DCE17

2nd DOCTORAL CONGRESS in ENGINEERING

8 - 9 JUNE 2017 • FEUP • PORTO • PORTUGAL

Book of Abstracts

2nd Symposium on Mechanical Engineering

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Book of Abstracts

of the

2nd Symposium Mechanical Engineering

Editors:
J. César de Sá, Abel D. Santos, Rui L. Amaral, João Ferreira

Porto
July 2017

This volume contains the abstracts presented at the Symposium on Mechanical Engineering, of the 2nd Doctoral Congress in Engineering - DCE17, held in Porto, June 8th and 9th, 2017.

Title: Book of Abstracts of the 2nd Symposium on Mechanical Engineering

Edited by **J. César de Sá, Abel D. Santos, Rui L. Amaral, João Ferreira**

Published by: FEUP Edições

https://paginas.fe.up.pt/~dce17/wp-content/uploads/2017/01/BoAME.7z

First edition July 2017

ISBN. 978-972-752-224-8

Universidade do Porto, Faculdade de Engenharia, Rua Dr. Roberto Frias s/n 4200-465 Porto, Portugal

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Preface

The Symposium on Mechanical Engineering was held within the Second Doctoral Congress in Engineering (DCE_{17}), hosted at Faculty of Engineering of the University of Porto (FEUP), from June 8th to June 9th, 2017.

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.

José César de Sá Abel Dias dos Santos

Chairmen of the Symposium on Mechanical Engineering in 2nd DCE

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Symposium on Mechanical Engineering
Chairs: César Sá and Abel Santos
Location: B025

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Mode I and II determination of CFRP as a function of temperature and strain rate

J.J.M. Machado[1,2], E.A.S. Marques[1,2], R.D.S. Campilho[3], L.F.M. da Silva[1,2]
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Abstract
Composite structures, such as carbon-fibre reinforced (*CFRP*), currently used in the automotive industry must meet strict requirements for safety reasons. They need to maintain strength under varied temperatures and strain rates, including impact. It is therefore critical to fully understand the impact behaviour of composites. These materials can also offer other advantages, such as lower structural weight, excellent strength and stiffness to weight ratios (Campilho *et al.* 2009, da Silva *et al.*2011). This work presents experimental and numerical results to assess the influence of a range of temperature and strain rate conditions on the fracture energy in mode I, G_{IC}, and mode II, G_{IIC}, of CFRP composite plates. In order to determine G_{IC} and G_{IIC} as a function of temperature and strain rate, Double Cantilever Beam (*DCB*) specimens and End Notched Flexure (*ENF*) have been tested, being the temperature conditions of 20, 80 and -30°C, and values of strain rate of quasi-static and 100 mm/min. The results from the DCB and ENF tests have been determined by the following methods: Compliance-Based Beam Method (*CBBM*), Corrected Beam Theory (*CBT*) and Compliance Calibration Method (*CCM*); and the results obtained from these methods have been compared with the aim to evaluate the more precise method. A numerical study was performed with finite element analysis software, to simulate the specimen behaviour when subjected to temperature and strain rate, leading to a more thorough understanding of the characteristics of this type of material under conditions required by the automotive industry.

Acknowledgments

Authors gratefully 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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Development of a cohesive zone element for adhesive joints subjected to fatigue and humidity degradation

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Abstract

The purpose of this research is to evaluate the combined effects of fatigue with moisture and to create a way for an engineer to correctly simulate a joint subjected to various environmental agents. This is accomplished through extensive experimental studies, where results will then be correlated using mathematical formulations, based on how the humidity levels affect the adhesive properties and fatigue response of an adhesive joint. These formulations will be verified experimentally and then implemented in a custom ABAQUS user element subroutine, coded in FORTRAN. Initially a triangular cohesive zone model will be used, but the nature of the custom code opens more possibilities, such as exponential and trapezoidal laws. These traction-separation laws used to model the joint will take penalties due to each of the environmental factors (calculated through the mathematical formulations), which will result in more accurate results that encompass all environmental factors when designing a joint.

Keywords. fatigue, moisture, Fick's law, Paris law, finite element method,cohesive zone model.

1. Introduction

Adhesive bonding is a joining method that is subjected to various solicitations: temperature, humidity, cyclic solicitations, and others. There is research on how each of these factors affect the adhesive joint (Silva and Sato 2013), but little is known about the combined effect of said factors. Cohesive zone models (Silva and Sato 2013) are one way to evaluate adhesive joints in finite element analysis. They are implemented using traction-separation curves, and those curves are defined as a function of the adhesive properties. If we determine how those properties change with humidity, we can develop tools to predict the behaviour of adhesives. Furthermore, if we study the fatigue crack propagation behaviour of the adhesives using Paris Law we can obtain the constants related to linear stable crack propagation zone, which may then be used to model the linear degradation of the adhesive in the numerical analysis. The purpose of this research is to evaluate all these factors and create a way for an engineer to correctly simulate a joint subjected to various environmental agents.

2. Extension of the abstract

The testing of 2 adhesives (Nagase Chemtex XNR6852-1 and SikaPower 4720) will be performed, and their mechanical properties characterized in both aged and unaged states. Experimental fatigue life tests are also performed, in both unaged and aged joints, to evaluate the effects of humidity intake in the number of cycles a joint can withstand before failure. Finally, all results are analysed and a correlation between humidity effects, fatigue cycles and mechanical properties is to be found so it

can be implemented in the FORTRAN routine.

3. Experimental results

Fig. 1 shows the mechanical and fatigue properties of both adhesives in the unaged and aged conditions.

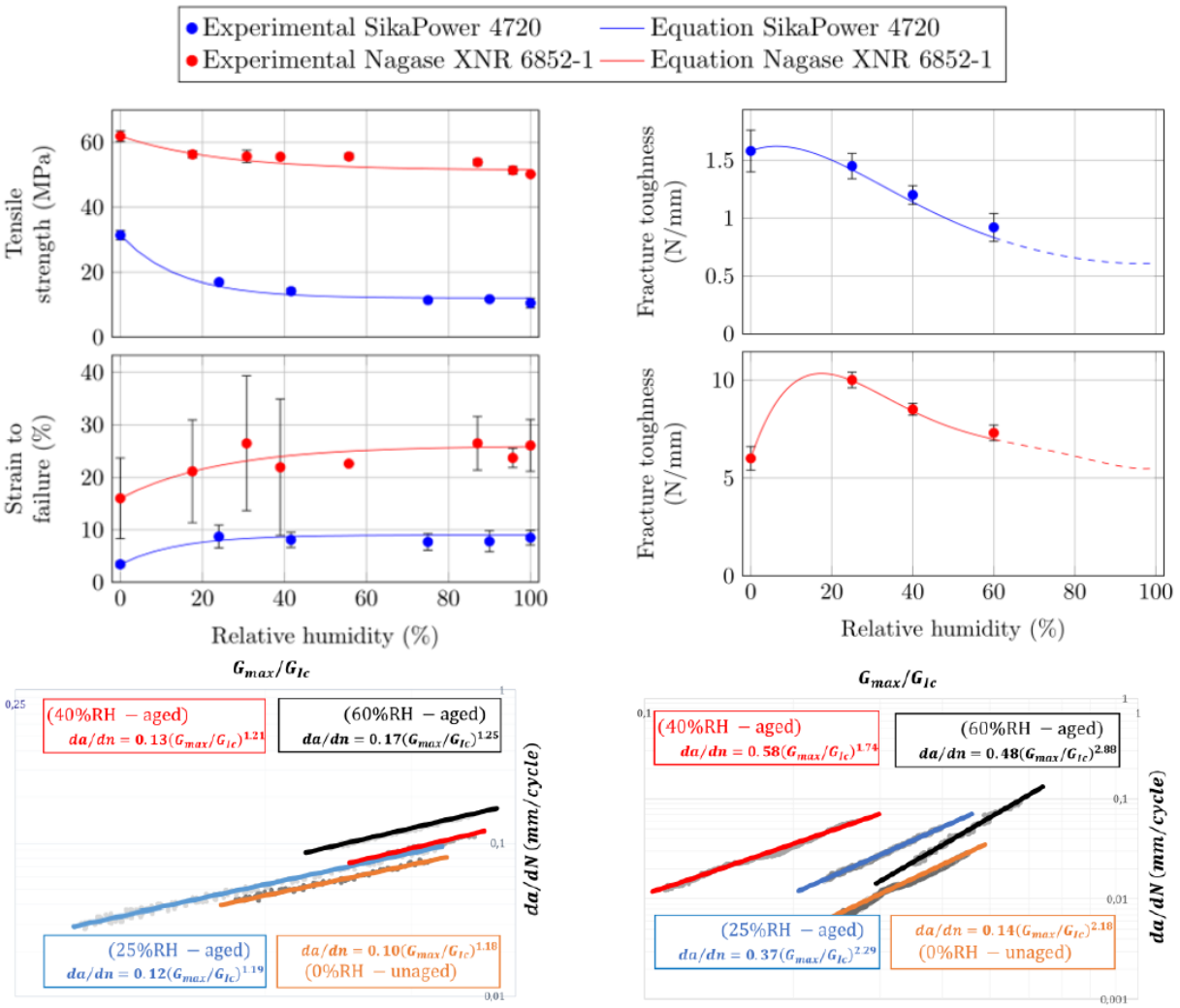

Figure 1: Degradation of mechanical properties (top), Paris Law for Nagase XNR 6852-1 (bottom left), Paris Law for SikaPower 4720 (bottom right).

4. Conclusions

Experimental results have provided valuable details on the distinct behaviour of property degradation for each adhesive, and equations have been deduced that fit the data which can then be used in the numerical model to degrade the properties. The numerical implementation is still being developed but promising results have already been obtained.

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Influence of size, amount and surface treatment on a brittle epoxy toughened with micro cork particles

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Abstract

Structural adhesives are being progressively used in new applications, replacing conventional joining methods. Epoxies resins are the most common structural adhesives used due to their good mechanical, thermal and chemical properties, as well for their low ductility and toughness (Silva *et al.* 2011). Along the last decades, several researchers, found it compulsory to reverse this fact and find new techniques to increase the toughness of these adhesives. There are many processes described in the literature to increase the toughness of brittle adhesives, being one of the most common the use of rubber particles. The inclusion of particles (nano or micro) is a successful method to improve toughness of structural adhesives (Kinloch 1997). In the present study, natural micro particles of cork are used with the objective to increase the toughness of a brittle epoxy adhesive. The concept is for the cork particles to act like as a crack stopper leading to more energy absorption (Barbosa et al. 2012, 2013). The influence of the cork particle size, amount and the presence of a surface treatment were studied. Particles of cork ranging from 38-53 and 125-250 µm were mixed in the adhesive Araldite 2020. The amount of cork in the adhesive was varied between 0.25 to 1% in volume. The toughness of the adhesive was assessed through fracture test, by means of three-point bending specimens. A Taguchi plan was used to comprehend the influence of each parameter under study (amount, size and presence of surface treatment) and the interaction between them.

Acknowledgments

Financial support by Foundation for Science and Technology (SFRH / BD / 88173/ 2012) is greatly acknowledged.

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A phenomenological study of chitosan nerve conduits for the regeneration of peripheral nerves

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Abstract
A new constitutive model is presented to predict the nonlinear behavior of chitosan. The proposed model is based on experimental data, which show that chitosan exhibits a typical elasto-plastic behavior. The constitutive model is combined with a nonlinear computational framework using advanced discretization techniques, such as finite element method and meshless methods. The obtained numerical results show a good correlation between the numerical results and the experimental data.

Keywords. Chitosan, elasto-plastic behavior, constitutive model.

1. Introduction

Chitosan is a natural copolymer of glucosamine and N-acetylglucosamine units that is obtained from the partial or full N-deacetylation of chitin, a polysaccharide present in the shell of crustaceans and insect exoskeletons (Shapira *et al.* 2015). As a biomaterial, it is very versatile because of its biocompatibility, biodegradability, promotion of cell adhesion and non-toxicity. Due to these characteristics, chitosan has been used in the regeneration of peripheral nerves in the shape of hollow nerve conduits (tubes) that bridge the gap between two nerve stumps, creating a favorable microenvironment for the regeneration process (Kim *et al.* 2008).

