RESEARCH PROJECTS

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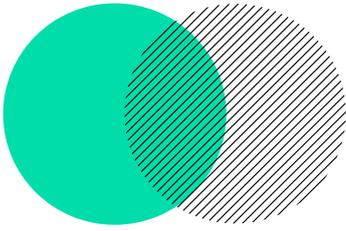
A STUDY OF THE BENDING-GRADIENT THEORY APPLIED TO CROSS LAMINATED TIMBER PANELS

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A study of the Bending-Gradient theory applied to Cross Laminated Timber panels

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KEYWORDS: Bending-Gradient theory; Cross Laminated Timber; shear stress.

ABSTRACT

Cross Laminated Timber panels (CLT), are a wooden structural product which consist in several lumber layers stacked crosswise and glued on their faces. The modelling of a CLT plate asks to consider a non-homogenous, anisotropic material. Buckling stress is currently considered as critical in the sizing process of CLT structures. Because classical theory to estimate the buckling load does not consider the shear stress, and because buckling of CLT panels conducts to the destruction of the panel, high security coefficients are arbitrarily implemented.

Using the mixed variational principle of Hellinger-Reissner, Reissner was the first to derive a modified plate theory including shear effects by taking into account the shear stress distribution according to the equilibrium equation. This lead to the well known 5/6 shear correction factor. The extension of this approach to the case of laminated plate requires that the Hooke tensor in plane stress of each laminae to be proportional.This very strong assumption is rarely valid and certainly not for CLT. In order to try to overcome this issue a new theory, still in its premises was proposed in [2]. Called the Bending-Gradient Theory or the Generalized Reissner plate theory, its principle is to introduce the gradient of the moment as an independent unknown leading to a higher order theory. The gradient of the moment introduces 6 unknowns, while the classical shear force introduces only two. This gives more flexibility to adapt the theory to composite plates , under mild hypotheses, enforcing local equilibrium of the transverse shear stresses [3]. Apart form the equilibrium equation, the complexity of the theory is associated to the corresponding kinematic quantities and associated constitutive relation. Moreover the correct boundary condition in the general case is still an issue.
In the first part of this project we have studied this theory whose understanding and mathematical developments are far to be simple. Thanks to different interviews with professors Lebée and Sab we discover that the numerical treatment of the theory in its general format was still the object of complex developments even for simple geometries. Therefore we have recently focus on its use in order to determine correction shear stress coefficients in simple cases. Our work has consisted in developing reasonable hypothesis that would make this theory easier to implement with an engineer perspective. We focus our work aiming to see if it would be possible to better calculate the shear operator of the Reissner-Mindlin theory and recovering the results obtained from the Bending-Gradient theory. We will remain in the frame of an mathematically one dimension field, extended

$$\begin{cases} U_3 \otimes \underline{\nabla} \otimes \underline{\nabla} + \underset{\sim}{\chi}^P + (\underline{\underline{V}}^{0P} \cdot \underline{\nabla}) \cdot \underline{\nabla} \\ \quad = -\underset{\sim}{\underline{d}} : \underset{\sim}{M} + ({}^T\underset{\sim}{\underline{q}} + \underset{\sim}{q} \vdots \underset{\approx}{P}^S - \underset{\sim}{\underline{h}}) \vdots (\underset{\sim}{M} \otimes \underline{\nabla} \otimes \underline{\nabla}) - \underset{\sim}{\underline{l}} \vdots \underset{\approx}{P}^S \vdots\vdots (\underset{\sim}{M} \otimes \underline{\nabla} \otimes \underline{\nabla} \otimes \underline{\nabla} \otimes \underline{\nabla}), \\ (\underset{\sim}{M} \cdot \underline{\nabla}) \cdot \underline{\nabla} + p_3 = 0, \end{cases}$$

Figure 1: Field equations for the cylindrical bending of mirror symmetric laminates

to a physically 2D field with no variation on this second dimension. We simplified the Generalized-Reissner theory for the cylindrical bending of mirror symmetric laminates, using the field equations which intervene in the figure 1, and we applied this theory to one-dimensional girder. Whereas Reissner derived a strictly 3D statically compatible field and applied the principle of minimum of complementary energy, the stress distribution satisfied the equilibrium equations at a higher order. The bending-gradient theory is still exactly statically compatible with the stress field derived following Reissner procedure. In order to respect these advances equilibrium equations first and second gradient of the bending moment have been introduced. This process had lead to a higher order plate theory with at most 15 kinematic degrees of freedom.

Finally, we plotted the Generalized displacement field with the Timoshenko displacement fields with shear correction coefficient, Timoshenko without shear correction coefficient, and Euler-Bernoulli displacement fields. As expected the Generalized Reissner displacement field is more important than Timoshenko with correction. Yet the difference is maybe too important, this might be the consecutive to an improper integration or an unfaithful understanding of material behavior by the constitutive equations.
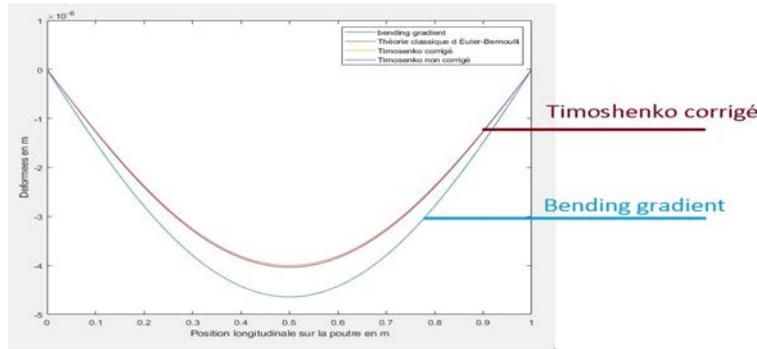

Figure 2: Vertical displacement of a girder over a linear load considering Euler-Bernouilli, Timoshenko with and without shear correction and the bending-gradient theory

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[2] A. Lebée, K. Sab. On the Generalization of Reissner Plate Theory to Laminated Plates, Part I: Theory. *J. Elast* , 2016.

