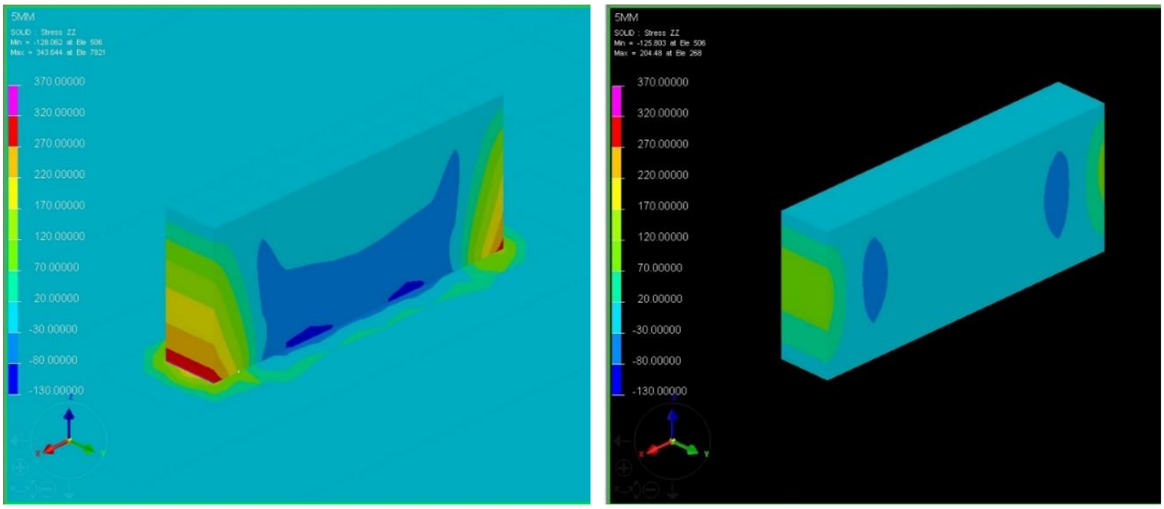

Figure *1*: Norma residual stress on building directions before and after the removal of the baseplate

Figure 2 shows some preliminarily experimental results, a board built via AM process was 3d scanned. After that, the final form of the workpieces can be easily measured and compared with the theoretical board dimensions (the original CAD used to manufacture the part). From this data, it can be measured the distortions on each surface. Subsequently, these distortions will be compared with the ones obtained by the numerical simulations. The numerical distortions are calculated based on the residual stress field, which will not be measured on the present work.

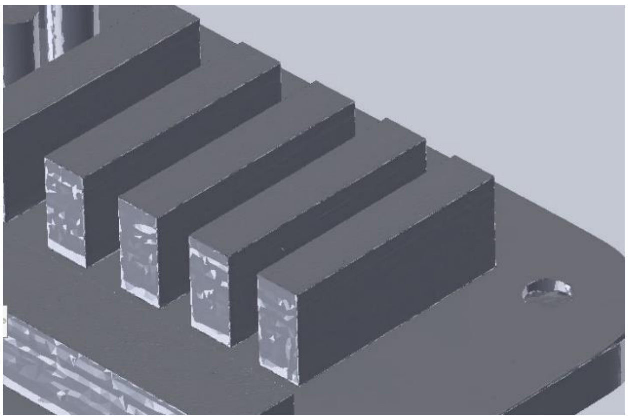

Figure 2: Point cloud scanning of AM built parts

Acknowledgments

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Biomechanical stabilization of bone metastases and tumor necrosis due to the thermal effects for different patient age group

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Abstract

Bone metastases are often diagnosed at an advanced stage of the tumor and have a high impact on patient's quality of life. After its diagnosis it is important to characterize the lesions of the bone tumor with specific attention to identify the size, type (osteolytic, osteoblastic), location, etc. in the involved bone (Oliveira 2018). Treatment of bone cancer is complex and may include surgery, chemotherapy and radiotherapy, or other combinations of local or systemic treatments, in order to cure or control the affected lesion area. Tumors can be benign or malignant, and they may also be primary or metastatic due to the spread of systemic cancer cells. The objective of this work is to evaluate the minimization of a metastatic bone lesion through the injection of bone cement that will fill the space of the lytic tumor lesion. The production of heat due to the effect of polymerization of the bone cement can result in irreversible damage and necrosis in the adjacent tissue. It is intended to obtain an evaluation of the beneficial effect of the heat production on the treatment of bone tumors. Careful analysis of the clinical parameters and materials involved are essential in the evaluation of this study. In this work, three different bone cement types were compared to fill an area of metastatic lytic lesion. The main purpose is to play a promising role for bone tumor necrosis due to the thermal effects and biomechanical stabilization for function. Different computational models, obtained by medical image evaluation, were performed for two different patient age group. The computational model incorporates a transient thermal analysis using the finite element method. All the thermal material properties (cortical, spongy, cement and titanium intramedullary nail) are in accordance with the literature. The effect of time-temperature dependence on cement type was introduced in numerical model according to experimental results from the literature. All the results were presented to promote a discussion for clinical benefit about the proper bone cement type, analysing also by patient age group, in order to validate it as an effective treatment for this patients.

Keywords. Bone tumor. Bone cement. Char layer. Computational model.

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Design of wood-steel connections with dowel fasteners subjected to fire

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Abstract

The main purpose of this study is to present different analytical and computational methods, in order to ensure the safety design calculation of the wood-steel connections, due to fire conditions. Wood-steel connections with dowel fasteners are very important parts of a structure. These elements are probably the most common mechanical connections type because they are effective at transferring loads while also being relatively simple and efficient to install. The motivation of this work is to design a wood-steel connection with safety and appropriate dimensions to transfer the imposed tensile loads in the structural member, in simultaneous, subjected to fire. Numerical approaches using the finite element method have been carried out to analyse the mechanical behaviour of connections by different authors. But, in this work the challenge is verify the effect of different materials in conjunction and subjected to fire. The high vulnerability of wood, with respect to fire, requires a rigorous thermal analysis. The study of fire resistance of wood-steel connections is therefore a topic of great interest. In this work the analytical methodology is based on simplified equations presented in Eurocode 5, part 1-1 and 1-2, for wood connections with dowel fasteners. The numerical methodology is based on finite element method, implemented to obtain thermal computational simulations, which allow to verify the heating effect through the dowel fasteners and the steel plate through the connection. In order to compare the temperature distribution through the wood-steel connection, two-dimensional cross-sections were identified, as the most relevant parts. According to the fire exposure, a thermal and transient effect will happen and a char-layer will appear on the side of the connection exposed to the fire. Therefore, the charring rate will be calculated, to ensure that it is safe to use, and compared with the constant value proposed by the Eurocode 5, part 1-2. This comparison provides additional information to reassure designers and professionals that this type of connection is safe to use.