2. Materials and Methods

A constitutive material model was developed in order to show the nonlinear elasto-plastic behavior typical of chitosan. This knowledge was based on experimental data obtained from the literature. This constitutive model was combined with a computational framework where models of chitosan nerve conduits were constructed and numerically simulated using advanced discretization techniques. They were analyzed using the finite element method (FEM) and the radial point interpolation method (RPIM), which is a meshless method. Stress and displacement fields were obtained for the analysis of the structural response of these chitosan nerve conduits when subjected to external forces.

For the constitutive model, both the yield criterion and the corresponding yield surface were considered. The model respected a flow rule defining the relationship between stress and deformation after the plasticity point and a hardening law which describes if, and how, the yield criterion depends on the plastic deformation (Belinha 2014). For this, it were obtained the chitosan mechanical properties, such as the Young's modulus (E), the yield stress (σ_y) and the strain for both compression and tension tests. In the compression test, it is also possible to obtain the tangential Young's modulus (E_t). These isotropic material properties were related with the degree of deacetylation of chitosan, which is a very important feature that differentiates chitosan from chitin.

3. Discussion

Being a nonlinear material, chitosan behaves differently when being compressed or stretched. When subjected to a compressive force, chitosan presents an elasto-plastic behavior, which can be simulated using an elasto-plastic model. On the other hand, chitosan exhibits a ductile behavior when a tensile force is applied. The computed geometric models were submitted to a uniform distributed load, following a typical cantilever beam loading case. For each model, displacement and stress fields were obtained. The results allowed to gauge the main difference between the analyzed tubes shapes and inner topologies.

4. Conclusions

Assuming the elasto-plastic behavior of chitosan and resorting to the literature, it was possible to obtain chitosan mechanical properties and to analyze how they change with the degree of deacetylation. Considering the results obtained from the computational study, one could predict the behavior of these chitosan nerve conduits after being implanted.

Acknowledgments

The authors truly acknowledge the funding provided by Ministério da Ciência, Tecnologia e Ensino Superior – Fundação para a Ciência e a Tecnologia (Portugal), under grants: SFRH/BPD/111020/2015, and by project funding UID/EMS/50022/2013 (funding provided by the inter-institutional projects from LAETA). Additionally, the authors gratefully 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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Simulation of the elasto-plastic behaviour of polymeric materials when subjected to compression loads

Daniel Rodrigues[1,2], Jorge Belinha[1,2], Lúcia Dinis[1] and Renato Natal Jorge[1,2]
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Abstract
Additive manufacturing (AM), also known as 3D printing (which is done layer-bylayer), is an emergent technology for the production of components and structures, and whose advantages have been extensively explored in the fields of mechanical engineering. Because AM processes operate with the variables space and time, the material systems produced by these means can be significantly heterogeneous, nonlinear and anisotropic. Dimensional errors, delamination of layers, porosity and poor or indeterminate material properties are obstacles to the widespread adoption of AM. Despite the stated issues, there are few numerical tools that could simulate these processes. This means that the optimization of the performance of the method and the properties of the final product are done nowadays only from experimental tests. This work intends to generate the first bases for the future construction of a numerical tool, using meshless methods (Belinha 2014), for the simulation of a particular AM process, the fused filament fabrication (FFF). Thus, the focus of this research is the analysis and simulation of the elasto-plastic behaviour of polymeric materials when subjected to compression loads. This phase constitutes as a key step in the development of the referred numerical tool.

Keywords. elasto-plasticity, non-linear mechanics, polymeric materials, simulation of compression processes.

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Tensor Fabric definition using micro-CT Images

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Abstract
A fabric tensor is a symmetric second rank tensor that characterizes the arrangement of a multiphase material, having encoded the orientation and anisotropy of the material. Fabric tensors can be obtained using different methodologies, from mechanical based methods to morphologic-based methods. Most of the fabric tensors obtained using morphologic-based methods are computed by an orientation distribution function (ODF) that is estimated from an orientation-dependent feature of interest, being the fabric tensor approximated from that ODF.
Cowin, 1985, developed a relation between the fourth rank elasticity tensor $\mathbf{C}_{ijkl}$ and a fabric tensor **A**. The results obtained by Cowin, 1985 shows that that an ellipsoid may be associated with the varieties of material symmetries observed in many natural materials, and so, that these three types of second rank tensors, and therefore these three types of ellipsoids, are associated with the material symmetries of orthotropy, transverse isotropy, and isotropy, respectively (Cowin 1985).
One of the most morphologic-based methods used in trabecular bone research is the mean intercept length tensor (MIL), developed by Whitehouse 1974 (Whitehouse 1974). It is considered a standard since there is a large amount of work that sustenance its appropriateness to predict mechanical properties of trabecular bone. This method implementation is efficient in the spatial and in frequency domains. One characteristic that makes this tensor wide popular is the fact that it shares the same eigenvectors, when used in binary images, with the MIL methodology, enabling the comparison of methodologies. In this work, the MIL technique is applied to obtain directly from the Micro-CT images the constitutive tensor of a trabecular patch. It is usually computed by defining a family of parallel lines to a specified direction *v*. The number of intersections, *C(v)*, between lines and the interface between both phases is counted. Begin *MIL* a function of *v*, *MIL(v)*, and computed as a ratio between the totality of the length of traced lines, *h*, with the number of intersections, *C(v): MIL(v)=h/ C(v)*. Researchers found that for many types of materials, particularly bone trabeculae, an ellipse could be fitted to a rose diagram of the MIL (Moreno, Borga, and Smedby 2014). With this, in 2D MIL, tensor, **A**, can be computed as the 2 × 2 matrix that represents the estimated ellipse.
Our methodology was developed using MATLAB©. A set of cuboid micro-CT images was used as input image for our study. All the processes up to the mechanical analysis, were developed using standard MATALB toolboxes. The MIL methodology was developed using image processing methodologies. Using the DICOM metadata associated to the image it is possible to define the real size of the image that is used in the process.
In order to fit the data acquired from the ODF into a ellipse, it was used the method developed by Fitzegbbon et al (Andrew *et al.* 1996).
Using the material law proposed by Belinha *et al.*2012 (Belinha, Natal Jorge, and

Dinis 2012) and the ellipse data, it is possible to define the material mechanical proprieties. In order to use this material law, first, it was necessary to calculate the apparent density of the square patch, which was obtained using the information of the binary image.
Thus, using the results obtained from the MIL and the material law proposed by Belinha *et al.* 2012, the mechanical proprieties of a specific bone patch were defined. Then, applying different numerical approaches (finite element method and meshless methods), specific trabecular bone patch was analysed and displacement, strain and stress fields were obtained.

Keywords. micro-CT, Fabric Tensor, MIL.

Acknowledgments

The authors truly acknowledge the funding provided by Ministério da Ciência, Tecnologia e Ensino Superior – Fundação para a Ciência e a Tecnologia (Portugal), under grants: SFRH/BPD/111020/2015, SFRH/BD/110047/2015, and by project funding UID/EMS/50022/2013. Additionally, the authors gratefully acknowledge the funding of Project NORTE-01-0145-FEDER-000022 – SciTech – Science and Technology for Competitive and Sustainable Industries, co-financed by (NORTE2020), through (FEDER).

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A Fracture Mechanics Analysis on a Compact Tension Specimen

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Abstract
This work aims to experimentally determine the mode I Stress Intensity Factor (SIF) for a standard Compact Tension (CT) specimen made of Aluminum alloy AA6082-T6 during a fatigue crack growth test. As an experimental solution, a 3D optical technique, Digital Image Correlation (DIC) was used to capture strain variations on the specimen surface. Using the acquired data together with a nonlinear overdeterministic algorithm, the SIF is evaluated for distinct crack lengths. Besides, the model is also simulated with two numerical discretization approaches, Finite Element Method (FEM) and Meshless Radial Point Interpolation Method (RPIM). Reliable results obtained from FEM and RPIM possess a coherent agreement with the experimental and theoretical solution, the latter one is derived from ASTM E647.

Keywords. Compact Tension Specimen, SIF, FEM, RPIM, Digital Image Correlation.

Determination of the friction coefficient in the flat track strip drawing test

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Abstract
The present work is focused on the influence of friction in deep drawing process. Four different tool surfaces using two tool materials were tested under similar contact conditions regarding contact area, normal pressure, sliding speed, lubricant and surface characteristics to calculate the friction coefficient between the tool surface and a high strength low alloy steel sheet. This study evaluates surface properties of tool materials for metal forming operations

Keywords. Lubricant, steel sheet, tool plate, modified strip draw tribotester.

1. Introduction

A modified strip drawing tribotester has been used to generate the movement between the tool and sheet. The uniqueness with this device compared to existing tribotesters used within sheet forming applications is the ability to fully control the applied normal force and drawing velocity during experimentation to simulate true tribological conditions more accurately. This option makes it possible to combine very accurate control of the relative movement between the sheet and the tool with consistent load and pulling force measurement. The test method enables comparison of different surface finishes and treatments, lubricants and coatings in terms of friction and galling under true sheet metal forming process conditions (Trzepieciński *et al.* 2015). Valid frictional data is also very important (Kirkhorn *et al.* 2013), as an input parameter for simulation models to achieve reliable results.

2. Test Methods and Experimental conditions

The basic functioning of the tribotester is illustrated in Figure 1. A tensile testing machine was used to provide force and displacement control for the modified strip drawing tribotester. The specification for the linear drive in terms of velocity, distance, force, and load was based on estimates from sheet forming processes. Table 1. illustrates the values used in the strip drawing tests.

Table 1. The specifications for strip drawing test.

	Test material properties
Test material:	Cold Rolled HC380LA
Test material thickness:	1.5 [mm]
Tool materials:	K 340 (X110CrMoV8-2) EN; C 265 (X160CrMoV12-1) EN
Surface conditions	Grinded, Polished, Nitrated and Quenched/tempered
Tools active area:	2745.9 [mm²]
Lubricant:	Press oil (viscosity 68 mm2/s)
Normal loads:	$F_N \approx$ 10.4 - 16.25 - 32.5 - 48.75 [kN]
Sliding speeds:	60 - 150 - 240 [mm/min]
Sliding length:	120 - 130 [mm]

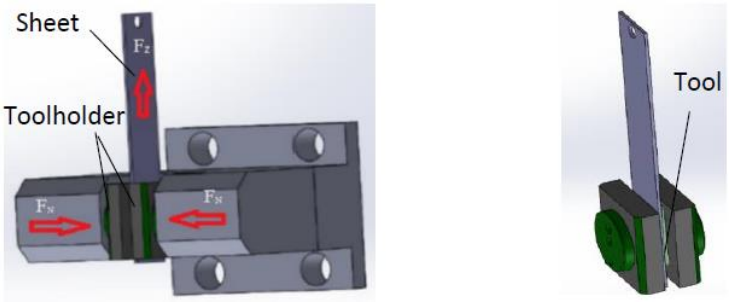

Figure 1: Set of tools and sheet metal.

3. Calculation of friction coefficient under constant speed and normal force

The friction force was acquired and the friction coefficient was calculated for constant speed and constant normal force. Each test was performed with lubricants. The corresponding plates involved four different surface conditions (grinded, polished, nitrated and quenched/tempered) and three different sliding speeds. Also, four different normal force values were applied. Therefore, twelve tests were performed for each set of tool plates.

Table 2. Experimental results.

Tool surface condition	Sliding speed [mm/min]	Coefficient of friction			
		10.4 [kN]	16.25 [kN]	32.5 [kN]	48.75 [kN]
Grinded	60	0.143 ±0.002	0.108 ±0.002	0.099 ±0.001	0.107 ±0.002
	150	0.108 ±0.003	0.122 ±0.001	0.092 ±0.001	0.097 ±0.002
	240	0.104 ±0.002	0.104 ±0.003	0.088 ±0.002	0.098 ±0.0006
Polished	60	0.084 ±0.002	0.081 ±0.0008	0.069 ±0.001	0.073 ±0.001
	150	0.085 ±0.002	0.082 ±0.002	0.070 ±0.001	0.079 ±0.0009
	240	0.099 ±0.0004	0.084 ±0.0006	0.074 ±0.0008	0.078 ±0.001
Nitrated	60	0.136 ±0.009	0.125 ±0.008	0.107 ±0.004	0.106 ±0.004
	150	0.141 ±0.003	0.138 ±0.003	0.111 ±0.003	0.118 ±0.001
	240	0.164 ±0.003	0.145 ±0.002	0.124 ±0.004	0.118 ±0.003
Quenched/tempered	60	0.119 ±0.004	0.216 ±0.014	0.119 ±0.003	0.182 ±0.04

4. Conclusions

Results of the experiments reveal that the modified strip drawing tribotester is a very useful tool to compare and evaluate the friction between tool and sheet surfaces meant for cold working applications. From test results it was found that, due to stability, generally 80–90% of the sliding length was used for average friction determination. However, for quenched/tempered surfaces, only 25–30% of the sliding length was possible to be used, due to more unstable conditions. Also, the friction data was not fully correlated with other parameters and future work will be needed to highlight this matter.