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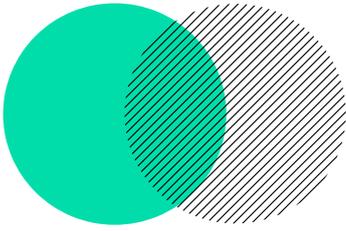
DESIGN OF A LIQUID MECHANISM FOR BIAXIAL COMPRESSION TESTS ON HOPKINSON BARS

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Design of a liquid mechanism for Biaxial Compression Tests on Hopkinson Bars

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KEYWORDS : Hopkinson bars ; biaxial test ; liquid finite element modelling.

ABSTRACT

Materials have not always the same properties when they face a static or a dynamic loading. So there is a need of experimental tools to characterise materials as dynamic loads occurs in many cases [1]. An usual experiment is the Hopkinson bar test which consists of a projectile thrown on a system composed of an input bar, a sample and an output bar which will enable force and velocity measurements. A biaxial Hopkinson test using a mechanism has been created [2] and shows limitations due to friction. The purpose of this study is to design a new biaxial system with a liquid mechanism which will apply a perfect symmetric biaxial compression on the sample.

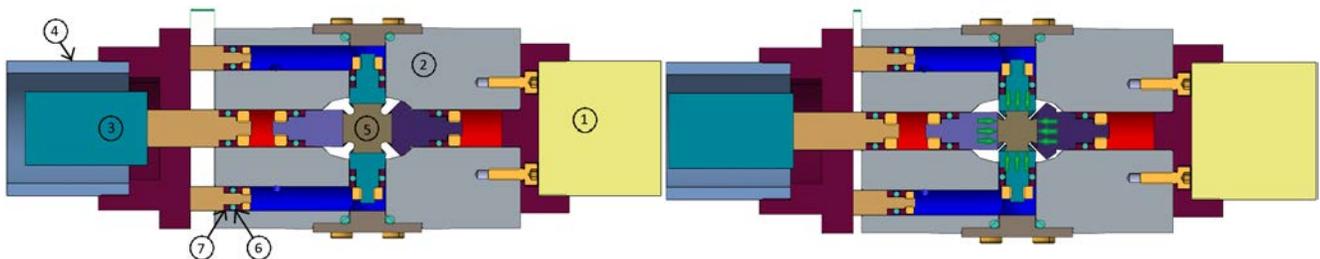## 1 Mechanism working and its design

FIGURE 1: Longitudinal cut of the mechanism before the impact

FIGURE 2: Longitudinal cut of the mechanism after the impact

The projectile impacts the input bar ① which moves the body of the mechanism ②. The inertia of the internal output bar ③ (resp. external output bar ④) leads to the compression of the liquid (which is represented with green arrows) in the axial cavities ■ (resp. the lateral cavities ■) thus the sample ⑤ is compressed bi-axially.
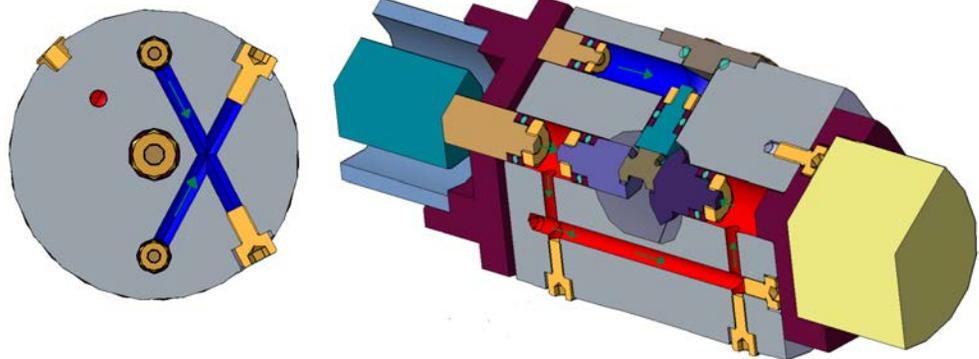

FIGURE 3: Transversal and longitudinal/45° cut of the mechanism after the impact

As the two axial cavities and the two transverse ones communicate, the axial loads applied on the sample boundaries are the same, as for the transverse ones. Thanks to this mechanism no friction will occur on the boundaries of the sample. The whole mechanism is made of high strength steel, moreover the body has to be as small as possible so that the stiffness of the mechanism and its inertia do not interfere with the measurements. The system static parts are entirely sealed with liquid joints and the dynamic ones with O-rings ⑥ and anti-extrusion rings ⑦.
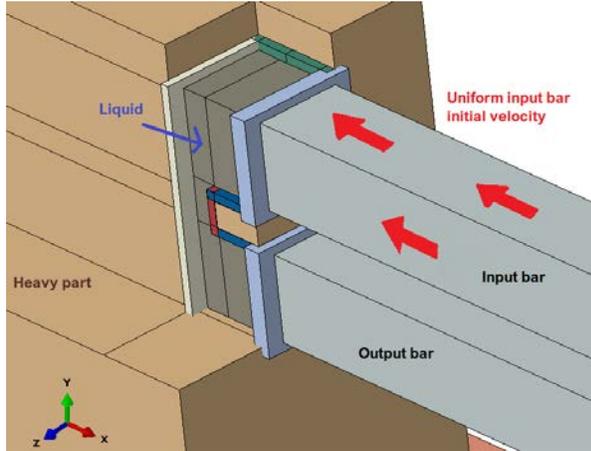
2 Simulation of fluid behaviour