Keywords. Wood connections. Steel dowel. Char layer. Fire.

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Numerical study of the human cochlea

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Abstract

The sound waves are directed through the ear canal towards the tympanic membrane, thus forcing its vibration. Such vibration is then transmitted through three ossicles. The last ossicle, the stapes, is connected to the cochlea through the oval window and its movement leads to the development of pressure waves in the perilymph present in the scala vestibular. This travelling wave causes the displacement of the hair bundle present along the basilar membrane, stretching the tip links, and, as result electrical impulses are sent to the brainstem through the vestibulocochlear nerve (Ni et al. 2014, Gillespie and Muller 2009). Numerical analyses provide an approximation of the behaviour of the real world. Such analyses can be employed to the human cochlea with the purpose of study and investigate its normal and pathologic dynamic behaviour. The 3D finite element model will be based on a computerized tomography scan.

Keywords. Cochlea, Hearing, Hair Cells, Finite Element Analysis.

Acknowledgements

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ADHESIVE JOINTS

Manufacturing functionally graded joints: An overview

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Abstract

Adhesive bonding is a constantly growing and compelling method of joining materials and structures mainly due to its cost-effectiveness, reliability and versatility. Its ability of joining a large range of materials and capability of reducing the stress concentrations in joining assemblies is preferred, in some situations, over the use of other mechanical joining methods such as riveting and bolting (Da Silva 2011). In recent years, adhesive bonding has become a key technology among the various industrial sectors, namely the automotive industry due to its constant demand for lighter, more resistant and environmentally friendly materials. Therefore, it is of great interest to further develop this kind of bonding, by developing functionally graded adhesive joints. Functionally graded adhesives (FGA) can be defined as tailored adhesives that have varying gradual mechanical properties along a desired dimension, allowing a more uniform stress distribution along the bondline (Stein 2016, Carbas 2014). Application wise these joints are very promising due to their potential high degree of customization, offering more solutions and options regarding application design. This overview aims to assess all the current experimental achievements and manufacturing processes in the field of functionally graded adhesives, as well as the complications and concerns that need to be addressed in order to achieve consistent, reproducible graded joints that can later be transferred to industrial applications.

Keywords. Adhesive bonding, Functionally graded adhesive (FGA) joint, Functionally graded materials (FGM), Adhesive joint manufacturing.

Acknowledgments

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Adherend material effect on the tensile strength on adhesive bonded tubular joints

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Abstract
In the last years many industries have replaced traditional joint methods by adhesively bonded joints. Comparison between those methods reveal that bonded joints have significative advantages, such as: corrosion and thermal performance, reduced weight, possibility to join different materials. In literature it is possible to find different joint configuration, each one chosen according the purpose. Nowadays tubular joints find many applications, including in the piping industry, vehicle frames or thin-walled tubes. The present work focuses in tensile strength of aluminium tubular joints bonded with brittle epoxy adhesive (Araldite® AV138) under tensile loads. The purpose of this work is to initially validate the numerical tool with experiments. Further, a numerical parametric study is performed on few geometrical parameters: overlap length and tubes' thickness. CZM was successfully validated, and the joint's behaviour was found to be highly dependent on the geometric parameters.

Keywords. Tubular Joint, Finite Elements, Aluminium and alloys, structural adhesive

1. Introduction

The bonding technology has been growing in the last years, and the first industry which used this method was the aeronautical. After this, many other industries implemented this method. In order to predict the strength, the first Finite Elements (FE) analyses were based on the continuum or fracture mechanics approaches. In the present time, CZM modelling is the most used technique for bonded joints' analysis. With CZM, it is possible to achieve accurate strength predictions, because this method uses fracture data to propagate the crack (Adams 1997). This work addresses the tensile behaviour of tubular bonded joints, and it initially validates the CZM technique with experiments. The numerical study comprises the analysis of peel (σ_y) and shear (τ_{xy}) stresses in the bondline by conventional Finite Elements. Following, CZM was used to predict the maximum load (P_m). The numerical study consists of analysing the effect of overlap length (Lo), inner tube thickness (t_{SI}) and outer tube thickness (t_{SE}).

2. Materials and Methods

The material used was tubes of aluminium alloy AW 6082-T651 as adherends and the brittle epoxy Araldite® AV138 as adhesive. The geometric parameters showed in **Figure *1***, are L_O=20 and 40 mm, L_T=80mm, outer diameter of the inner tube (d_{SI}) of 20 mm, t_{SI}=2 mm, t_{SE}=2 mm and adhesive thickness (t_A) of 0.2 mm. The tubes were machined in a lathe with the specified tolerance in order to get the desirable diameters. Then it was necessary to prepare and clean with a degreaser the bonding area. For joint assembly, three equally spaced wires with Ø0.2 mm were placed between the tubes, to achieve t_A=0.2 mm. The cure of the samples occurs during a week inside of a jig, following the manufacturer's recommendations. To conclude the process after testing the samples it was necessary to remove the excess of the adhesive. Five samples for each joint configuration were tested in a Shimadzu-Autograph AG-X tester (Shimadzu, Kyoto, Japan).