Acknowledgments

Authors gratefully acknowledge support of Erasmus Mundus program for “TOSCA” project, as well as INEGI, for their financial support (RH LAETA CETRIB 73/16) and resources to this work. Also acknowledged is funding of SciTech, R&D project NORTE-01-0145-FEDER-000022 cofinanced by NORTE2020, through FEDER and the financial support of the Portuguese Foundation for Science and Technology (FCT) under project PTDC/EMS-TEC/6400/2014. Finally, one of authors is grateful to the FCT for the Doctoral grant SFRH/BD/119362/2016.

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In-vitro degradation test and effect of freezing on mechanical performance of meshes used in hernia surgery

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Abstract
The use of prostheses for hernia surgery, made from synthetic polymers, may lead to the development of postoperative complications. The reason for this can be the mismatch of the mechanical properties of meshes and the loads acting on them. The aim of this investigation was to explore the effect of *in-vitro* degradation process and repetitive loadings on the mechanical performance of the meshes used for hernia repair, made from different materials. The second point was investigate the effect of freezing (preservation) on mechanical properties of the mesh samples
Keywords. Hernia mesh, mechanical properties, degradation, freezing.

1. Introduction

The use of prostheses for hernia surgery, made from synthetic polymers, may lead to the development of postoperative complications. Complications can be linked with the mismatch of mesh mechanical properties and the acting loads (Cobb et al., 2005). The working life of surgical meshes is associated with two periods: functional and passive. During the first period, the implant becomes part of the musclefascial complex and should have properties as compatible as possible to the biomechanics of abdominal wall. The second period is related to the biodegradation process.

One of the aims of this investigation was to study *in-vitro* degradation process and repetitive loadings on the mechanical performance of the meshes used for hernia repair. The second aim was to analyse the effect freezing (storage) on the mechanical properties of the mesh samples.

The most common method to investigate the mechanical behaviour of explants consists of conducting mechanical tests on animal tissue explants. These tissue samples are often stored in cold/freezing storage (at -20 °C) before being used (Feola *et al.*, 2013; Roman *et al.*, 2016; Rubod *et al.*, 2007). Previous studies have found different results on the effect of temporary cold storage on the mechanical properties of arteries (Venkatasubramanian *et al.*, 2006; Erin *et al.*, 2004). The mechanisms of this change in mechanical properties may be caused by ice crystal growth. The majority of surgical meshes currently available for use are made from synthetic materials and may also be susceptible to loss of properties, during storage (before testing) at low temperatures. Understanding these changes is important in choosing appropriate storage methods for explants.

2. Materials and methods

Three meshes of different materials, Ultrapro (poliglecaprone and polypropylene), Dynamesh (Polyvinylidenefluoride) and Surgipro (polypropylene), were selected this study. A total of 20 samples were obtained for each mesh.

To study *in-vitro* degradation processes of the materials, all stages of the work were conducted in accordance with ISO 10993 (ISO). Phosphate Buffer Solution (PBS) (pH=7.4) and Potassium Hydrogen Phthalate (KHP) (pH=4.3) were used. Samples were kept in the solutions at 37° C during 42 days. The degradation of the material was evaluated via thickness and weight loss. Cyclic tests were performed in order to mimic the effects of repetitive loading, similar to expected *in vivo* loads. Using 11 N/cm, 16 N/cm and 27 N/cm, the equivalent forces acting on the mesh samples were estimated. A preload of 0.11 N was applied, after preloading, samples were loaded to estimated force and then unloaded back to 0.11 N. A constant elongation rate of 5 mm/min was used. Three levels of cyclic loading were set (C1, C2, C3), with 100 cycles applied at each level. After the 300 cycles, samples were stretched to failure. This number of cycles was selected in order to simulate the geometrical changes of a freshly implanted mesh under physiological loads during postoperative recovery. The equipment used for

cyclic loading test is a prototype developed at INEGI Biomechanics Laboratory.

To study freezing (storage) effect samples were divided in two group: control and 1 month frozen in saline solution (at -20° C) in freezer. Uniaxial testing was performed using a Zwick tensiometer (Zwick GmbH & Co. KG, Ulm, Germany). Specimens were pre-loaded till 0.11 N, using a constant elongation of 5 mm/min, then were loaded until failure.

3. Results

During the degradation process Ultrapro mesh samples lost 38% ($p<0.001$) of their initial weight, in both mediums. The mesh thickness decreased by ~22% ($p<0.001$). There was no significant difference between samples after degradation in PBS and KHP mediums. Significant difference was found among dry and degraded samples, during all periods of cyclic loading. During the degradation Surgipro mesh samples lost 3.8 % of initial weight in both mediums. There was no thickness variation after and no significant difference in weight loss. No significant differences during all periods of cyclic loading were found among all groups. Dynamesh samples significantly lost weight and thickness during degradation. Significant differences were found between dry samples and samples in KHP ($p<0.05$). Dynamesh samples could not withstand applied loads over 22 N/cm. Therefore, the last cyclic period at 27 N/cm load, was not carried out. After freezing, significant difference in elongation and load showed Dynamesh and Ultrapro meshes. Meshes become more fragile, and less elastic.

4. Discussion

This work investigated the behavior of 3 different meshes under *in-vitro* simulated physiological conditions, freezing effect and mechanical loadings. Despite the different compositions and architectures of the meshes, all three underwent permanent plastic deformation, which will induce decreased mesh flexibility over time. Mechanical hysteresis was observed in all three meshes. A decreased flexibility of the hernia mesh is possibly related with reported complications, such as reduced abdominal wall mobility and long-termed pain and discomfort. Degradation caused a significant geometrical changes of the mesh. As expected, the greatest weight loss and thickness reduction were suffered by Ultrapro, a partially absorbable mesh. In addition freezing effect showed a loss of mechanical properties of materials.

5. Conclusions

Biodegradation and cyclic tests of mesh material renders more knowledge about the physical mechanisms of the implant. Controlled *in-vitro* degradation testing is typically used to complement animal trials to understand the implant material, the design, and the fabrication factors that affect *in vivo* implant ingrowth.

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Design and Fabrication of supersonic shock tube capable of producing shock waves

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Abstract
The advent of supersonic flight has created a need for better understanding of shock waves and of the properties of gases processed by shock waves. The shock tube, a laboratory instrument used to generate shock waves under controlled conditions, is a natural tool for experimental investigations of shock-associated phenomena. There are different kinds of mechanisms used all around the world to produce shock waves, in-depth literature review lead us to come up with the best possible economical and feasible design which meet the requirements. In this research a shock-tube capable of producing supersonic shock waves have been designed and fabricated from stainless steel materials and various materials were used as diaphragm.

Keywords. Mach Number, Shock waves, Supersonic flight, diaphragm

1. Introduction

A shock tube is an instrument used to produce supersonic gaseous flows. It works by creating a large pressure difference across a thin diaphragm causing it to rupture due to high pressure. This produces a high speed shockwave in the low pressure region which moves across the length of the tube causing the stagnant gas to start flowing at supersonic speeds. Working principal of shock tube is that a diaphragm is a membrane separating high and low pressure regions in the shock tube. High pressure region is continuously pressurized by mean of compressor. When reaching a critical value for diaphragm stress, diaphragm burst and exposes high pressure gas to low pressure on removal of membrane high pressure particles move to low pressure regime, bombarding its particles to low pressure particles.

2. Materials and Methods

The tube was manufactured by bending the sheets of stainless steel into pipes because the cost of the stainless steel pipe of required diameter was very high and unaffordable. Due to this reason a sheet of stainless steel with thickness 2 mm was selected and then bent into the desired shape by welding. The welding joint was strong enough to bear pressures of up to 14 MPa. Stainless steel was used because of its very smooth surface and moreover high strength. There were two different diameter pipes one of 8 inch diameter and other of 6 inch diameter. These two were connected by using a flange. The diaphragm was mounted in between the two pipes by using this flange. The joint was sealed by using a foam as a seal. The flange was joined by using 8 stainless steel bolts. At the end of the 6 inch diameter pipe our test section was mounted by using 8 nuts and bolts. The test section was made by 2 mm thick Mild Steel sheets in square shape. Two holes were drilled in it for the mounting of the shock wave sensors. The material of the diaphragm was selected according to the ultimate tensile strength of the metal and market availability. In this research work three types of diaphragms made up of Aluminum Sheets of different gauges have been used.

Figure 1: Fabricated shock tube.

3. Results & Discussion

Table 1 indicated comparison of theoretical values and calculated values. As it is clear from figure 16 and figure 17 that experimental Mach No. is greater than theoretical because pressure required for Diaphragm Rupture while experiment is large. Difference in pressure is because of difference in UTS of material theoretically and practically bought material. Due to less accuracy of Diaphragm Type Sensor Switch there is variation in experimental values.

Table 1. Comparison of theoretical values and calculated values.

Diaphragm Thickness (mm)	Driver Section Pressure (P4/P1) Experimental (Bar)	Driver Section Pressure (P4/P1) Theoretical (Bar)	Experimental Time of Shock wave (micro seconds)	Shock Mach No. (Experimental)	Shock Mach No. (Pressure Table) Theoretical
0.09	2.2	1.4	680	1.188	1.0823
0.19	2.85	1.85	645	1.2498	1.14
0.48	4.8	3.22	580	1.3931	1.2816

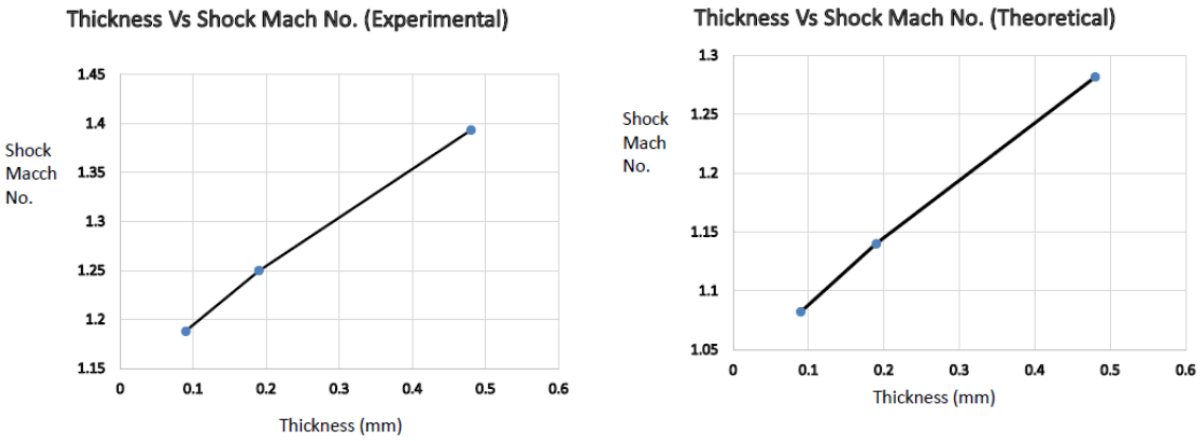

Figure 2: Experimental Results (left) and Theoretical Results (right).

4. Conclusions

The experimental setup of shock tube was successfully detected and shown shock wave Mach No. for diaphragm ruptures of different Aluminum sheets. The experiments showed the presence of shock wave produced. Further, theoretical values matches with the experimental values with a tolerance due to practical factors involved. Thus Experimental results are also confirmed and backed by theoretical study of shock tube and diaphragm rupture analysis.