FIGURE 4: Mechanism cut view

A possible limitation of the mechanism is the dynamic liquid cavity behaviour. In order to qualify its effect on the experiment, we developed an Abaqus 3D explicit simulation. The real system geometry is complex and can be simplified as shown on the figure $\boxed{4}$. All solid parts have steel properties. Moreover, the liquid is represented by an equivalent elastic-plastic material whose properties fit the water one : a 7000 MPa Young Modulus, a 0 Poisson ratio, a 1000 kg/m^3 and a Von-Mises behaviour with a very low yield stress. One can prove that the material celerities that will result of these proprieties is 1500 m/s. Heavy steel part inertia blocks the displacement. Results show input/output pressure equilibrium and velocity non stationnarity due to high compressibility of water.
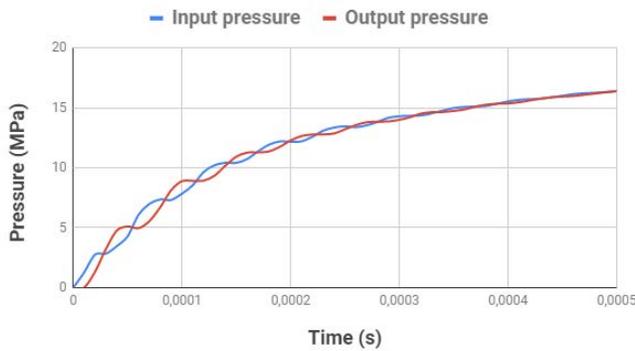

FIGURE 5: Pressure equilibrium through time
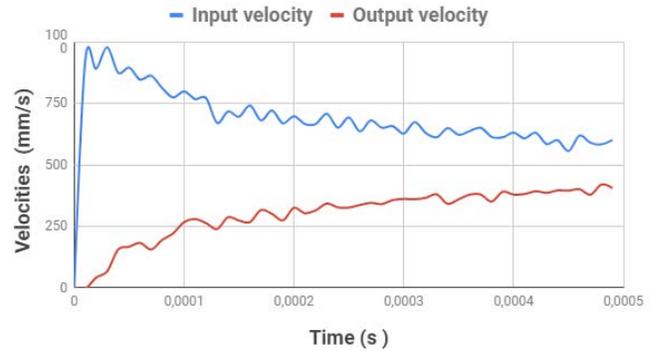
FIGURE 6: Liquid velocities through time

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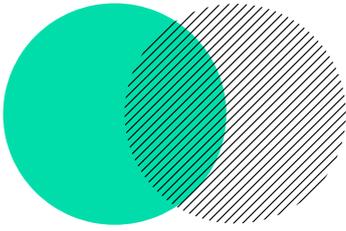
TOPOLOGY OPTIMIZATION FOR MECHANICAL DESIGN : CONTRIBUTION OF NEW COMPUTATIONAL STRATEGIES

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Topology optimization for mechanical design : contribution of new computational strategies

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KEYWORDS: Topology optimization, Model Order Reduction, Proper Generalized Decomposition, Parameter-Multiscale PGD.

ABSTRACT

General Information

In the context of mechanical design, topology optimization consists in finding the optimal material layout in a specified design space, in regards of a cost function such as a structure stiffness and for a given set of loads and boundary conditions. The Solid Isotropic Material with Penalization (SIMP) methods allows the discretization of the design space into n_{el} elements of densities x_e. The local Young modulus is then expressed as a function of element density, and the optimization problem is to find the optimal set of x_e so that the cost function is minimal. The topology optimization Matlab code [1] which was chosen as a basis in this research uses this method to maximize the stiffness of a structure by minimising its elastic energy.

The quality of the optimized structure is highly dependent on the design space refinement [2], as shown in Figure 1, but the computational time of the optimization program can increase drastically as the discretization is refined, due to the high number of degrees of freedom to find with a finite element resolution.

The Proper Generalized Decomposition method

Previous works [3] have used reduced order models by projection to accelerate the optimization algorithm and have obtained savings by up to a factor 12 on computational cost. The aim of this research is to introduce another model order reduction method, the Proper Generalized Decomposition (PGD), to increase the optimization process speed. To do so, the element densities are treated as extra-coordinates of a
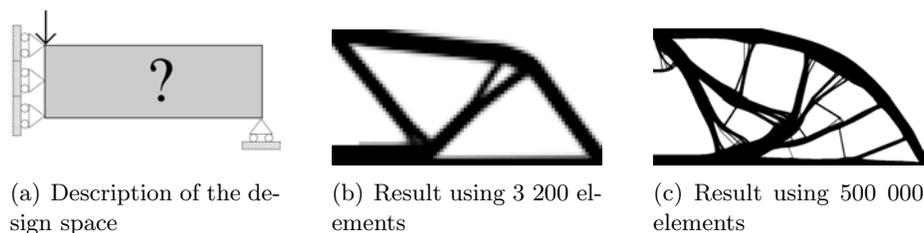
(a) Description of the design space

(b) Result using 3 200 elements

(c) Result using 500 000 elements

Figure 1: Optimized structures for the symmetrical 3-point bending beam problem

(a) With finite element solving
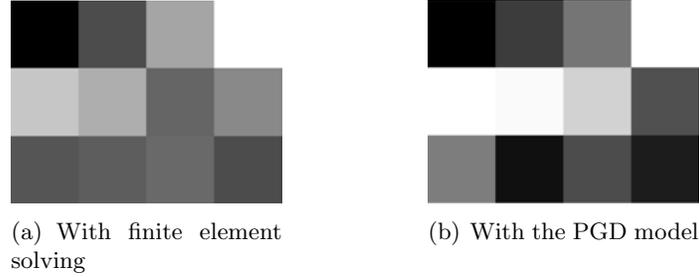
(b) With the PGD model

Figure 2: Solution to the optimization of the symmetrical 3-point bending beam problem in a 12 elements design space

multidimensional problem. The solution to this problem is sought once before the optimization process, in the *offline* phase. Once computed, this solution is then used *online* at each step of the optimization program; the new displacement field is not computed by a finite element method but evaluated as a particular solution of the multi-parameter problem.