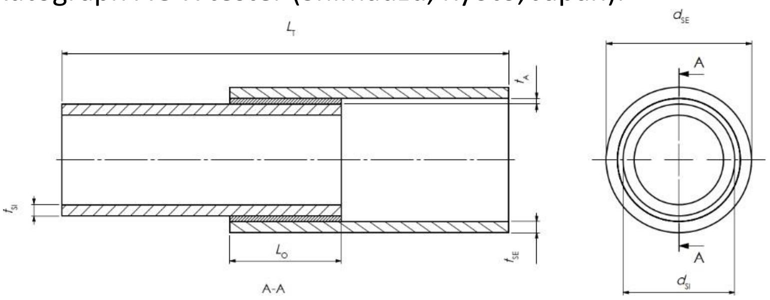
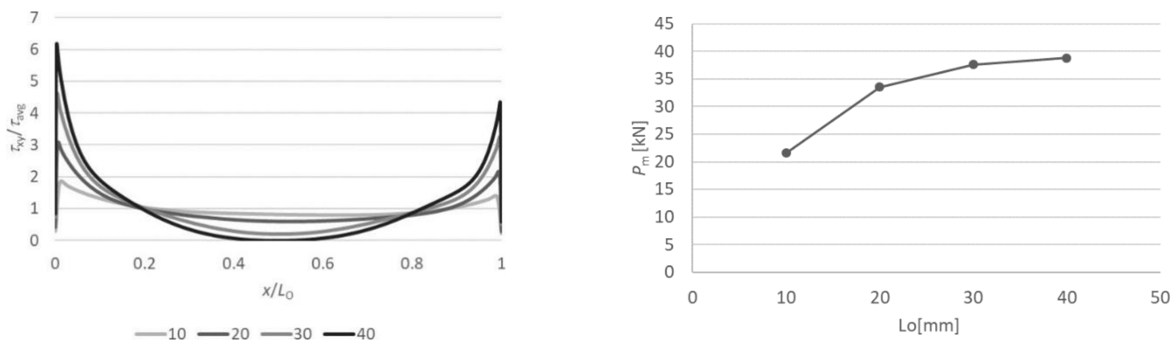


Figure *1*: Tubular Joint parameters.

3. Discussion

This work consists in the evaluation of the joints' behaviour, modifying the overlap length. The following values for L_o were considered: 10, 20, 30- and 40-mm. Peel (σ_y) and Shear stress (τ_{xy}) were initially analysed. In order to normalize the obtained values, it was necessary to divide τ_{xy} by the constant τ_{avg}, given by the average of τ_{xy} for the respective L_O. **Figure *2*** a) shows, as an example τ_{xy} stress as function of L_o. Peak τ_{xy} stresses appear at both edges, which is called the shear-lag or differential adherend straining effect. Moreover, in tubular joints, due to the smaller cross-sectional area of the inner tube. Higher peak stresses are found near x/L_O=0. From the figure, it can also be concluded that, by increasing L_o, τ_{xy}/τ_{avg} peak stresses also increase, due to increased proportions caused by the shear-lag effect. **Figure *2*** b) depicts the maximum load (P_m) for different L_o. It can be concluded that the results reveal a non-proportional P_m with L_o. The percentile P_m improvement between L_o=10 and 20 mm is approximately 55%, and this value gradually reduces with the increase of L_o.



(a) (b)

Figure *2*: a) τ_{xy}/τ_{avg} stress along x/L_o; b) P_m as a function of L_o.

4. Conclusions

The CZM technique was positively validated. The values obtained numerical, shows that, by increasing L_o, τ_{xy}/τ_{avg} peak stress also increase. On the other hand, by increasing L_o, the percentile P_m improvement between Lo progressively reduces.

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An apparatus for fracture envelope determination of adhesives under impact loads

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Abstract

The utilization of different lightweight materials is continually increasing in the automotive industry due to the necessity of reduce emissions and fuel consumption. The construction techniques for vehicle bodies with these materials differ greatly from the techniques used for the most commonly used steel bodies, with adhesive bonding being used extensively due to its capability to bond dissimilar materials. As a result of the high safety standards imposed by the automotive industry, the use of adhesive bonding poses several challenges to the automotive engineers, as the bonded joints must be designed to perform well under impact. In order to accurately design bonded joints, engineers resort to numerical models which require cohesive laws, constructed with the adhesive mechanical properties. With the intention of defining such laws, adhesive fracture toughness characterization in mode I, mode II and mixed mode (I+II) conditions must be obtained. The aim of the presented work was to adapt a tool based on the jig presented by Spelt in order to access the above mentioned properties at impact conditions for fracture mode angle (θ) of 0° (the pure mode I), 22.5°, 45°, 72.5° (the mixed mode I and II) and 90° (the pure mode II). The apparatus was then validated against standard tests like DCB´s and ADCB´s. Finally, a fracture envelope at high strain rate was determined.

Keywords. impact, mixed-mode, fracture toughness, cohesive zone model.

Acknowledgments

The authors gratefully acknowledge the funding provided by PhD grant SFRH/BD/139341/2018 "Impact strength optimization with cohesive zone elements of multi-material bonded structures used in the automotive industry", Project Nº 028473 POCI-01-0145-FEDER-028473 "Design methodology for impact resistant bonded multi-material automotive structures (ImpactBondDesign)", Project NORTE-01-0145-FEDER-000022 – "SciTech - Science and Technology for Competitive and Sustainable Industries", co-financed by Programa Operacional Regional do Norte (NORTE2020), through Fundo Europeu de Desenvolvimento Regional (FEDER). The authors would also like to thank NAGASE ChemteX® for the financial support provided.

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Using Radial Point Interpolation Meshless Methods to Analyse Adhesive Single-Lap Joints

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Abstract

Considering that adhesive joints are a common joining technique, it is important to develop numerical tools that aid in the design of these joints. Currently the Finite Element Method is the most commonly used numerical method to study adhesive joints. In this work, two different meshless methods, the Radial Point Interpolation Method and the Natural Neighbour Radial Point Interpolation Method, were used to study adhesive single lap joints showing promising results, which compared well to results obtained using the Finite Element Method.

Keywords. Meshless Methods, Adhesive Joints, RPIM, NNRPIM.