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Springback analysis using finite element method of an aluminium panel processed by sheet metal forming

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Abstract
Accurate prediction of springback is a long-standing challenge in the field of sheet metal forming and especially with aluminium alloys. The objective of this study is to predict the springback of an aluminium panel used in automobiles, through the use of finite element analysis. Proposed component was defined as benchmark in NUMISHEET 2016, series of conferences. At defined section planes, the profiles of the formed part were analysed and evaluated numerically to predict the final geometry after springback. Results were compared with experiments and the numerical submitted by the benchmark participants. Obtained results show a good accuracy in predicting the springback when compared with the experimental values.

Keywords. sheet metal forming, aluminium alloys, springback prediction, FEM

1. Introduction

In modern manufacturing industries, aluminium has been a popular and widely used material. Especially in aerospace, defence and automotive industries, aluminium alloys are preferred because of their relatively light weight and satisfactory strength properties. Although aluminium alloys have relatively low tensile properties compared to steel, their strength to weight ratio appears to be satisfactory. Springback denotes the property of sheet metal parts to change shape upon unloading after forming. This shape change is elastically driven since upon removal of the deformation load a stress reduction takes place and the total strain is decreased by the amount of elastic strain which results in springback (Vladimirov, Pietryga, and Reese 2009). The phenomenon of springback is a growing concern in the sheet metal forming industry because it leads to major assembly problems and complicates the design of the die. Thus, prediction and compensation of springback are essential in the design stage of forming processes to achieve precise final part shapes to avoid problems in the assembly.

Due to the fact that traditional trial-and-error methods for springback compensation are time-consuming, while empirical adjustments are not applicable to complex geometries, the finite element simulation of springback has become essential for the tool and process design. The major advantage of finite element methods is the possibility of modelling complicated tool descriptions and realistic material behaviour (Esat, Darendeliler, and Gokler 2002).

2. Finite element simulation

A finite element simulation was performed to form an automobile aluminium panel. The material parameters and the boundary conditions for the simulation were defined as provided by the NUMISHEET conference. The material used is the AA6451-T4 aluminium alloy with a blank thickness of 3.0 mm. The single stage forming operation is followed by a trimming step and the removal of tools with springback. The combined Swift–Hockett/Sherby hardening law and Barlat'89 yield criteria

were applied. Table 1 shows some fundamental mechanical properties for the aluminum alloy.

Table 1. Uniaxial Tension Test Data.

Test Direction	YS, σ_{yld} (MPa)	r-value
0°	151.28	0.62
45°	171.2	0.33
90°	163.6	0.8

3. Results

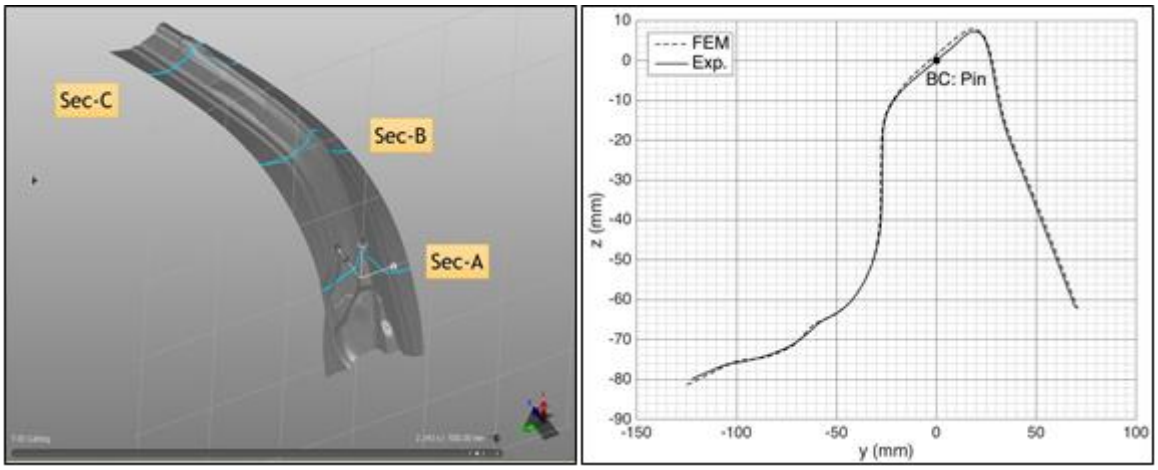

Figure 1: a) Section profiles of formed part; b) FEM and experimental springback results of section A.

The springback of the aluminium part was analysed at the cross-sectional profiles of specific provided section planes. Figure 1 a) shows section profiles of formed part and b) shows springback at section A compared with the experimental values (with an offset). It is shown that the springback profiles are in very close agreement for that section after trimming and springback.

4. Conclusions

A springback analysis has been performed by FEM and applied to an automobile sheet metal part. The material model defined and hardening law, with Barlat'89 yield criteria were successfully applied to carry out the simulation of the forming of an aluminium alloy part. The results also show good agreement between obtained results and experiments, as well as other participants who applied different hardening law and yield criteria.

Acknowledgments

First author is thankful for the doctoral scholarship from ERASMUS MUNDUS under LEADERS project coordinated by City University of London, UK. Authors gratefully acknowledge the funding of SciTech, R&D project NORTE-01-0145-FEDER-000022 co-financed by NORTE 2020, through FEDER and the financial support of the Portuguese Foundation for Science and Technology (FCT) under project PTDC/EMS-TEC/6400/2014. Two authors are also grateful to the FCT for the Postdoctoral grants SFRH/BPD/101334/2014 and SFRH/BD/119362/2016.

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Flow stress and damage constitutive models identification for metal cutting simulation based on experimental tests featuring shear mechanism

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Abstract
In metal cutting process, very high temperature, strain and strain rates are reached. In order to properly simulate the process, it is of utmost importance to identify material flow stress and damage constitutive laws under those conditions. Even though multiple characterization techniques are available in the literature, it is still challenging to establish which technique is suitable for a certain manufacturing process as well as its calibration procedure. This paper investigates several techniques of material characterization as well as their calibration. Due to the shearing mechanism involved in metal cutting, focus is given to shear-punch tests and shear-fracture tests, which are compared to conventional compression tests. The influence of punch-die clearance, specimen thickness and ligament length is studied. The experimental work was conducted with aluminium alloy AA1050 and numerical simulation of the tests was performed on DEFORM commercial software. Furthermore, different constitutive laws are discussed, including hydrostatic pressure and lode angle sensitive models.

Keywords. Shear tests, FEM, Aluminium, Flow stress, Damage model, Metal Cutting

Ductile failure modelling using gradient and phase field approaches

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Abstract

This work concerns bridging a gap between the gradient-enhanced nonlocal models and the phase field approach focusing on regularizing the internal degradation in microstructural level. This requires making a meaningful relation among the diffusive equation of the phase field approach and the continuous damage constitutive relations to reduce the mesh-induced issues of the local degradation description. Flexibility and convergence rates of the proposed model will be analyzed via the assessment of several benchmarks.

Keywords. Gradient-enhanced nonlocal damage models, Phase field approach, Internal degradation, Mesh-induced issues

1. Introduction

Prediction and assessment of the failure in structures is an essential design step in today's industry and manufacturing processes. The softening induced in the overall structural response when damage effects are introduced at the constitutive modelling of the material is, traditionally, a source of numerical pathologies associated with the geometric discretization. It has been proved that the inclusion of an intrinsic microstructural length scale within the material constitutive model may solve some mesh dependent issues and retrieve the well-posedness to the initial boundary value problem. Gradient-enhanced damage models were proposed as a remedy to accomplish such improvements by delimiting the localization of the plasticity and damage-related variables, see [1-4]. Another school of thought departed from the regularization of the fracture-induced failures based on the physics of phase transformation, named as the phase field approach. Such regularization needs the definition of an order parameter which distinguishes between the intact and fractured material phases, likewise the internal degradation variable in continuous damage mechanics. This methodology initiated from the initial attempts by Francfort & Marigo who proposed the variational formulation of brittle fracture based on energy minimization principles [5] and its regularized format by Bourdin et al. [6], which was further elaborated in brittle fracture [7-9] and ductile fracture contexts [10-11].

2. Formulation

Assessment of the failure induced by the microstructural evolutions via phase field approach requires establishing a coupled framework which integrates the local description of damage with the diffusive equation associated to the phase field concept. Such model may enhance the performance of the classical gradient models by possessing the advantages of the phase field approximation, such as flexibility to analyse intricate crack patterns as is the case in branching and merging cracks, while at the same time it can also be viewed as an improvement of gradient damage approaches.

Focusing on the regularization of internal damage field and departing from local damage models, such as the phenomenological framework by Lemaitre[12], a multi-field initial boundary value

problem based on the displacement and a phase-field parameters constructed and implemented into a finite element package. To further clarify the advantages and disadvantages of the proposed model and for the sake of comparison with other gradient models, several influential factors such as the role of length scale parameter or the broadening of damage zone, as reported in [13], are investigated resorting to various benchmarks

Acknowledgments

Authors gratefully acknowledge the funding of Project NORTE-01-0145-FEDER-000022 - SciTech - Science and Technology for Competitive and Sustainable Industries, cofinanced by Programa Operacional Regional do Norte (NORTE2020), through Fundo Europeu de Desenvolvimento Regional (FEDER).

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Optimal Robust Trajectory Control of Atmospheric Flights

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Abstract
One of the operational requirements for unmanned aerial vehicles (UAVs) is the autonomous navigation and control along a given sequence of waypoints, or along a predefined trajectory. Existing autonomous navigation procedures are mostly done in 3D because of the stringent certification requirements for 4D flight and due to the complexity in coping with time of arrival at waypoints, whilst actual flight plan fulfillment requires 4D navigation. The present PhD thesis deals with the trajectory optimization and optimal control of unmanned aerial vehicles along sequences of 4D waypoints. The main objectives rely on elaborating methods that require low computational load for online trajectory generation and optimal trajectory control subject to fuel saving and energy minimization requirements in the framework of 4D navigation UAVs. Validation of the methods to be developed will be done through real-world applications under the collaboration of the research team with some Portuguese manufacturers of UAVs.

Keywords. 4D Navigation; Autopilot System; Trajectory Control; UAV.

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4D Commercial Trajectory Optimization for Fuel Saving and Environmental Impact Reduction

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Abstract
Fuel consumption is one of the main sources of high operating cost of commercial aircraft. Besides, environmental impact due to commercial flights has also been a major concern for air transportation. Fuel saving and environmental impact reduction have been dealt with so far in the context of 2D and 3D trajectory optimization, which is inefficient and far from being optimal since actual flight plan fulfilment requires 4D navigation.
The 4D-trajectory optimization problem can be formulated as an optimal control problem. This approach has been studied extensively over the last decades for fuel saving as well as environmental impact assessment and reduction. However, realistic path constraints as imposed by operational and air traffic constraints have not been considered specifically due to the underlying models and concepts that are not suited for practical flight operations. Recently, the aims in 4D trajectory optimization shifted to the use of Dynamic Programming (DP) as a promising numerical optimization method and demonstrates its applicability and feasibility into the optimal control problems through practical application examples in the aerospace engineering field. This method has many favorable advantages over the other methods. The most conclusive one is that DP can provide a global optimum.
However, it is well known that conventional dynamic programming is impracticable since the number of grids under consideration grows exponentially as a function of the number of stages. Luus built an iterative dynamic programming framework with reduced number of grid-points at each stage; this framework has been improved by Bousson who devised a method in which only a single grid-point at each stage is sufficient for trajectory optimization. Meanwhile, the limitations of almost all the current methods for 4D trajectory optimization may be summarized by the fact that they do not cope with waypoint-based trajectories, except to the work that has been recently initiated by Bousson and co-workers to deal explicitly with waypoint-based trajectory optimization.
The research work is centered on devising a new framework for single-grid iterative dynamic programming for 4D trajectory fuel saving and environmental impact reduction in a network of predefined waypoints on the basis of these previous research works.

Keywords. 4D Trajectory Optimization, Optimal Control, Dynamic programming, Fuel conservation, Environmental Impact Reduction.