The method is based on the assumption of a separated form of the displacement field $\mathbf{U}$. The PGD approximation is therefore built as a sum of N functional products, each of them involving n_e parametric functions $X_i^e(x_e)$ and a spatial function $\mathbf{\Psi}_i(x, y)$, as written in Equation (1).

$$\mathbf{U}(x, y, x_1, \cdots, x_{n_e}) = \sum_{i=1}^{m} \mathbf{\Psi}_i(x, y) \cdot \mathbf{X}_i^1(x_1) \cdots \mathbf{X}_i^{n_e}(x_{n_e}) \tag{1}$$

The PGD solution is constructed by successive enrichments, where each functional product is sequentially computed using the previous enrichments, so as to make the solution converge. The use of a separated form involves significantly fewer degrees of freedom to solve than standard mesh-based discretizations, by up to ten orders of magnitude, even for relatively simple problems [4]. It also allows to evaluate easily the partial derivatives of the cost function.
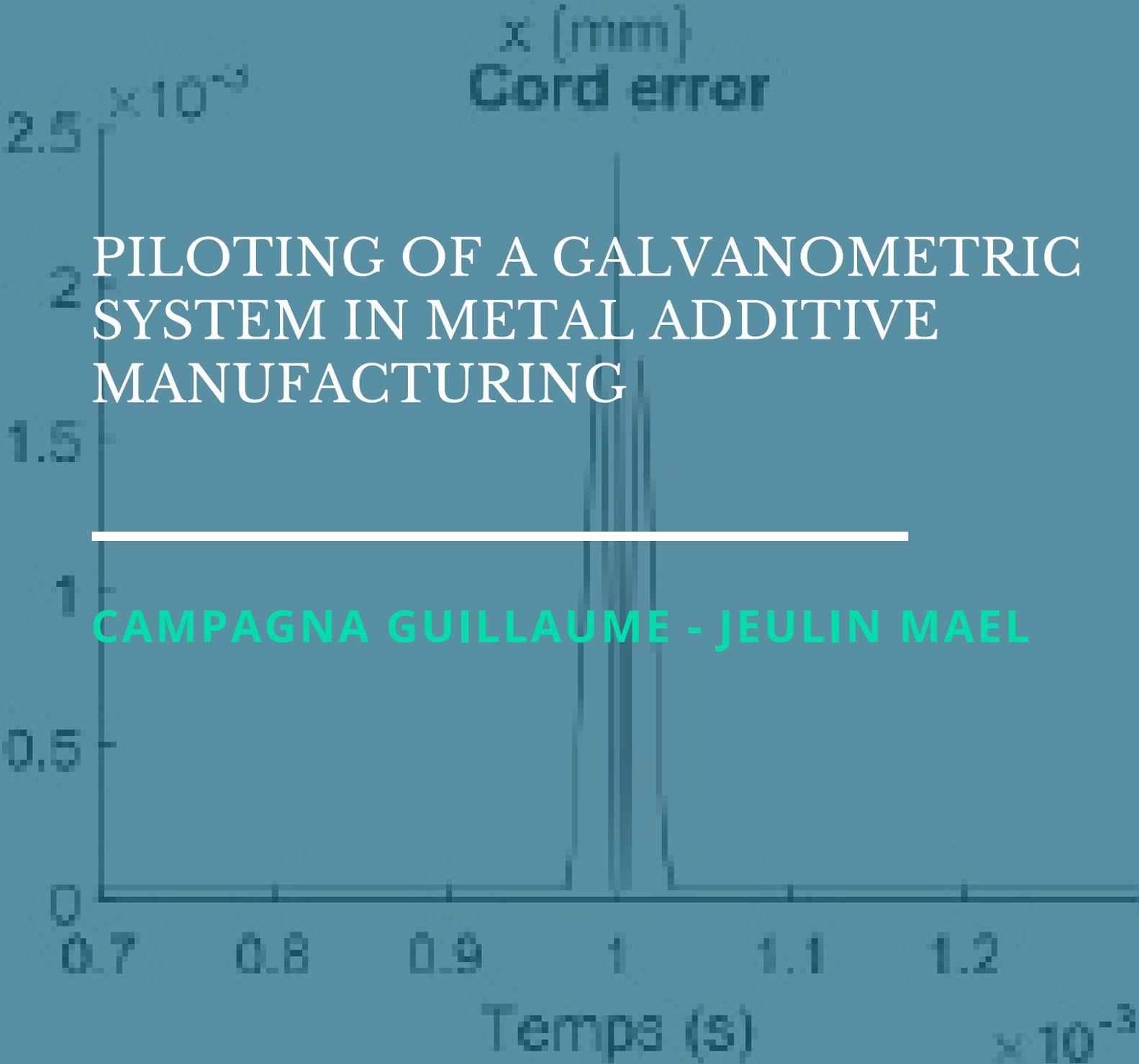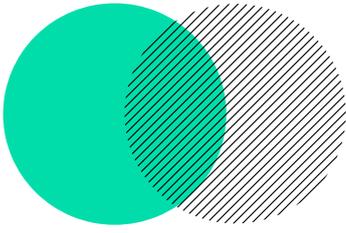
Method

A first *Matlab* code has been conceived to create a Reduced Order Model (ROM) for the topology optimization problem, under the form (1). For each enrichment, the spatial mode is computed by solving a finite element model, and each parametric mode is assessed by a trivial resolution of a one dimensional problem. The quality of the ROM is evaluated by calculating the energetic norm of the error of some particular solutions.