1. Introduction

Adhesive joints are increasingly used in a wide range of industries, such as maritime, automotive and aerospace, this increase stems from their advantages over traditional joining methods, namely lower weight, higher strength or a more uniform stress distribution. However, adhesive bonding also presents some disadvantages, such as impossibility of disassembly, low peel strength and a need for high temperature curing in some cases. The stress analysis of adhesive joints is generally performed using the Finite Element Method (De Sousa et al. 2017). The use of meshless methods to obtain the stresses in adhesive joints is a relatively unexplored field. To date, very few papers use meshless methods to study adhesive joints, a recent example can be found in (Mubashar and Ashcroft 2017).

2. Materials and Methods

In the single lap joints studied in this work, **Figure 1**, the substrates were made of Aluminium with a Young's modulus, $E = 70.07 \pm 0.83$ GPa, Poisson's ratio, $\nu = 0.3$ and Tensile yield and failure strengths, $\sigma_y = 261.67$ and $\sigma_f = 324$ MPa, respectively (De Sousa et al. 2017).

(a) (b)

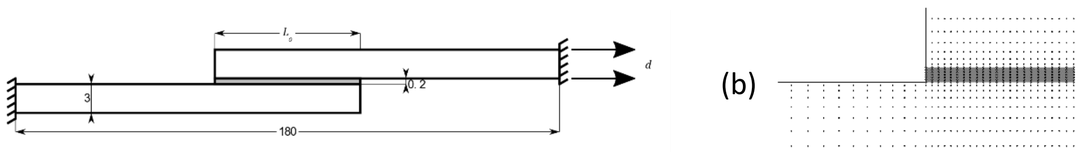

Figure 1: (a) Scheme of the Single Lap Joint, measurements in mm and $L_O = 12.5;\ 25;\ 37.5;\ 50$ mm and imposed displacement $d = 0.1$ mm, (b) Example discretization for $L_O = 12.5$ mm

The adhesive used in this study was Araldite AV138, which has the following properties: $E = 4.89 \pm 0.81$ MPa, $\nu = 0.35$, $\sigma_y = 36.49 \pm 2.47$ MPa, $\sigma_f = 39.45 \pm 3.18$, Shear modulus, $G = 1.56 \pm 0.01$ GPa, Shear yield and failure strength, $\tau_y = 25.1 \pm 0.33$ MPa and $\tau_f = 30.2 \pm 0.4$ MPa, respectively (De Sousa et al. 2017).

3. Results and Discussion

The problem described was analyzed using three different numerical methods. **Figure 2** shows the shear stress distribution obtained at the adhesive mid-thickness plane. **Table 1** presents the strength prediction of the adhesive using the maximum shear stress criterion. The results show a very close correlation between the solutions of the distinct numerical techniques, but they differ from the experimental strength, which is expected with this failure criterion.

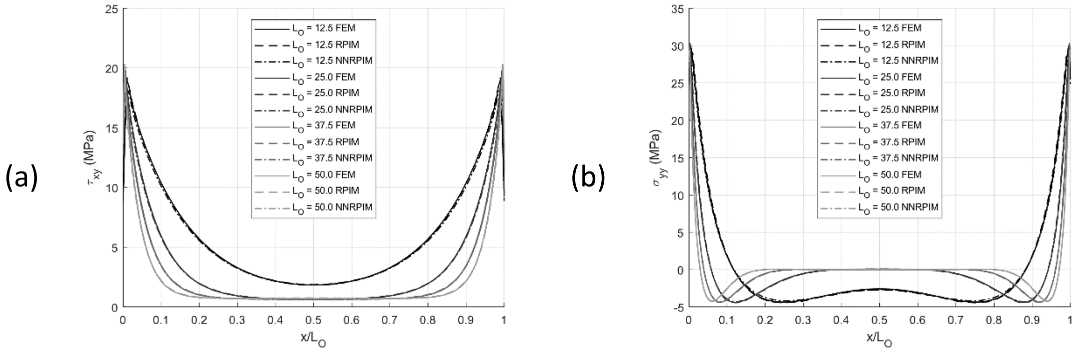

Figure 2: (a) Shear Stress (b) Peel Stress at the mid-thickness plane of the adhesive for the different overlap lengths and numerical methods

Table 1: Strength prediction using the maximum shear stress criterion

Overlap (mm)	FEM	RPIM	NNRPIM	Experimental
12.5	3.07	3.04	3.18	5.79±0.15
25	3.38	3.45	3.53	7.08±0.05
37.5	3.77	3.90	3.96	8.41±0.21
50	4.21	4.44	4.44	9.34±0.28

4. Conclusions

The stress distribution along the adhesive mid-thickness plane using the NNRPIM and RPIM meshless methods shows a similar profile to the stress obtained with the FEM for different overlap lengths. This shows that these methods can be used to study this type of structure. The strength prediction is bellow the experimental results, but this is due to the criterion used.

Acknowledgments

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DYNAMIC ANALYSIS, FLUIDS AND EXPERIMENTAL MECHANICS

Influence of 3D printing process parameters on the mechanical properties of PLA parts and comparison with simulated values

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Abstract
Fused Filament Fabrication (FFF) is an Additive Manufacturing technology that has experienced a large outburst in popularity, which led to a wide variety of FFF printers being made available to all users. In addition, due to the fact that FFF is strongly dependent on processing parameters, it is of the upmost importance the development of simulation software able to predict the behaviour of desired components before its actual production, taking into account the used materials and process parameters. Thus, it becomes necessary to validate the software's output by comparison to real experimental results. After upgrading the machine's instrumentation capabilities, bending, compression and tensile test specimens were produced using different nozzle diameters, printing speeds, temperatures and raster angles in order to verify the impact of these process parameters and compare the results to the software output.

Keywords. Process parameters, simulation, experimental validation, 3D printing, fused filament fabrication.

1. Introduction

Fused Filament Fabrication consists of an Additive Manufacturing technology where a part is built layer by layer using a thermoplastic filament in a semi-molten state. The material is extruded through a nozzle of known diameter and pre-defined shapes are formed using a CAD model in STL format (Gibson, Rosen and Stucker 2009). According to Górski et al. (2015), components produced by FDM are substantially weaker than their injected counterparts due to improper bonding between layers, dimensional and geometrical inaccuracies, all of them highly dependent on the material and process parameters used, namely the nozzle diameter, printing speeds, raster angle and printing temperatures.