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Identification of Flow Stress Curve for the AlSi9Cu3 using Johnson-Cook formulation

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Abstract

The analysis of metal forming processes using FEM based simulation have many advantages compared to the analytical processes (Klocke *et al.* 2001). During simulation, most important input data is flow stress curve of work material. The result of the simulations mostly depends on the correct flow stress curve (Sekar and Kumar 2012). The aim of this study is to find out appropriate flow stress curves for AlSi9Cu3 alloy by using the constitutive model by Johnson-Cook, based on experimental works such as high strain rate turning tests with 0˚rake angle PCD turning tool, fracture tests and compression tests of the AlSi9Cu3 alloy. The compression tests are done on two different environmental temperatures, room temperature and higher than room temperature. A hybrid direct/inverse identification strategy will be adopted to overcome the difficulty of performing high strain rate tests. The investigated material has high strength to weight ratio and it is widely used in automobile and aerospace cast parts (Roy *et al.* 2009), which requires extra machining operations. The simulation of such machining processes requires information on flow stress curve, which is not available in the literature for the required machining conditions.

Keywords. Flow stress, Johnson-Cook constitutive model, AlSi9Cu3 alloy.

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Parameter Identification Strategies for non-linear mechanical models

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Abstract
Nowadays, the characterization of materials has received increasing attention due to the need of precise input data to computational analysis software. Simulation software uses complex material constitutive models and its success reproducing the real behaviour depends on the quality of this material models implemented and their material parameters. In general, the parameters of nonlinear models are determined by standard tests under the assumption of homogenous strain and stress field in the zone of interest (A. Andrade-Campos, et al., 2007). However, the homogeneous stress and strain fields generated in these relatively simple tests do not resemble the complex stressstrain fields which occur in metal forming operations. Additionally, the inverse methodology of curve-fitting between the experimental and FEM model is not reliable (F. Pierron and M. Grédiac, 2012). Nevertheless, in the last decade, Digital Image Correlation (DIC) techniques and full-field measurements have enabled the development of new parameter identification strategies such as the Full-field Finite element model updating (FEMU), the virtual fields method (VFM), the constitutive equation gap method (CEGM) and the equilibrium gap method (EGM). Although these new strategies have proven effectiveness in linear models, their use in nonlinear models should be discussed. Therefore, this work compares and discusses these modern methodologies and strategies for the solution of the inverse problem of determining constitutive parameters for nonlinear elastoplastic models (de-Carvalho, et al., 2010). The detailed flowcharts of each strategy are presented as well as its advantages and disadvantages. Examples are included.

Keywords. Material parameters identification, Inverse problem, Full-Field measurements, Finite Element Method.

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A comparative analysis on the ability of ductile damage models to predict fracture

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Abstract
In this paper, different ductile damage models are studied, namely Johnson-Cook (JC) model, Gurson-Tvergaard-Needleman (GTN) model and Lemaitre's damage model, under different loading conditions. The aim is to evaluate and validate their ability to predict damage growth and fracture initiation by using finite element analysis. The numerical results are compared with two experimental failure components, a deep drawing cylindrical cup and a cross-shaped part. Uniaxial tensile tests and hydraulic bulge test are performed to obtain the material behaviour and the corresponding material damage parameters are identified by an inverse analysis procedure, based on reference tests results.

Keywords. Ductile damage; fracture prediction; inverse analysis; numerical simulation.

1. Introduction

In order to obtain components from sheet metal forming processes, the material mechanical characterization is one important factor, which may affect significantly the accuracy of results.

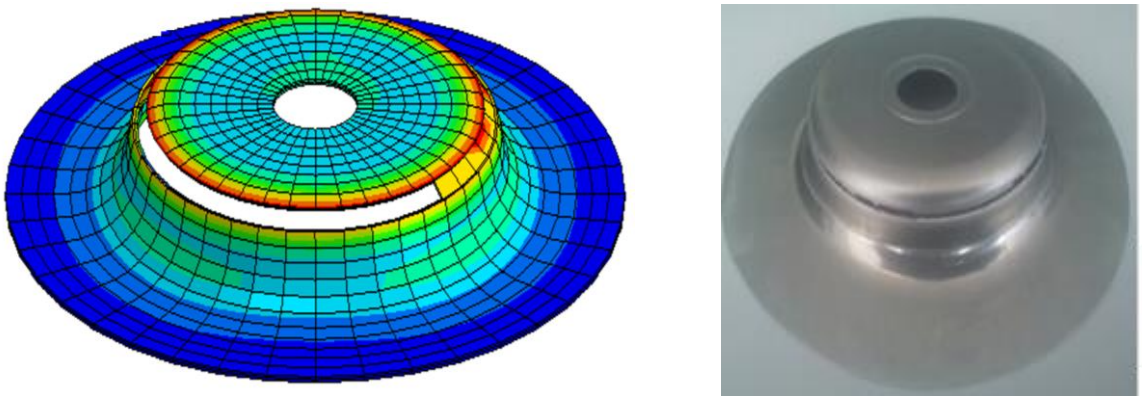
Usually, sheet metal materials can be subjected to huge confined deformations and consequently significant through thickness necking, therefore developing 3D stress states and promoting the fracture occurrence at the part. To predict this effect it is necessary to use damage models and the corresponding parameters can be obtained using experimental results from reference tests (Bai *et al* 2015). Traditionally in the characterization of material ductility the combination of equivalent plastic strain and stress triaxiality parameters are taken into account. Some well-established models like the Johnson-Cook model, Lemaitre model and GTN based models and many others perform relatively well, giving adequate answers for fracture prediction, but some may fail in specific cases due to the stress triaxiality state (Amaral *et al.* 2016).

2. Material modelling and damage parameter identification

Uniaxial tensile tests were performed, as well as, hydraulic bulge test to obtain the material characterization. The experimental test results were used in the inverse analysis procedure to identify the corresponding ductile damage model parameters. The implemented minimization algorithm, gives the best fitting parameter values that minimize the mean square error (MSE) between the numerical data and the experimental results

3. Finite element simulation of experimental cases

Figure 1 shows one of the experimental components in which failure occurred, being this example used to evaluate and analyze the ability of the selected damage models to predict the damage growth and fracture initiation.



a) b)

Figure 1: Numerical failure result and experimental part with corresponding fracture location for a deep drawing cylindrical cup.

A 3D finite element explicit analysis was performed, in order to compare the results of the different implemented damage models with experimental data. JC and GTN have its models already implemented in Abaqus FE package, but a user material subroutine was developed for Lemaitre damage model to be combined and included in the FE package.

The numerical punch stroke and force, as well as, the equivalent plastic strain were analyzed and evaluated in order to test the different models and their ability for prediction of damage growth and fracture initiation.

4. Conclusions

A damage prediction analysis has been performed using different ductile damage models by finite element simulations of experimental cases, e.g., a deep drawing cylindrical cup and a cross-shaped component. For the deep drawing cylindrical cup, the obtained finite element results using the Johnson-Cook and GTN models show a good correlation in punch stroke and fracture location, but for the cross-shaped component the Lemaitre and Johnson-Cook ductile damage models show better results when compared to experiments.

Acknowledgments

Authors gratefully acknowledge the funding of SciTech, R&D project NORTE-01-0145-FEDER-000022 cofinanced by NORTE2020, through FEDER and the financial support of the Portuguese Foundation for Science and Technology (FCT) under project PTDC/EMS-TEC/6400/2014. The first author is also grateful to the FCT for the Doctoral grant SFRH/BD/119362/2016.

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Adaptive Nonlinear Filter and Optimal Radar Tracking of Aerospace Vehicles

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Abstract

In nature, most physical systems are inherently nonlinear so nonlinear filters are extremely useful in diverse real world applications, including target tracking, navigation of aerospace vehicle, multi-sensor data fusion, robotics, communication systems, inertial navigation, chemical plant control, predicting weather, as well as estimating structural macroeconomic models.

Regarding the aerospace field, radar tracking of space objects is a critical problem since it always needs to deal with real-time processing of noisy information, requiring robust filtering methods that are able to deal not only with the uncertainties of the vehicle dynamics but also with environmental disturbances and instrumental inaccuracies related to the data acquisition systems. One of the main tasks related to radar tracking is the nonlinear filtering of trajectory data, which is based on the availability of highly accurate information.

Current nonlinear filtering methods are based either on the local linearization or on the statistical approximation of the nonlinear flight dynamics of the vehicle. The key practical issue with nonlinear filters is the real time computational complexity to achieve a given estimation accuracy. Filtering methods based on the Monte-Carlo simulation concept have also been used for trajectory estimation; however, they require intensive calculations that may be prohibitive for time-critical radar tracking applications.

Due to the high usage and the ability to provide a high performance, nonlinear filters are considered an important topic in modern control theory and control system engineering and since Kalman filters were invented, there has been intensive research activities on these filters attempting to improve estimation accuracy and reduce real time computational complexity.

In order to overcome the current methods limitations, the present research work intended to develop a robust adaptive filter, this means, a method that accounts the variability of environmental disturbances and instrumental inaccuracies inherent to data acquisition systems, providing a more accurate, precise and robust estimate without compromising the processing time and computational complexity. It is intended to validate the propose method on aircraft tracking (takeoff and landing situations), spacecraft atmospheric reentry and orbital transfer.

Keywords. Nonlinear Filters, Optimal Tracking, Trajectories Estimations, Kalman Filter, Monte-Carlo Method, Adaptive Nonlinear Filters.

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Air Bending Analysis using Artificial Neural Networks

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Abstract

Press Brake bending is a sheet metal forming deformation process in which the geometric interpretation is simple, but the control of final geometry is complex due to the interaction of different variables, either from the process or from the geometry. The main topic to be considered in this article is the development of a method capable of establishing the required punch displacement to obtain a given forming angle, in press brake air bending using an artificial neural network (ANN). ANN training is based on data obtained from finite element simulation of the forming process. A developed model has been used to obtain results from multiple tool geometries and sheet thicknesses. The results obtained show that ANN can provide a better approximation of the function relating the forming angle with the punch displacement. Validation of implemented models, methodologies and its results are also performed by comparison with experimental data.

Keywords. Sheet Metal Forming, Press Brake Bending, Air Bending, Artificial Neural Networks

1. Introduction

The linear bending is one of the most common industrial forming operations. Today most press brakes are equipped with CNC control, used to program the execution of various parts without the frequent exchange of tools, because the concept of air bending allows this flexibility.

Through a geometric triangulation, is possible to define the required punch penetration (*y*), to get the needed bending angle (α), for a defined die opening (*V*). One approach is proposed by J. Bessa Pacheco (Pacheco *et al* 2013), in which radius of the die (*rm*) is also taken into account:

$$y = \frac{V}{2 \cdot tan\left(\frac{\alpha}{2}\right)} - (r_i + t + r_m) \cdot \frac{1 - sin\left(\frac{\alpha}{2}\right)}{sin\left(\frac{\alpha}{2}\right)} \quad (1)$$

However, the analytical approach is established upon simplifications, usually based on the material properties and tool geometry. An alternative that overcomes these limitations, with accurate results and validated by experiments, is based on finite element analysis (FEA). Artificial neural networks (ANN) are another alternative to conventional analytical methods. Developing an ANN solution involves a development phase, through which the ANN model parameters are adjusted using available data from the problem and a training phase where a well-defined mathematical function provides the desired solution. In current work, the input data for ANN was obtained through numerical simulation of the air bending process to train the network with the aim of predicting the punch displacement to a defined bending angle. The proposed range of combinations include not only recommended V/t relations but also those values outside such recommended range. Some experimental tests are performed to evaluate and validate the numerical model, as well as the proposed methodology.

2. Materials, Numerical simulation and Experimental tests

A 2D finite element model was used where the blank is discretized using deformable four node solid elements (CPE4R type from ABAQUS® Library), while punch and die are modeled as analytic rigid surfaces. Two materials has been used, a dual-phase steel (DP500) and a high strength low alloy steel (HSLA420). The experimental tests were performed with a die opening of 11.1 mm and die radius of 1 mm, for 1 mm punch radius. The width and the thickness of the specimens is 0.8 mm and 1.8 mm, respectively. A comparison is made between the ANN with experimental and numerical results of bending angle with punch displacement (figure 1).