This first implementation of the PGD method is able to produce good models with a relative error smaller than a few percents. In Figure 2, optimal material distributions computed using either with finite element or with a ROM are presented. However for a number of elements greater than a dozen, the computing time becomes far too important to be interesting for the optimization problem, hence the need for a new approach in the construction of the reduced model.

A possible solution has been developed in [5], where a *Parameter-Multiscale* PGD is built on the Saint-Venant principle, which highlights two different levels of parametric influence, thus leading to introduce a multiscale description of the parameters. This allows to reduce the computation cost, as for each element, the influence of neighbors elements is thoroughly computed whereas the influence of distant elements is only roughly approximated. After a modification of the code developed in [5] to adapt it to the topology optimization context, it has been implemented in order to produce Reduced Order Models more efficiently.

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PILOTING OF A GALVANOMETRIC SYSTEM IN METAL ADDITIVE MANUFACTURING

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Piloting of a galvanometric system in metal additive manufacturing

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KEYWORDS: Additive Manufacturing; Selective Laser Melting; Filtering; Trajectories; Interpolation.

ABSTRACT

General Information: Metallic additive manufacturing has been flourishing over the last decades by various cutting-edge industries ranging from aeronautics to watchmaking. These technologies allow the design of products unconceivable with common manufacturing processes: internal features or organic shapes. This work focuses on Selective Laser Melting (SLM), a layer by layer powder bed fusion process using a high intensity laser to melt material called.
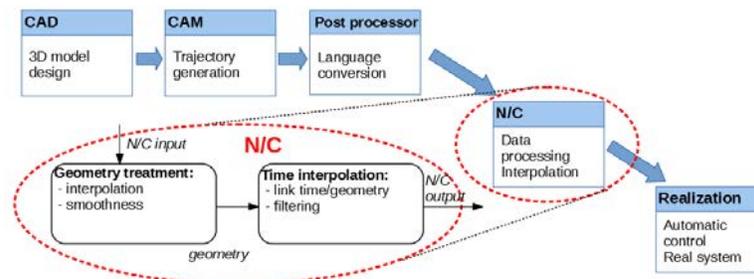
Figure 1: Digital chain

However, there are still significant SLM issues waiting to be solved. To guarantee high quality material it is needed to have an homogeneous deposit of energy from the laser. Consequently, the feedrate variations of the laser spot have to be minimised. This constraint is opposed to real kinematic behaviour of the system during the execution of the trajectory, in particular for angular trajectories. Indeed, a sharp angle on a trajectory creates a discontinuity for the feedrate laser velocity and an infinite pick for its acceleration that the two galvanometers cannot physically perform.

Some studies proposed to optimize the numerical control's unit of the digital chain (Fig. 1). The idea is to use Finite Impulse Response (FIR) filters in order to modify the geometry of the laser's path and be in conformity with the dynamic of the system. Yet, only one or two rectangular filters sized on velocity, acceleration and jerk limitations have been convolved with the path of each axis with significant results [1]. This suggests that the design of a new filter could be a good compromise between the machine's dynamic and the path's geometry.

Methodology and results: This study aims to enhance material quality, the respect of the path by improving the trajectory interpolation without exceeding the machine's dynamic. A case study contribute to this investigation. Indeed, configurations of different paths performed in additive manufacturing are restricted to U-paths for infill phases and sharp angle paths for contours.

Then, a new filter (here called hat filter) was designed for this study (cf Fig. 3). In order to find the four parameters used to built the hat filter, four criterions were settled:

- The respect of velocity and acceleration limit of each axis.
- A filter algebraic area equal to 1 to avoid any amplification of the path.

- The tangential velocity should not differ more than $\pm 20\%$ to the set one. Indeed, velocity variation impact the deposit homogeneity.
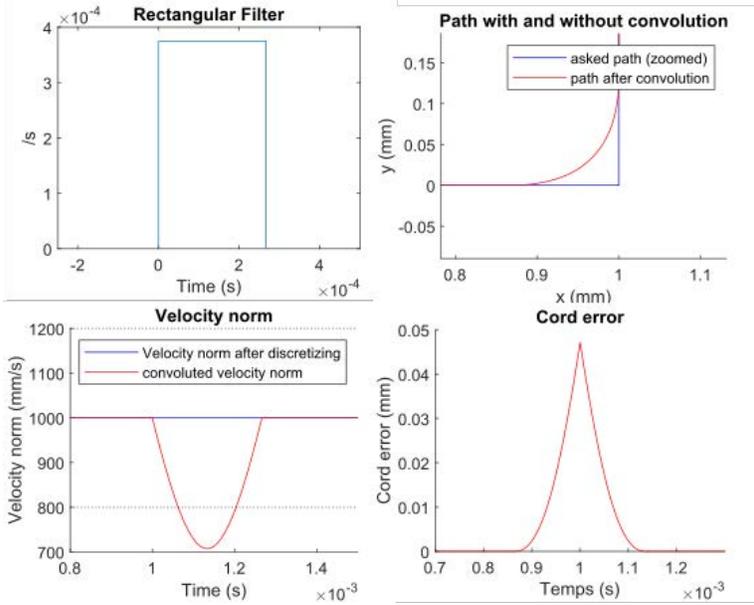- The chord error should not exceed $5\mu m$ [2].