Presently, this technology is experiencing an increase in popularity amongst the general public. It is now possible to obtain printing devices for noticeably low price points, defined as desktop printers. As a result of a combination between different process parameters and the use of devices like these, printed parts with lower resistance levels than the expected ones occur, which means a waste of resources.

This creates an opportunity for the development of a software able to simulate produced components and their mechanical resistance, allowing the user to structurally design the part and then move to the printing stage with confidence. Such a software would be using the material mechanical properties and process parameters as an input and it would be able to simulate both the manufacturing stage and structural behaviour. The purpose of the study is to print a series of test specimens in polylactide acid (PLA), a biodegradable thermoplastic, for bending, compression and tensile analysis using a desktop printer, while varying the before mentioned process parameters, and compare the obtained results to the ones outputted by the software so as to validate them. In order to do so, two FFF printers were built based on blueprints noticeable models and similarly calibrated.

2. Materials and Methods

ISO 178, ISO 604 and ISO 527 test specimens were printed with 100% infill and raster angles of 0°, 90°, 45° and ±45° (ten of each, amounting to 160 test specimens). Afterwards, new test specimens were printed by varying the process parameters as shown in **Table 1**, noting that the infill was kept at 100% and the raster angle at ±45°, amounting to 675 test specimens.

Table 1: Different values used for the process parameters.

Nozzle diameter (mm)	Printing Temperatures (°C)	Printing Speeds (mm/s)
0,2	190	30
0,4	200	45
0,6	210	60
	220	75
	230	90

During the printing stage, platinum resistance thermometers (Pt100 sensors) were coupled to the heating blocks in order to externally monitor the extrusion temperatures and both printers were kept inside acrylic casings so as to mitigate external factors such as temperature fluctuations and unexpected ventilation phenomenon.

3. Conclusions

It was possible to verify with the first batch of printed test specimens that the raster angle of ±45° was the one that provided the most isotropic behaviour to the test specimens, as expected.

Acknowledgments

The authors truly acknowledge the funding provided by Ministério da Ciência, Tecnologia e Ensino Superior - Fundação para a Ciência e a Tecnologia (Portugal) by project funding MIT-EXPL/ISF/0084/2017. Additionally, the authors acknowledge the funding of Project NORTE-01-0145-FEDER-000022 - SciTech - Science and Technology for Competitive and Sustainable Industries, co-financed by Programa Operacional Regional do Norte (NORTE2020), through Fundo Europeu de Desenvolvimento Regional (FEDER).

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Analysis of the Dynamic Tooth Loads on Integer Overlap Ratio Helical Gears

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Abstract

Integer overlap ratio helical gears have the peculiarity of having constant length of the contact lines which leads to minor mesh stiffness fluctuations. The single teeth pair dynamic loads are going to be compared for these gear pairs. The dynamic loads were obtained with a single degree of freedom dynamic model that considers teeth contact loss. The results show that the integer overlap ratio gears have a dynamic component which is really close to the static, so a smoother dynamic behavior is expected.

Keywords. Gear Dynamics, Integer Overlap Ratio Gears, Dynamic Loads.

1. Introduction

Integer overlap ratio gears were developed by (Marafona et al. 2019); due to the imposed integer overlap ratio these gears have theoretical constant length of the constant lines. Two different integer overlap ratio gears were optimized from a standard helical gear: one with an overlap ratio equal to one (CMS50-E) and another with overlap ratio equal to 2 (CMS60-R). Their mesh stiffness was analyzed through the quasi-static elastic model in (Marques, Martins, and Seabra 2017), which revealed that they had less mesh stiffness fluctuations than the starting gear.

A dynamic model was developed (Marafona et al. 2019) based on the work presented by (Parker, Vijayakar, and Imajo 2000). The dynamic model has a single degree of freedom and considers teeth contact loss but no backlash. Resorting to this model the dynamic transmission error (DTE) can be calculated and from it, the single teeth pair dynamic load distribution can be achieved.

2. Static vs Dynamic Single Teeth Pair Loads

Figure 1 shows the dynamic and static load distribution for the integer overlap ratio gears and the gear which gave origin to them. These results were obtained considering a torque of 98.82 Nm (K6 standard torque for the FGZ test rig) and for the speed that resulted in the highest RMS of the oscillating DTE component.

From **Figure 1**, the dynamic component is clearly reduced for the integer overlap ratio gears (CMS50-E and CMS60-R) when comparing to the stating gear (H501). It possible to verify the different shapes from the CMS50-E (optimized for efficiency) and the CMS60-R (optimized towards robustness) as well as the different load they are subjected to. The H501 is the only gear which presented “negative” loads – caused by teeth contact loss.

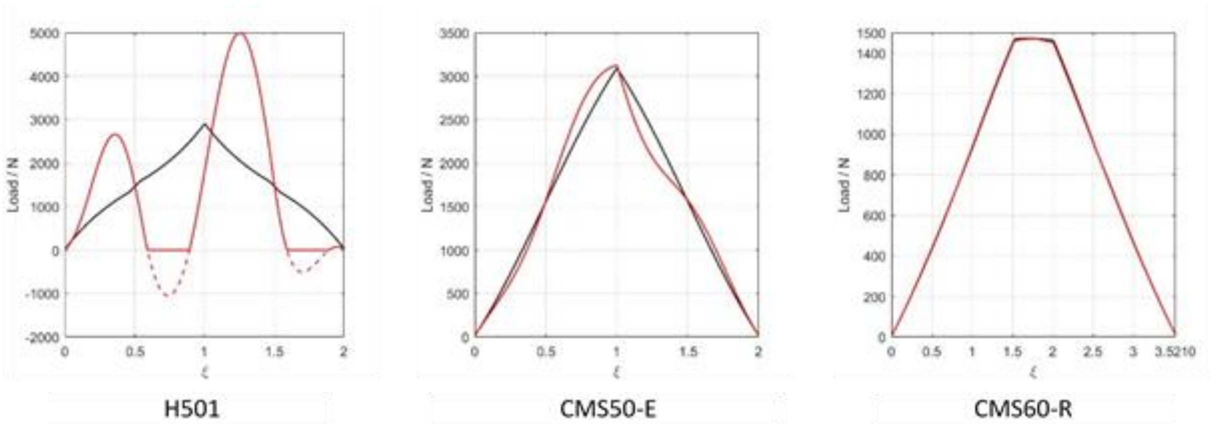

Figure 1: Dynamic (red) and static (black) single teeth pair load.