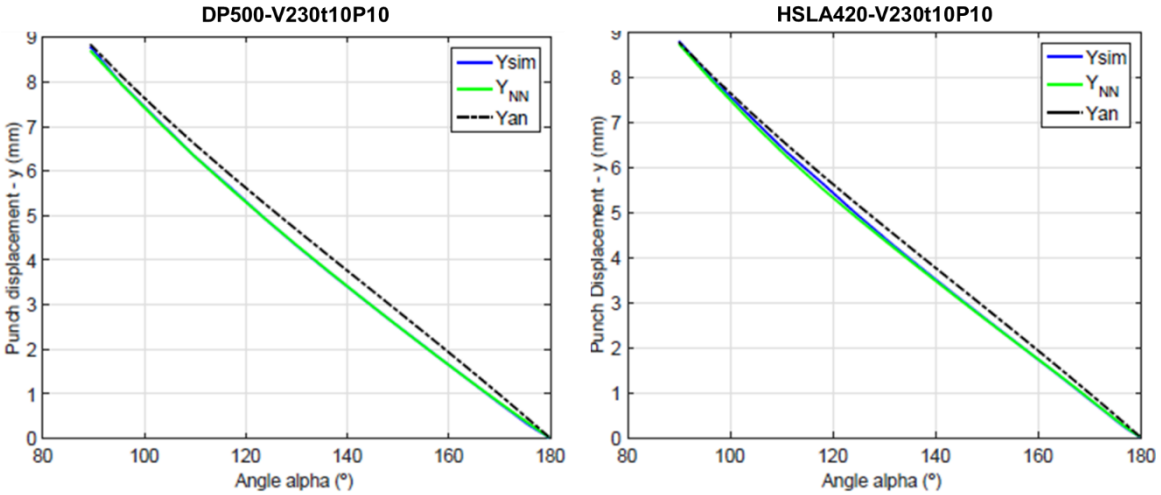

Figure 1: Comparison of artificial neural network results with numerical and experimental data for evolution of bending angle with punch displacement.

3. Conclusions

In this paper different methodologies are presented for the analysis of press brake bending processes and the study of fundamental variables. Numerical results of punch penetration are obtained, as well as the prediction of bending angle. Artificial neural network results show a good correlation for numerical bending angle evolution with punch displacement. The comparison with experimental tests, also carried out in this work, allow the validation of implemented numerical models and the performed implementation of artificial neural network.

Acknowledgments

Authors gratefully acknowledge the funding of SciTech, R&D project NORTE-01-0145-FEDER-000022 cofinanced by NORTE2020, through FEDER and the financial support of the Portuguese Foundation for Science and Technology (FCT) under project PTDC/EMS-TEC/6400/2014. The last author is also grateful to the FCT for the Doctoral grant SFRH/BD/119362/2016.

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Passive Vibration Control Using Viscoelastic Damping Patches

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Abstract
The present trend towards lightweight structures has had a significant impact on the field of vibration control, especially because structures with improved specific stiffness are prone to higher vibration amplitudes. Viscoelastic materials have already proved their efficiency on vibration suppression due to their damping capacity. However, an enhanced distribution of such materials could lead to improved vibration performances. Based on appropriate mechanical models along with efficient numerical methods the primary goal is to address issues on the proper use of partial treatments as a passive technique for vibration control.

Keywords. vibration, damping, viscoelastic

1. Introduction

The use of viscoelastic materials is a powerful method for vibration damping with systematic applications in automotive, railway and aerospace industries since the beginning of the second half of the last century. The trend towards lightweight structures, a ceaseless ambition of the aforementioned industries, has also had an increasing impact on viscoelastic damping treatments themselves which can be locally applied to ensure a remarkable damping capacity without increasing the added mass unnecessarily.

(Nokes et al. 1968) pioneered the study of partially covered structures with viscoelastic material disclosing the possible uselessness of covering a whole beam for maximum damping. In addition, a great deal of research has already been done mostly concerning with the appropriate modeling of structures integrating viscoelastic materials.

2. Materials and Methods

The use of viscoelastic damping patches is a typical example of an inhomogeneous multilayered structure which needs suitable mechanical models along with efficient numerical methods to perform optimisation studies promptly. Studies involving equivalent single layer are ready to efficiently perform a broad range of studies due to the low computational complexity but fail to capture the mechanical phenomena from layer to layer correctly. On the other hand, layerwise models are capable of dealing with the intrinsic laminar structure of multilayered systems by properly capturing the mechanical phenomena of each layer. However, these models bring some difficulties regarding computational efficiency once the degrees of freedom increase with the number of layers. The present work deals with a deformation theory developed by (Loredo et al. 2013) involving a hybrid approach to model multilayered structures which combines the advantages of both equivalent single layer and layerwise models by appropriately capturing the individual contribution of each layer requiring only the generalized displacements of a simple equivalent single layer theory.

3. Discussion

Some preliminary results are presented in order to set the appropriate targets and helpful design guidelines for vibration control using viscoelastic damping patches. A cantilever beam with the geometric and mechanical properties listed in Table 1 is considered. Variables h_d and h_c represent the thickness of damping and constraining layers, respectively. The mechanical properties of the viscoelastic layer are those presented in (Castel et al. 2012).

Table 1. Geometric and mechanical properties of the cantilever beam.

ℓ	b	h	h_d	h_c	E	w	q
1 m	20 mm	5 mm	1.2 mm	0.5 mm	65 GPa	0.3	2700 Kg.m^{-3}

The effect of a viscoelastic damping patch position and covered length is illustrated in Figure 1. Three different cases were considered, a viscoelastic patch located at the tip, a patch located at the center and the last one located at the clamping region. The patch performance is evaluated considering a specific modal loss factor taking the full coverage case as reference.

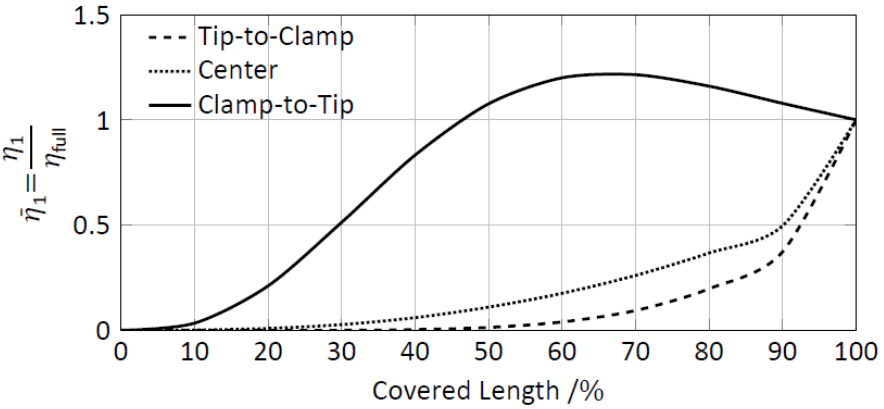

Figure 1: Modal loss factors for different positions and covered lengths

The first modal loss factor of a cantilever beam with a viscoelastic damping patch located at the clamping region is fairly higher even considering a relatively small covered length. Besides, a maximum damping capacity is achieved with partial coverage.

4. Conclusions

Viscoelastic damping patches could provide higher damping capacity with less material when compared to fully covered treatments. This phenomenon could be possible if the viscoelastic material is subject to higher deformation patterns which proved to be quite sensitive to the patch positioning and covered area.

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A Review of Milling of The Gamma Titanium Aluminides

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Abstract
The present trend towards lightweight structures has had a significant impact on the field of vibration control, especially because structures with improved specific stiffness are prone to higher vibration amplitudes. Viscoelastic materials have already proved their efficiency on vibration suppression due to their damping capacity. However, an enhanced distribution of such materials could lead to improved vibration performances. Based on appropriate mechanical models along with efficient numerical methods the primary goal is to address issues on the proper use of partial treatments as a passive technique for vibration control.

Keywords. Vibration, damping, viscoelastic.

A low-cost system for the biomechanical analysis of tennis players

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Abstract
This paper presents a low-cost system for the biomechanical analysis of tennis players. This platform consists of three main components: a biomechanical model of the upper limb for tennis players, specifically of the shoulder, elbow and wrist joints, developed in OpenSim; an Arduino platform, which performs the collection of data associated with the movement executed by the tennis players, through a set of sensors placed on the frame of the tennis racket and elastic bands placed on the elbow and wrist joints, to perform the direct measure of the movement angles; and finally, a graphical user interface developed in LabVIEW platform to visualize the biomechanical parameters under analysis.

Keywords. Biomechanics, sport, tennis, modeling, visualization, data acquisition and synchronization, instrumentation and control.

1. Introduction

In the last years, several researcher groups have developed and implemented methodologies and systems for biomechanical analysis of athletes in sports activities with the aim of improving their athletic performance, as well as reducing the risk of injuries. Particularly focus has been given to the analysis of racket vibrations and shock transmission to the wrist, elbow and shoulder during the movements performed by tennis and badminton players (Rogowski 2015). The present work describes a low-cost system for the biomechanical analysis of tennis players.

2. Materials and Methods

The developed system includes three main components: 1) a biomechanical model of the upper limb for tennis players, specifically of the shoulder, elbow and wrist joints, developed in OpenSim; 2) an Arduino platform, that performs the collection of data associated with the movements executed by the tennis player, through a set of sensors placed on the frame of the tennis racket, in order to obtain the linear an angular accelerations of the racket, a force sensor to obtain the tightening force exerted by the hand to grip the racket, and elastic bands placed on the elbow and wrist joints, in order to directly measure the movement angles, two electromyography sensors (EMG) used to assess the electrical activity of the Biceps and Triceps muscles; and finally, 3) a graphical user interface developed in LabVIEW in order to visualize the biomechanical parameters under analysis. The data acquisition is obtained in real time and the signals are synchronized by a real-time clock (RTC) (Gomes 2015). The developed biomechanical model of the upper limb consists of 32 bones, 30 junctions and 38 muscles, which are involved in the movements under analysis. The tennis racket is considered as being an additional body segment, with the adequate inertial and elastic characteristics (Gomes 2015, 2015a). The interface of the developed system consists of various menus organized by tabs, which allow the easy visualization of the biomechanical parameters under analysis. Figure 1 shows the low-cost system developed for the biomechanical analysis of tennis players. In this figure, one can see also a detail of the monitoring window concerning the wrist movements: radial/ulnar deviation and flexion/extension (Gomes 2015b).

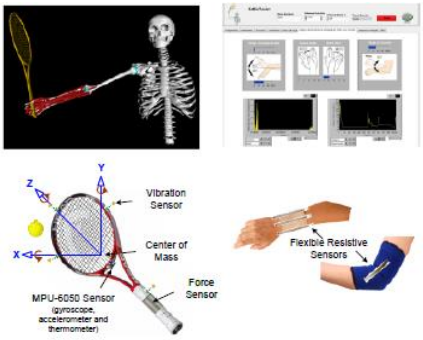

Figure 1: Components of the low-cost system developed for the biomechanical analysis of tennis players.

Figure 2 shows an example of the active force values obtained regarding the muscles of the wrist joint during a tennis serve.

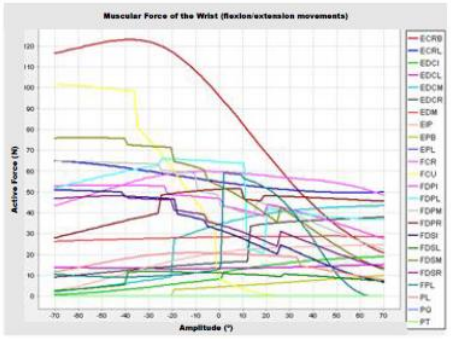

Figure 2: Active muscular force of the wrist movements during the execution of a tennis serve.

3. Conclusions

Viscoelastic damping patches could provide higher damping capacity with less material when compared to fully covered treatments. This phenomenon could be possible if the viscoelastic material is subject to higher deformation patterns which proved to be quite sensitive to the patch positioning and covered area.

Acknowledgments

Authors gratefully 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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Experimental Study on Machinability of Gypsum Plaster with Potential Application in Hybrid Manufacturing

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Abstract
The gypsum plaster moulds have been extensively used in ceramic industry, slip casting process, as well as in metal casting process. This kind of industries, with the innovation or customization, need to produce reduced series or even single parts, which leads to the large production of moulds. The recent advances in extrusion base additive manufacturing (AM), in large size applications, allows a new application for gypsum plaster in production of large size moulds, not only in these industries, but also as a low cost substitute of other materials, such polyurethane and epoxy resins (Caetano et al. 2017) . However, AM presents some disadvantages concerning the surface quality of the parts produced. In this case, a hybrid-manufacturing concept, that combines additive manufacturing and subtractive manufacturing for finishing operations, in the same machine, is an interesting process to produced gypsum parts. An innovation application on the extrusion base of gypsum plaster has been explored and opens another unexplored field related to the machining of this material. The focus of this work is the CNC milling study of plaster, in order to stablish the influence of cutting speed, feed rate, depth of cut and humidity of gypsum blocks on cutting forces and the most important, surface integrity, namely surface roughness, and sharp edges. The results of the experimental work allow the establishment of fundamental cutting parameters that will be used in the machining of patterns or moulds obtained by additive manufacturing.