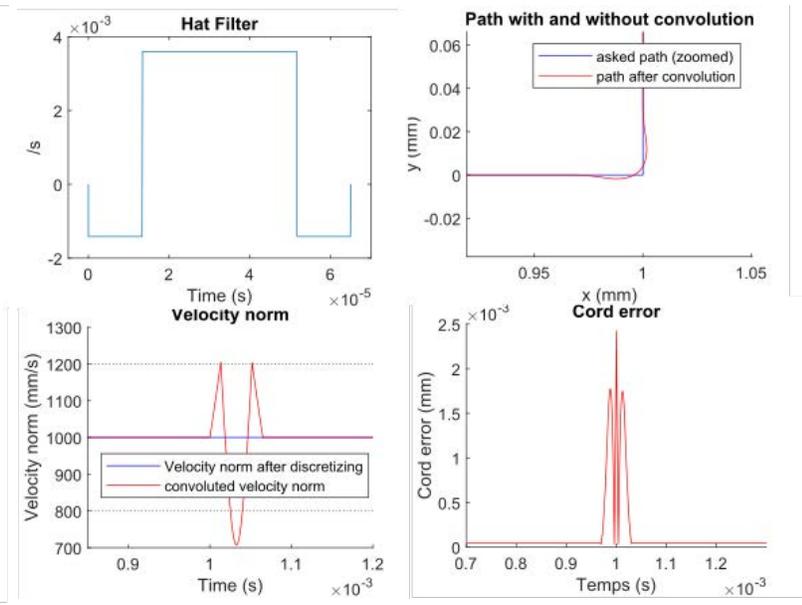Figure 2: Simulation results for rectangular filter

Figure 3: Simulation results for hat filter

The algebraic resolution of this 4x4 system led to the identification of optimised hat filter's parameters. Then it had be compared (see Fig. 2) to a rectangular filter optimised on the machine's maximum velocity and acceleration rebuilt from the constructor data and from the literature [1]. A homemade *Matlab* program was achieved to numerically evaluate the performances of this two filters convolved to a 90° angle path.

As expected, velocity and acceleration were not exceeded for both filters. Yet, the hat filter allowed higher velocities due to its design. Then, as represented on Fig. 2 and 3, the paths after convolution were different for the two filters. Rectangular filter's path was restricted inside the corner, whereas the hat filter's path get around it due to its negative parts. The chord error is 20 times lower for a hat filter than for a dynamically sized regular filter. Furthermore, the values of the maximum of this chord error stay below the imposed one for the hat filter which validates the filter ability to respect the geometrical criterion.

In addition, the minimum of tangential velocity was independent of the type of filter. Therefore it could not be set to respect the velocity criterion. However, the maximum of the tangential velocity had been maximised on the hat filter as it reached the limit imposed by this criterion on Fig. 3. This allows a gain in time at each corner, which are numerous in additive manufacturing.

Overall, this study suggests that the use of hat filters in SLM can decrease and control chord error in corner compared to actual filter without compromising the dynamic of the system.

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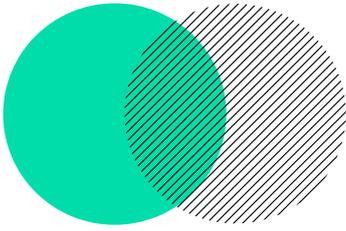
THERMAL MODELLING OF HUMAN SKIN EXPOSED TO LASER

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Thermal modelling of human skin exposed to laser

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KEYWORDS: skin; modelling; thermal equation; simulation.

ABSTRACT

Surgical treatments involving lasers are used in medical treatments such as tumour or tattoo removal. It is important to understand the precise thermal effect of the laser on skin to ensure the safety of the operation. Therefore, we propose to quantify the amount of laser-generated particulate matter (LGPM) in order to evaluate the damage to the skin.

Previous studies conducted on porcine skin have identified the temperature field and heat flux during a cauterization procedure along the edges of a wound [1]. In order to measure these values, a multi-scale finite element model of porcine skin had been implemented using the real geometry of one single slide of tissue. 3D mechanical models of the human skin based on the real geometry of the tissue and including the three skin layers have been also constructed but without a multi-scale approach [2].

The aim of the presented study is to create a 3D multi-scale model of the epidermis of human skin based on its real geometry to simulate the thermal effect of a laser on human skin. The model assembled the reconstructed tissue for multiple adjacent 6.5 μm thick slides. The samples that were used to digitise the geometry were harvested on a 50 years-old female armpit. After having gathered the relevant data on the histological slides of the sample, a 3D model of the sub-layers of the epidermis was constructed using an level set algorithm. The epidermis is composed of four sub-layers: stratum corneum, stratum granulosum, stratum spinosum and stratum germinativum. The profiles of the upper and lower surfaces of each epidermis sub-layer were then post-processed to remove any intersection in the model [3].

In order to build a multi-scale model, it was necessary to "translate" the upper surface in order to obtain a lower surface of each of the different sub-layers. First of all, there is no unique method to move a complex 3D surface over a short distance. To create the new lower surface of each sub-layer, one can either vertically translate every point of the upper surface or move the point along the normal to the surface using a gradient method or level set method. The number of intersections for each method was determined for different test thicknesses. The results showed that the second method or gradient method was

more suitable for short distance movement up to 45 μm than the fist method or vertical translation method that created no intersection only for thicknesses of 250 μm.

For these reasons, a gradient based algorithm was implemented to avoid any surface intersections that would prevent the creation of a mesh. Nonetheless, a modified level set method was necessary to create such geometry for the new 3D curve of the lower surface for each sub-layer in each observed slide. Based on the morphological observations in the skin samples, several local geometrical criteria were added to complement a simple level set method. The different layers were created one by one (Figure 1) and were then assembled into a multi-scale 3D model.