In order to evaluate the loads from a different point of view, the RMS of the difference between the dynamic (F^D) and static (F^S) components was calculated; the results obtained are exhibited in **Table 1**.

As expected, the robust gear (CMS60-R) presents the lowest variation between the static and dynamic load components with a value for the RMS equal to 5.5 N. The efficient gear, also had a significant improvement when compared to the starting gear – decreasing from 1703.3 N to 161.0 N.

Table 1: RMS of the difference between the dynamic and static load for the tested gears

Gears	H501	CMS50-E	CMS60-R
RMS(F^D-F^S) [N]	1703.3	161.0	5.5

3. Conclusions

The integer overlap ratio gears present a significant improvement in the dynamic load distribution as the dynamic and static components are closer. Also, as opposed to what happens in the H501 ("negative" dynamic component), both the CMS50-E and the CMS60-R do not exhibit teeth contact loss. The results shown in this work unveil the potential of the integer overlap ratio gears in reducing the dynamic overload and consequently increasing the gears' lifetime.

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Geometry and Defect Extraction of Scaled Railway Tunnels Using a 3D Laser Scanning Technique

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Abstract

This study aims to establish an inspection methodology which relies on obtaining the 3D geometry of railway tunnels and monitoring them through time to signal the possible appearance of structural defects and return the exact position where monitoring equipment will have to be deployed to. Therefore, a demonstrator of a 3D laser scanning system was built. The functionality and robustness of the developed system is evaluated through the implementation of a prototype on a scaled tunnel model. The tunnel's interior wall is scanned while the system is passing through the tunnel. The captured images are thereby processed to examine the tunnel's shape. Geometry changes, features and defects could be identified by comparing acquired profiles. Digital Image Correlation (DIC) is also performed to characterize and monitor the defects. In conclusion, encouraging results were obtained leading to a methodology for examination of tunnel conditions.

Keywords. Defect Detection, Tunnel Inspection, Laser Scanning, DIC.

1. Introduction

Recent improvements in imaging techniques keep fueling progress towards inspection systems to enable remote procedures with no direct human intervention. Detecting local defects remains decisive for an effectual examination, attesting the tunnel status, and performing maintenance if required. The main defects typically found in tunnels are cracks, spalling and leakage. The use of image-based techniques may be a fitting response for the analysis of those defects and check whether a structure that has been functional for years is still operationally safe, once those defects have been detected and accurate problem locations have been spotted.

Moreover, current progress in full field image-based techniques such as DIC, have been used to analyze defects in large structures, in tunnel locations signaled by 3D geometry changes, although some work remains to be done in order to bring these solutions to the field.

2. Methodology

The presented investigation relies on a 3D image processing approach where a scaled railway tunnel is taken into account. To assess the geometrical state of the tunnel, an optical setup is built encompassing of a circular laser module and a camera to capture the projected light on the tunnel's interior surface. The designed system moves throughout the tunnel with a constant linear velocity between 2 and 10 mm/s. The inspection consists of the detection of cracks via computer vision algorithms. Therefore, it firstly aims at determining the tunnel profile adopting the proposed optical scheme. It is beneficial to identify the geometric characteristics of existing defects besides the full 3D tunnel profile. The detected defects are then monitored by a non-contact measuring tool based on 3D DIC.

3. Discussion

Taking into account the system's originality and to assess the applicability and accuracy of the proposed 3D laser system, the implementation of a model prototype is proposed for laboratory tests. Within an initial study, a 3D shape of the tunnel's interior surface is acquired. Afterwards, the intended defects (i.e. cracks or bulges) are added to the model and the obtained profile is compared to the initial pattern. Moreover, to assess the reliability and accuracy of the designed system, in all stages, the tunnel model is also scanned by a commercial 3D laser scanning system and the obtained results are comparable. The system is tested in laboratory conditions and will be implemented in a real environment.

In addition, the defects, detected by the deployed 3D laser scanning system, are monitored and characterized by the developed 3D DIC system.

4. Conclusions

This work presents a methodology for railway tunnel defect detection and monitoring, based on tunnel geometry appraisal. A demonstrator was built based on a 3D Laser Scanning System to examine the railway tunnels and accomplish geometrical and mechanical inspection. The capability and integrity of the developed system has been evaluated through a model prototype, which has been conducted on a scaled tunnel model.

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Fatigue Behaviour of Double Shear Bolted Butt Joints Made of Thin Steel Plates

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Abstract

Racking systems are usually connected by bolted connections that are often loaded with high-intensity dynamic cycles, raising fatigue issues. FASTCOLD project aims at providing fatigue rules that there are no exist in EC3 for cold-formed steel profiles. That way, fatigue tests on bolted joints were carried out, revealing differences between the EC3 suggestions.

Keywords. Rack structures, Bolted Joints, Fatigue behaviour, Numerical simulation, Failure modes.

1. Introduction

Racking systems made of cold-formed steel have been used in industrial sectors, supporting and guiding S/R machines, which raising fatigue issues. Nowadays, EC3 (CEN (European Committee for Standardization) 2005) has no reference about fatigue design of cold-formed thin-walled. This work is part of the FASTCOLD project, which aims at providing fatigue design rules for EC3, namely for bolted joints that are often used to connected racking structures.