Keywords. Gypsum Plaster, Hybrid Manufacturing Process, Machining.

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Identification of the work hardening parameters using the bulge test with elliptical and circular dies

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Abstract
The accurate modelling of the plastic behaviour of metal sheets is an important aspect to be considered in the numerical simulation of metal sheet forming processes. In this way, an inverse identification strategy is proposed to identify the work hardening parameters, making use of the hydraulic bulge test with circular and elliptical dies. The strategy identification representing a clear improvement compared to the membrane theory.

Keywords. Parameters Identification, Work Hardening, Inverse Analysis, Elliptical Dies.

1. Introduction

Sheet metal forming processes are among the most common and important sheet metal working operations because of their high manufacture rate and low costs for high volume productions. The evolution of the computer technology and the development of more accurate and robust algorithms had led to the application of finite element methods in the industrial processes development and optimization. Nevertheless, the numerical results depend of the mechanical characterization of the material.

The hydraulic bulge test has become increasingly common to examine the plastic behaviour of metal sheets, due to the possibility of determining the stress-strain curves under a biaxial strain path and up to levels of deformation significantly higher than those achieved in uniaxial tensile tests. In this way, the bulge test allows a better description of the plastic behaviour of the metal sheet during the forming processes. Circular and elliptical dies have been used for the identification of the materials parameters. In particular, the circular die has been used to estimate the parameters of the isotropic hardening law (Reis 2015), while the elliptical die has been used for identifying parameters of the yield surface (Chamekh 2006). The evaluation of the biaxial stress vs. strain curves is commonly performed using the membrane theory, which requires the experimental measurements of the strains at the pole, the radius of curvature and the hydraulic pressure. Although the recent standardization (ISO 16808 2014), Reis (2015) showed that for anisotropic materials, the membrane theory presents significant errors due to the equibiaxial stress state assumed in the standard. To overcome the limitation of the membrane theory, an alternative strategy is now proposed to determine the work hardening parameters of the Voce law:

$$Y = Y_0 + (Y_{Sat} - Y_0)(1 - e^{-C_Y \bar{\varepsilon}}) \quad (1)$$

where Y is the equivalent stress, $\bar{\varepsilon}$ is the equivalent plastic strain, Y_0, Y_{Sat} and C_Y are the work hardening parameters of the material.

2. Parameters Identification

The proposed strategy follows an inverse analysis methodology making use of numerical and experimental results of pressure vs. pole height curves of bulge tests with circular and elliptical dies. The proposed strategy and the membrane theory are used to identify the parameters of a fictitious

material, highly anisotropic, for which the pressure vs. pole height results were numerically generated. The parameters of this material and those obtain by the membrane theory and the proposed strategy are given in table 1. Figure 1(a) allows comparing the identified and the experimental parameters, in terms of the equivalent stress vs. strain curves. The relative errors between the identified and the experimental curves are also represented, see Figure 1(b). The proposed strategy allows the accurate identification of the work hardening with an average relative error of 1.56%. In contrast, the membrane theory supplied a poor identification with an average relative error of 10.6%.

Table 1. Comparison between the parameters of the experimental material with those obtained with themembrane theory and the proposed strategy.

Parameters	Experimental Material	Membrane Theory	Proposed Stratagy
Y_0 [MPa]	431.43	388.512	429.816
Y_{Sat} [MPa]	1522.79	1442.588	1583.668
C_Y	5.82	5.009	5.039
r_0	0.50	-	-
r_{45}	2.24	-	-
r_{90}	4.02	-	-

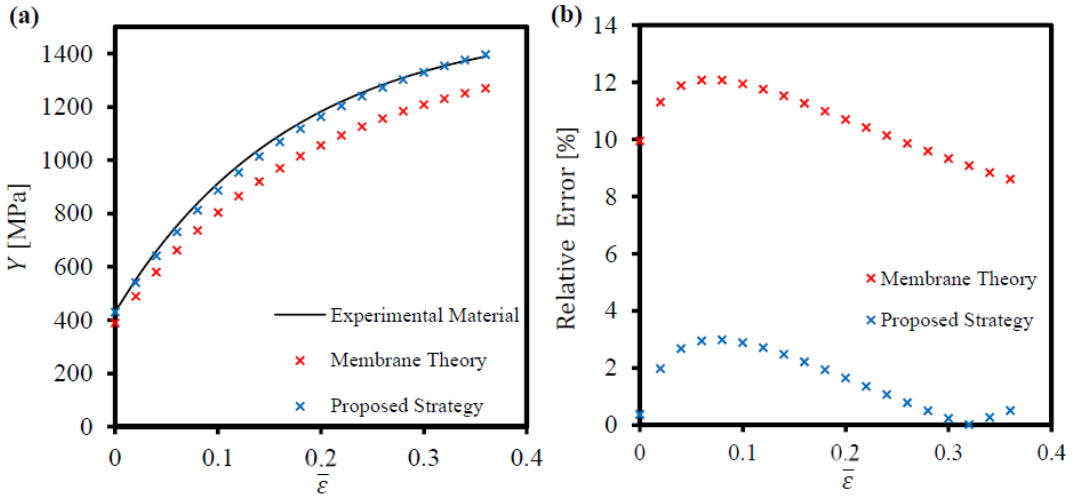

Figure 1: (a) - Experimental and identified equivalent stress vs. equivalent strain curves. (b) - Relative error between the experimental and the identified equivalent stress vs. equivalent strain curves.

3. Conclusions

In summary, the proposed strategy show to be an accurate alternative to determine the work hardening parameters of anisotropic materials. In these cases, the proposed strategy represents a clear improvement compared to the membrane theory.

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Damage models in metal forming

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Abstract
The aim of this work is to compare the main damage model approaches of the last decades, such as Gurson's (and GTN) model and Lemaitre's model. Several topics are analysed for models comparison: voids and microcracks, the softening effect, stress triaxiality, Lode angle and J3 influence. During large plastic deformation, voids and microcracks cause a reduction of the Young modulus and induce a softening effect, which is strongly related to the stress triaxiality level.
The phenomenological models of ductile damage currently available in the literature can be grouped in two main families: uncoupled and coupled models. The uncoupled models define a fracture locus without any effect in the plasticity description of the material. This means that a failure surface is constructed and it works as a damage (limit) indicator. Gurson's and Lemaitre's model are examples of these uncoupled models. While Gurson's and GTN models predict the ductile fracture based on microcracks and voids growth, Lemaitre presented a model for damage caused by plastic flow micromechanically.
The models of Wierzbicky, Xue and Lou are examples of uncoupled ductile damage models. The coupled models have been extensively applied on industrial applications because it is simple not only to characterize the material but to implement numerically as well. Wierzbicky have introduced the strong dependence of the stress triaxiality and Lode angle. He has suggested different uncoupled damage models, according to different fracture locus and experimental analysis, including a new modified Mohr-Coulomb fracture criterion. Khan & Liu (2012) suggested a new magnitude of stress vector (MSV) fracture criterion and realized that a ductile fracture criterion should represent the influences of elastic and plastic work.
Other authors have proposed different uncoupled approaches. Xue (2007) was the first one to invoke that ductile fracture is J3 dependent. He defined a fracture envelope in the space of the principal stresses. Recently, Lou et al. (2014) proposed a model fracture behavior of sheet metals regarding nucleation, growth and shear coalescence of voids during plastic deformation. This model is stress triaxiality and Lode angle dependent.

Keywords. Damage, Triaxiality, Lode angle, Gurson's model, Lemaitre's model.

Poster Session

Low cost 3D printing applied to Design for Assembly: building snap fits

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Abstract
The Design for Assembly (DFA) is an important analysis tool for measuring quality in product development. Among the main guidelines suggested by these methodologies are the use of snap fit systems. Such systems are largely used in industries as the automotive due to the reduction of time and costs it allows. Because of the process simplification it causes, the use of snap fits is quickly replacing conventional components for joints like screws. Snap fits are usually built in polymeric material by the injection molding process. Nevertheless, due to its complexes geometries the mold used for snap fits can be significantly complicated and expensive. Therefore, Additive Manufacturing (AM) emerges as a relevant technique to build these structures. Technical literature includes studies that have applied AM to prototype or test the feasibility of the use of snap-fits built by Selective Laser Sintering, PolyJet and Stereolithography. However, all these processes have high value associated to them. Based on this scenario we are developing a PhD research to suggest a design of fitting systems methodology for low cost extrusion based on 3D printing. A series of small experiments is being carried out: analysis of the gaps designed for male and female elements of snap fit connections; dimensional analysis; material selection and characterization; and manual measurement of the insertion force. The initial goal of the research is to collect data that allow specialist studies with highly advanced analysis techniques and comparisons between printed parts and injected ones. Preliminary findings indicate the need of further development of investigations about dimensional tolerances and the influence of friction and material rigidity on the assembly efficiency.

Keywords. Design for Assembly, snap fits, Additive Manufacturing, low cost 3D printing.

Computational model for W-W-W connections at ambient and high temperatures

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Abstract
The aim of this work is to present an approach for wood-wood-wood (W-W-W) connections design in double shear at ambient and high temperatures, using dowelled connectors. For each situation, all calculations will be performed to determine the cross-section and the number of fasteners. A procedure will be presented to calculate the load carrying capacity per shear plane and per steel fastener, using a glued laminated in birch W-W-W timber GL28h.
The designed connection will be considered unprotected at ambient temperature, and protected for high temperatures. In this study, it is important to determine the type of insulation material and the correct dimension for guarantee a fire time resistance.
All developed study will contribute to the knowledge in these connections, where the wood material represents a complex behaviour in fire situations and the combination with steel fasteners intensify the heat conduction inside the material. All proposed methodologies could be used to study W-W-W connections with or without insulation material to assess and contribute for a safe design.

Keywords. W-W-W connections, dowels, insulation, thermal analysis, mechanical analysis.

1. Introduction

The use of wood, as a structural material, continues to grow far beyond traditional application. Therefore, connections, indeed, are often considered as the critical point of timber structures because their resistance and durability mainly depend on the connections joining design of the different structural elements. Also they find themselves subject to localized stresses and strains, and may expose the overall stability of the structure. For imposed thermal loads, it remains important to improve the knowledge of the connection behaviour under fire conditions.

2. Methodology

In order to guarantee an intact design for W-W-W connections, the calculation obtained following the rules presented in Eurocode 5 are compared with the results of a numerical model based on finite element method.

The materials properties at both situations will be presented, according the standards, and considering the orthotropic wood.

3. Discussion

The model represents three wooden plates connected to each other by steel bolts, submitted to axial loading and high temperatures, developed into a computational model for independently thermal

and mechanical analysis, using a finite element program.

A 3D W-W-W connection was developed according the calculations for un imposed axial load and the shear effect into the fasteners, figure 1.

All materials are considered as non-linear with an elastic-plastic behaviour, as a multilinear material. For the structural analysis the material strength and elastic properties (isotropic for steel and orthotropic for timber) are the major determining factors to obtain desired results of the structural capacity, damage and failure. Due the geometric symmetry and loading conditions, only one quarter of the model was analysed. In this assembly many contacts occur between surfaces such as, the dowels hole, wood-wood plates and wood dowels interactions.