The 3D model was assembled in Abaqus in order to calculate the quantity of LGPM using the bio-heat equation. The physical properties of each layer were taken from previous studies [1]. In the simulations, the regions where the temperature is higher than the critical temperature will be vaporised and indicate the volume of LGPM.
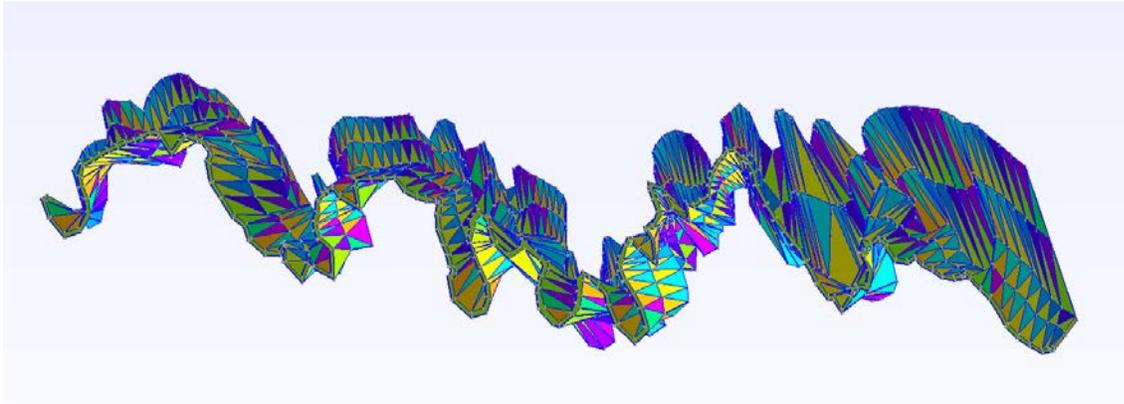

Figure 1: 3D model of the 2nd layer of the epidermis : the granulosum

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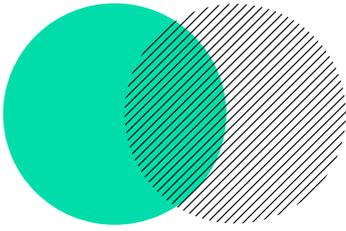
MODELING AND IDENTIFICATION OF THE LOCAL LOADING DURING A DELAMINATION TEST ON LAMINATED COMPOSITES

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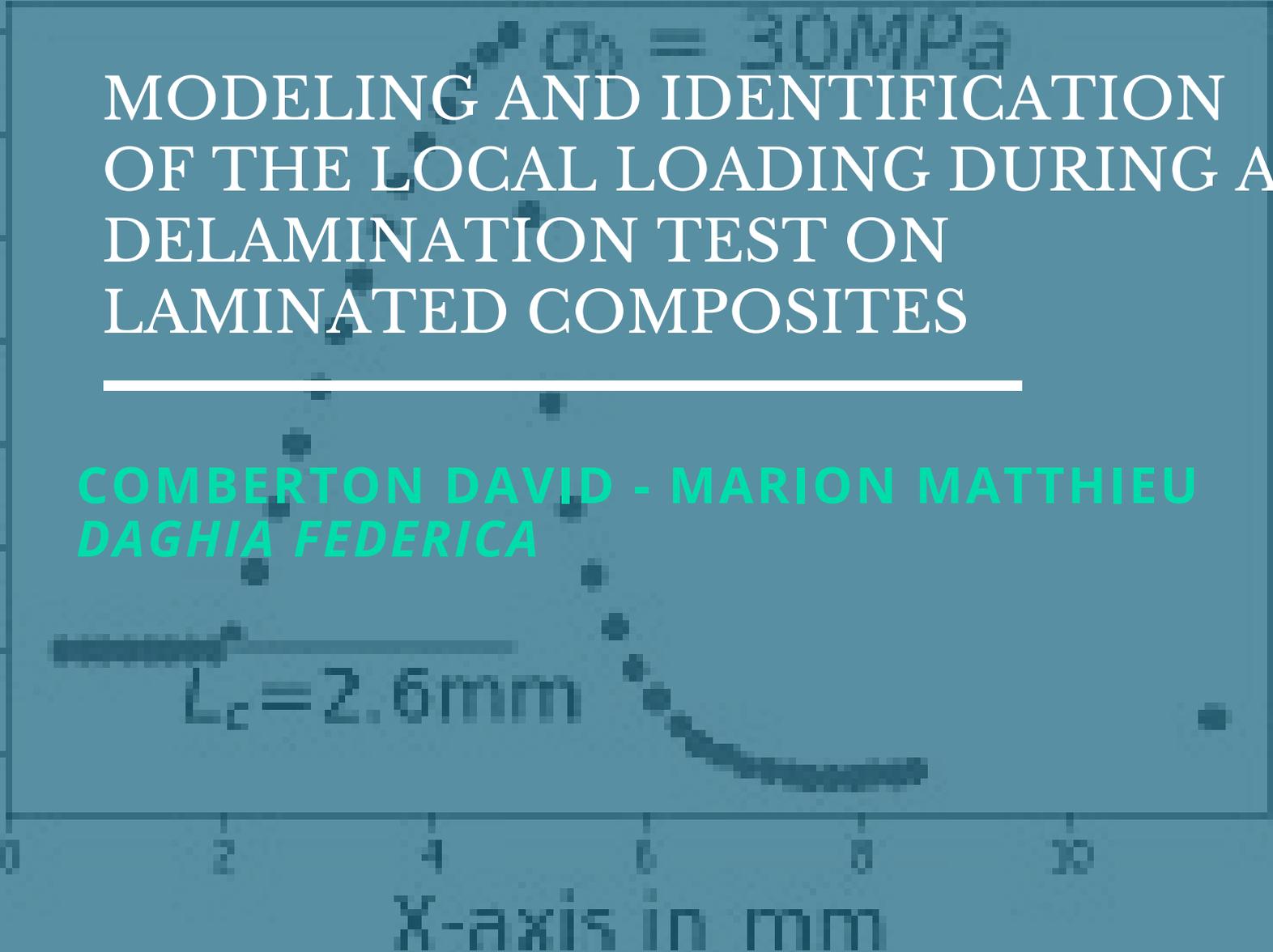
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Modeling and identification of the local loading during a delamination test on laminated composites

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KEYWORDS: Laminated composite; Cohesive zone ; Delamination.