2. Material and Methods

Metal sheets of 2mm of thickness made of S350GD steel grade, connected with M12 (Bolt 8.8 DIN933; Washer DIN125; and Nut 8 DIN934) were tested experimentally. S-N curves were obtained in accordance with ASTM (2012). Numerical simulations, using ANSYS FEM R18.2 were carried out in order to predict the fatigue strength. Instead of S350GD, Ramberg-Osgood's cyclic curve of S355 steel grade (de Jesus et al. 2012) was considered. Also, ¼ of the real model, and standard surface-to-surface contact conditions, with the augmented Lagrangian algorithm and a constant friction coefficient, were taken into account.

3. Discussion and Conclusions

Figure 1 shows the results that reveal an average slope of around 8 instead of 3 like suggested by EC3. This discrepancy may be due to the higher importance that cracks initiation plays in the bolted joints fatigue behaviour. The preloaded effect increases the fatigue strength. Also, for lower loads, the failure occurred along the gross cross-section due to the clamping effect. Changing the R-ratio effect, but maintaining the maximum load, the fracture tends to move away from the centre. The reduction of the net section (less 10mm) increased fatigue strength. Multiple connections presented higher strength than single connections. However, specimens with drilled holes resulted in worse results than punched holes due to a low quality of holes. Normal stress and strain were evaluated in the hole, verify from a stabilized hysteresis loop average stress almost null, and the S-N curve is concordant with experimental results (black). The tensile residual stress of the punching process around the hole was also predicted (black). The discrepancy of results may be associated with differences in fatigue properties, and due to the accounting of crack initiation, and not the initiation and propagation. However, they appear to have good correspondence between them.

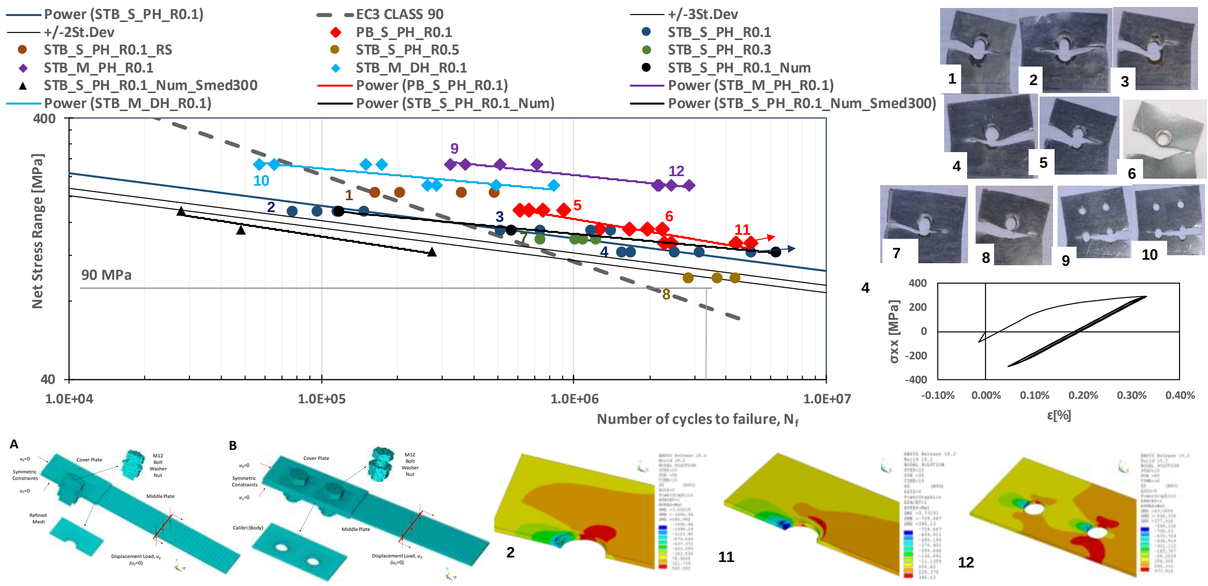

Figure 1: S-N Curve and failure modes: STB - Snug Tight Bolt; PB - Preloaded Bolt; S – Single; M – Multiple; PH - Punched Hole; DH - Drilled Hole; R - Stress Ratio; RS - Reduced Section. Numerical Models: A- Single/B-Multiple (Normal Stress XX); Stabilized stress-strain hysteresis loop.

Acknowledgements

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Development of a small scale triple effect desalination unit driven by solar energy

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Abstract

The scientific community looks to desalination as a primary alternative to increase water supply for domestic, agriculture and industrial use. Besides, desalination is a sustainable solution in regions where renewable (e.g. solar) energy is abundant. Thermal vapour compression (TVC) desalination could be one of the suitable technologies for small scale applications. However, the key component, the steam ejector, is sensitive to operating variables. This could be rectified by developing a variable geometry ejector. Besides performance, considering simple applicable mechanism is also important. It is proposed to develop a solar driven desalination prototype composed of two subsystems: solar thermal collector field and desalination subsystem. The solar field should be compact and other components of the subsystem include hydraulic connections, pump and energy storage unit. The TVC subsystem include variable geometry ejector, condenser, evaporator, generator, seawater pre-treatment, product and brine containers and pumps, instrumentation and control.

Keywords. Desalination, Solar, Thermal, Ejector.

1. Introduction

Thermal vapour compression (TVC) desalination units use an ejector. Ejectors are simple in construction and have no moving parts, which reduces the required skills for maintenance and operation. They are relatively low-cost and have a long lifespan. Additionally, the electricity demand of a TVC desalination system is considerably lower and can eventually be supplied by PV modules. The material used for the construction of the system components is important, since they operate in a highly corrosive environment and at a pressure different from atmospheric. The effect of operating conditions on the performance is well established. Studies suggest that fixed geometry ejectors lack acceptable performance under variable operating conditions (e.g. solar energy source). A deviation from design conditions has a strong negative influence on performance indicators (Ji, Wang, Li and Ni 2007). An advanced variable geometry ejector (VGE) could be developed. Although the advantage of the concept was clearly demonstrated (Dennis and Garzoli 2011), only limited technical solutions can be found (Ma, Zhang, Omer and Riffat 2010; Varga, Oliveira, Ma, Omer, Zhang and Riffat 2011). Typically, a TVC unit requires motive steam in the medium temperature range (120°C-250°C). Solar energy can supply heat in a wide temperature range. However, there is research needed on the selection of solar collector type for small scale systems. Collector efficiency, working temperatures, cost and collector field size should be taken into consideration.