The objective is to determine the maximum capacity of the connection, until end of the running structural problem. The ultimate capacity of the connection leads to a failure mode, as the start splitting or maximum stresses reached in the glulam W-W-W in the direction parallel to wood grain. For ambient temperature, calculations for the ultimate limit state permits to determine the cross-section and the number of dowels for the W-W-W connection in study, according the design equation:

$$\sigma_{t,0,d} = \frac{F_d}{A_s} \leq f_{t,0,d} = \frac{k_{mod} \times f_{t,0,k}}{\gamma_M} \quad (1)$$

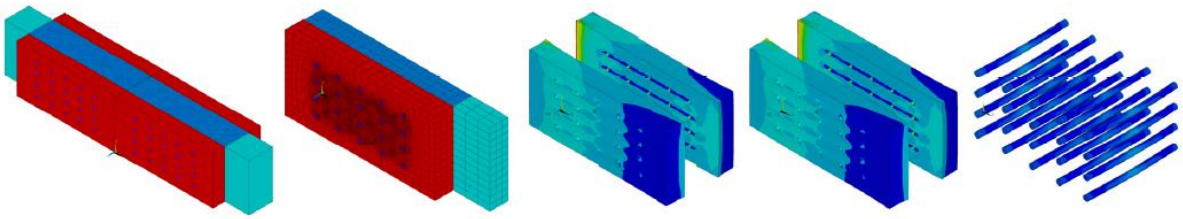

Figure 1: W-W-W connection and equivalent stresses at ambient temperature.

For high temperature calculations, the 2D half-model is introduced for different sides (front, top and horizontal cross-section) exposed to fire conditions. A transient and thermal analysis was conducted to determine the char layer thickness and compared with the proposed from the Eurocode 5, as represented in figure 2. For a required fire resistance period, the following expression is used to determine the char layer needed to guarantee the fire resistance:

$$\alpha_{f_i} = \beta_n \cdot k_{flux} \cdot \left(t_{req} - t_{d,f_i}\right) \quad (2)$$

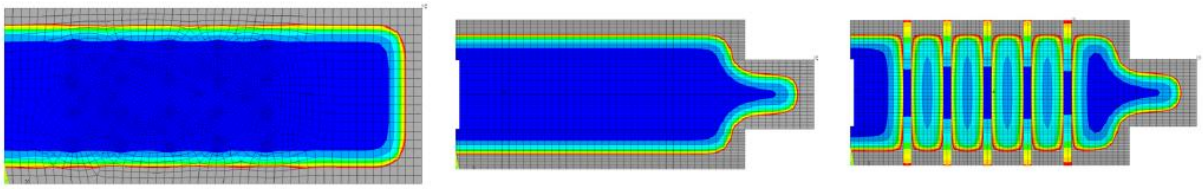

Figure 2: Char layer for different sides (front, top and horizontal cross-section), fire exposure until 30 min.

4. Conclusions

For both situations, W-W-W connections are designed using Eurocode 5 formulations and the results are discussed and compared with numerical experiments.

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Numerical model to evaluate the protected and unprotected wooden slabs under fire

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Abstract
The main objective of this work is to present a numerical methodology, based on the finite element program, to predict the thermal assessment in wooden cellular slabs under fire. The designed wood models represent different building applications in construction engineering, as walls, ceilings and floors. The proposed models represent protected and unprotected wooden slabs to determine the fire resistance, and increase the use prevention of these materials.

Keywords. Fire behaviour, charring rate, temperature, wood.

1. Introduction

Wood has been broadly used as construction material due to their availability in nature, variety, lightness, having good physical characteristics, as chemical and mechanical properties. This material is used in many different civil construction applications, namely in floors, ceilings and walls. Furthermore, the mentioned advantages, wood has excellent architectural, thermal and acoustics characteristics, allowing easy assembly of sets (Pinto, et al., 2004).

Under adverse work conditions, the material properties might degrade, compromising its performance and safety. Over the last few years new numeric and experimental studies have been performed, which objective was to predict the material behaviour, under influence of external factors, as fire situations (Janssens, 2004), (Gay et al., 2011), (White et al., 1999), (David et al., 2016), (Fonseca et al., 2012). Wood is considered a combustible material, when it burns, flames are released. However, wood on fire, it presents a peculiar behaviour, since its core may remain unchanged. When being consumed by flames, a char layer formed will condition the heat inside wood, therefore protecting its core. The wood charring rate is one of the major parameters used to describe wood behaviour towards fire, as it allows determine the time fire resistance that the structures will performed in site and its structural safety (Frangi, A. 2009).

To improve wood fire resistance, some insulating materials are used in wood structures. In general, these materials have low thermal conductivity, therefore a reduced heat transfer rate is transferred through the wood member.

2. Work discussion

The main goal of this study is to evaluate the thermal behaviour of wooden cellular slabs exposed to fire conditions, according the standard ISO 843 curve. Different numerical simulations for nonlinear thermal and transient analysis will be obtained, using the finite element method. The wood thermal material properties are temperature dependent and vary according to the Eurocode 5. The wood specie considered in the present study is Douglas-Fir tree, with a density equal 341[kg/m³] and moisture of 11% (Frangi, et al., 2008).

To validate the proposed thermal numerical model, the wood charring rate was determined in different time instants. The mean value was determined to guarantee the results precision. A comparison between the obtained numerical value and the value prescribed by the Eurocode 5 were verified with a good agreement.

The importance of this study relies on its contribution to an alternative numerical methodology, which allows to determine the safety and fire resistance levels in wooden cellular slabs, with or without insulation materials.

3. Conclusions

Results identified in all models permit to determine the temperature evolution and the residual cross-section through the slab element at different time instants for fire situations. Different wooden cellular slabs configurations were developed to identify the best and worst design model. Discussion of the numerical results and the comparison between protected and unprotected slabs will be obtained.

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Drilling of bone: numerical and experimental investigations

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Abstract
Implant failures and post-operative problems may occur after implant placement as a result of the inappropriate conditions during drilling. The analysis of different materials and drilling parameters is crucial to reduce the bone damage and contribute to the success of this medical interventions. In this research, the effect of drilling parameters on the generated stresses and temperatures in the bone during the process was investigated. Experimental methods were performed using synthetic and biological materials. Also, a numerical model was developed and calibrated using a three-dimensional elasto-plastic dynamic finite element method. The examined variables were the drill speed, the feed-rate and the drill bit diameter. Results indicated that the temperature and stresses increased with increase in the drill speed and drill diameter and decreased with increase in the feed-rate. The experimental results permit to calibrate the numerical model, which could be used for any dynamic analysis according this procedure.

Keywords. Bone drilling, temperature, stress, drilling parameters.

1. Introduction

Bone fracture or tooth replacements are a common public health problem due mainly to age factors and accidents. The fracture repairing or dental implant placement require the use of drilling procedures in the bone, as a preparation for mounting screws, prosthesis attaching and bone fractures fixation. During drilling, mechanical work resulting from the friction between the drill bit and the bone tissue is transformed into thermal energy which leads to increase of bone temperature as well as cutting tool (Gupta and Pandey 2016). Besides the negative thermal impact, high drill speed with higher cutting forces and tool vibrations can also cause mechanical damages on the bone microstructure, resulting in microcracks formation and bone fracture. It has been proven that drilling parameters such as drill bit geometry, drill speed and feed-rate have direct relationship with the quality of bone during the drilling procedure (Fernandes et al. 2015; Fernandes et al. 2016; Fernandes et al. 2017; Fernandes, Fonseca, Natal et al. 2017).

In the present study, experimental and numerical investigation are developed in order to find more details about the effects of drill speed, feed-rate and drill bit diameter on temperature, strains and stresses evolution during drilling. Different experimental tests were performed using three test material: synthetic bone (solid rigid polyurethane foams from Sawbones Pacific Research Laboratories, Inc., Vashon. WA, USA), animal bone (bovine femurs) and human bone (human cadaveric tibiae). The materials were instrumented with multiple thermocouples and strain gauges to measure the temperature distribution and the level of strains, respectively (Figure 1). Temperature control in the cutting tools were carried out using a thermal camera (ThermaCAM 365, FLIR Systems) at distance of 1.5 m from the drilling area.

Subsequently, a numerical study was conducted using a nonlinear transient dynamic finite element code. The numerical models aim to simulate the drilling process and to predict the bone damage, while taking into account of the drilling parameters (f = feed-rate and ω = drill speed), as show in Figure 1(d). The performed numerical analyses were correlated with experimental results in order to validate the results and gain new knowledge. The drilling tests were conducted for drill speeds rates of 520, 600, 800, 900, 1200 and 1370 rpm; feedrates of 0.42, 0.83 and 1.25 mm/s; and drill bit diameters of 4, 5 and 6 mm (all of them were twist drill bits with a point angle of 118º and helix angle of 30º). All experiments started from room temperature (approximately 20 ºC) without applying cooling at the drilling zone. The holes were performed in a computer numerically controlled (CNC) system and a vertical drilling machine.

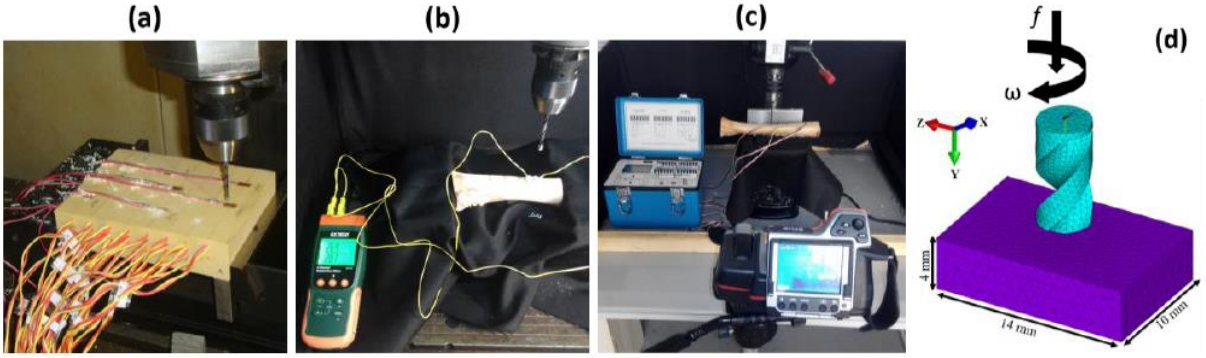

Figure 1: Experimental and numerical procedures: (a) polyurethane foam, (b) bovine femur, (c) human cadaveric tibiae and (d) numerical model for drilling.

2. Results and Conclusions

Results identified the drill bit diameter as the most critical parameter for inducing higher temperatures and stresses in bone drilling. The increase in drill speed caused increase in bone temperature and stresses during drilling. With the increase in feed-rate, increase in bone temperature and stresses are lower. Validation of the numerical models was carried out comparing numerical results and experimental results with good accuracy

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Optimization of Post-Processing of Infiltration in Pieces Obtained by 3D Printing with Plaster Powder Material

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Abstract
Parts printed by Binder Jetting (BJ) additive manufacturing technology present high brittleness due the ceramic characteristics of the plaster powder material. Therefore, post-processing is an essential requirement for improving the mechanical strength. One of the most widely used post-processes, due to its simplicity, is the infiltration of the printed part. This impregnation, in accordance with the equipment suppliers, is conducted with materials such as wax, cyanoacrylates, epoxy resins and saline solutions. The large gap between the initial fragility of the three dimensional parts (3DP) (just manipulated), and the final mechanical strength, is due essentially to the type of material to be infiltrated and the process itself, which involves many parameters to be analyzed. The proposed research, suggests optimization of both material and infiltration processes. As for the material of infiltration, it can take advantage of the recent development of new materials for the most diverse applications. These should become impregnated with an appropriate methodology of infiltration to get 3DP elements that go beyond conceptual models, with potential applications where, their mechanical resistance is an indispensable requirement. This transition will show the interaction between the final technological properties (i.e., mechanical strength) with the properties of both, printing and infiltration materials in addition to their methods of application.
In this context, the following studies were initially carried out: characterization of printing material (powder) — chemical composition, particle size and size distribution —, and measurement of the flexural mechanical strength of printed and infiltrated specimens with parameters and infiltrating materials suggested by the supplier of the technology (3D Systems). Studies are currently being carried out with new materials proposed. The following analyses were performed for the new conditions: molecular composition, viscosity and mechanical strength. Preliminary results with 3DP samples and infiltrated with the proposed materials, show a significant improvement on flexural strength, however, it is still necessary to optimize the process, so that future work will focus on this second objective.

Keywords. Post-processing, 3D printing, Binder jetting, Infiltration, Mechanical strength.

Awards

Best oral communication award for the Symposium on Mechanical Engineering

- João Pereira Amorim. Passive Vibration Control Using Viscoelastic Damping Patches

Best poster communication award for the Symposium on Mechanical Engineering

- Leonardo Santana. Low cost 3D printing applied to Design for Assembly: building snap fits

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ISBN: 978-972-752-224-8

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