2. Description of the proposed prototype

The proposed research, Small scale desalination with solar energy project (P2020 project), aims to develop a small scale (<10 m3/day) low maintenance thermal vapour compression (TVC) unit for seawater desalination, running on solar thermal energy. The desalination unit will employ a high performance variable geometry ejector (VGE) capable of responding to unsteady operating conditions. An adequate control system will be also elaborated and implemented. The developed system will be compact and low maintenance, which is of great importance in regions where skilled personnel is not available. The maintenance needs will be reduced to regular cleaning of the parts. It is also expected that the small unit will produce fresh water at a cost from 1.5 to 2.5 €/m^3, which is very competitive to any other existing solar desalination technologies. The proposed project is composed of two subsystems: solar field and the desalination sub-systems as shown in **Figure 1**.

Solar collectors (SC) convert solar radiation into thermal energy, which is transported by a heat transfer fluid to the generator. In the generator high pressure steam is produced that drives the variable geometry ejector and the desalination process. Proper collector design and the choice of representative climatic conditions are very important, with a strong influence on the initial cost. The proposed VGE will operate with high performance with driving temperatures from 120°C to 180°C. A target of the proposed project is to select collectors with average conversion efficiency around 60% for this range. Three collector types will be studied: evacuated tube, compound parabolic (CPC) and parabolic trough. The heat required to generate motive steam for the VGE is estimated to be about 40 kW, which can be supplied with a collector area of 100 m^2. The actual collector field area and type will be selected based on dynamic numerical simulation results with local climatic data, using an in-house computer model. Alternative energy sources will not be considered; the system will be designed to operate during daytime under variable conditions. Nevertheless, a small thermal storage tank (see **Figure1**) is needed to compensate instantaneous variations of solar radiation. The desalination subsystem is coupled to the solar collector field through the steam generator (see also **Figure 1**). In the generator, motive steam is produced at high pressure, which is used to recompress low pressure steam coming from the (last) evaporator of the TVC unit. The seawater enters the desalination unit at the tube side of the condenser, where its temperature increases. One portion of the seawater intake is dumped back to the sea, since its only function is to remove the extra heat introduced in the generator. The feed water enters the evaporator on the shell side where its temperature is raised to its boiling point. A demister is applied in the vapour side in order to trap all the brine droplets inside the evaporator. One or more evaporators can be applied in series. Multi-effect (more than one evaporator) units improve energy efficiency, but also increase system complexity and cost. The low pressure vapour leaving the (last) evaporator is split in two streams, one entrained by the ejector and another that is condensed in the condenser. The compressed vapour leaving the ejector is the sum of the motive and secondary streams. On the tube side of the evaporator it is condensed while transferring heat to the feed water. The portion of the condensate corresponding to the entrained flow from the evaporator is added to the effluent water from the shell side of the condenser. The total fresh water production is given by the sum of these two streams. The concentrated brine is discharged from the bottom part of the evaporator shell.

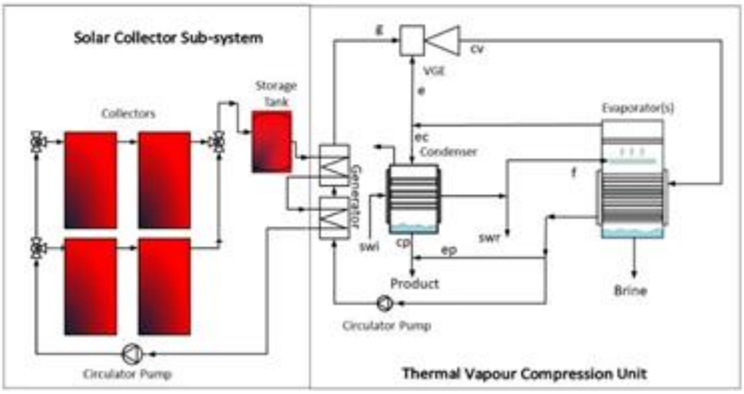

Figure 1: Schematic representation of the system to be developed

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Further Developments on Complex Viscoelastic Flows

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Abstract

Throughout the last decades several models were proposed to predict the behavior of complex fluids such as, for example, polymer melts and polymer solutions (Bird, Armstrong, and Hassager 1987). These models can be classified as: differential (that make use of the local deformation field) and integral (that take into account all the past deformation along time). Differential models usually allow a faster numerical solution, while integral models become computationally expensive and may lead to error propagation. However, integral models allow a better modeling of complex fluids, since they incorporate the memory inherent to viscoelastic fluids. Therefore, it is important to improve the fitting capabilities of differential models and reduce the computational effort needed to compute integral models. In this work, we propose new analytical solutions and numerical studies for viscoelastic fluids, described by the recently proposed viscoelastic model, known as the generalised simplified Phan-Thien-Tanner (gPTT) constitutive equation. This model considers the Mittag-Leffler function instead of the linear and exponential functions of the trace of the stress tensor, and offers one or two new fitting constants in order to achieve additional fitting flexibility (Ferrás et al. 2019). The analytical solutions derived allow a better understanding of the model, which in turn contribute to improve the modeling of complex materials.

Keywords. PTT model, Mittag-Leffler, generalised simplified PTT

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AUTHORS INDEX

AWARDS

The Symposium on Mechanical Engineering has awarded the following:

• **Best poster presentation Award** to Daniel Cruz, Miguel Trindade, Abel D. Santos, Joaquim Mendes, Rui L. Amaral and Sara S. Miranda. Development of a miniature testing for sheet metal mechanical characterization. #114

• **Best oral communication Award** to Daniel Rodrigues, Jorge Belinha, Lúcia Dinis and Renato Natal Jorge. A modified Hill yield criterion combined with meshless methods formulation for the elasto-plastic analysis of FFF printed thermoplastics. #77

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