ABSTRACT

General Information

  The delamination of a composite structure is the spread of a crack between two layers of fibre, it is one of the major failure modes of a composite structure. It is the reason why it seems necessary to improve our understanding of this process. As every failure mode, delamination is a non linear process, however the major part of delamination studies did not take into account non-linear aspects. Indeed the study of crack propagation in double cantilever beam (DCB) test is transposed to a linear bending bar problem. In that case the crack front is seen like a singular point. This approximation, called linear elastic fracture mechanics (LEFM) is also made when we study a plate with a hole. G. Bao and Z. Suo [1] defined the limits of this model. If characteristic length of the hole or the crack is small before the characteristic length of the structure, LEFM is valid. If not they defined a length of a cohesive zone (l_c). They have demonstrated that this length is linked to the Young's modulus, the energy release rate and the fracture stress. Nevertheless they only studied massive structures. Q. Yang and B. Cox [2] have introduced a corrective parameter (l'_c) in the of a slender structure, where the size of the cohesive zone is closer to the size of the characteristic length (h).

$$l_c = \frac{EG_c}{\sigma_0^2} \qquad l'_c = (l_c)^{1/4} h^{3/4} \qquad (1)$$

In the case of a composite structure h can be equal to the thickness of the piece or of a fold. In LEFM the loading and the distortion of the structure is unknown in the cohesive zone. Knowing this loading could be very helpful to predict the direction of propagation of a crack. This study focus on modeling and identification of a local loading in the cohesive zone during a delamination and the influence of propagation modes of a crack on G_c the critical strain energy release rate.

Model

We have created a model on Abaqus of a DCB test in order to determine the behaviour of the structure around the crack front. We have chosen to study an asymmetrical stack ($[0/90/90/0/90/0/0/90/90/0/0/90]_2$) to characterise the influence of the local lack of symmetry. In order to model the spread of the crack, we used the cohesive element of Abaqus. This element has a non-linear triangular low between $[\![u]\!]$ and σ. This law can be described by three parameters: G_c=0.7 J.mm^2 the critical strain energy release rate, σ_0=30 MPa the stress at failure and k=250.10^3 N/m a rigidity.
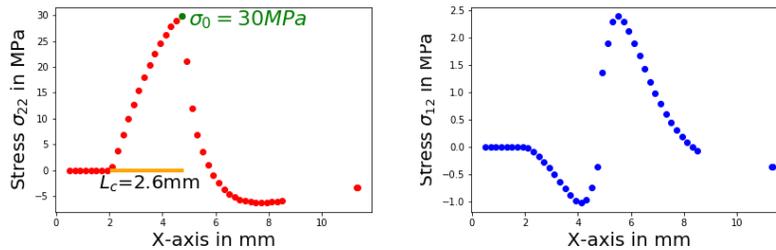

Figure 1: Stress in cohesive elements

Within those calculations we can find a value of the length of the cohesive zone. We found that L_c=2.6mm, l_c=4.9mm, l'_c=1.1mm. It is coherent with the equation (1). We can also notice that there is some shear due to the local loss of symmetry.

Experiment

In correlation with our model we performed two DCB test with digital image correlation, in order to study the real local stress field and the impact of the shear stress. The first to verify how it moved and the second to focus on an area of interest, to see the crack crossing the area.

The Figure 2 is the results of the experiment, we can clearly see the impact of the shear stress, we identified in the simulation. Due to the local loss of symmetry, the crack was spreading between the fibres of the layers at 90° and not between the two layers where was the pre-crack . Whereas in the simulation it is trapped in the cohesive material : this shear stress is not negligible.

Figure 2: Result of the tensile test

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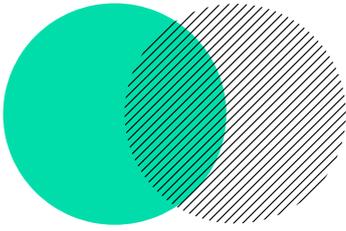
PATTERN ADAPTATION FOR CAD-BASED CALIBRATION AND SHAPE MEASUREMENT WITH STERODIC

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Pattern adaptation for CAD-based calibration and shape measurement with StereoDIC

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KEYWORDS: Stereo DIC; Projector calibration; Pattern adaptation.

ABSTRACT

CAD-based shape measurement with stereo digital image correlation (DIC) is a newly studied subject [1]. Stereo DIC is based on the comparison of two different shots of the studied part on which a texture like a painted speckle pattern is applied. In the method proposed by Beaubier [1], the comparison of the two images is conducted according to the criterion of gray scale conservation with the projection of CAD shape in the two images of the surface.

The adaptation of this method in an industrial context involves questions concerning the texturing of the studied surface. Even if the use of a projected pattern was preferred to the painted one in order to not modify the studied part, the procedure for setting up and using the video projector are not clearly defined. Moreover, the influence of the adapted pattern with regard to the dimensions, the calibration of the stereo system and the shape measurement is currently not defined.

The aim of this research is to determine a method to adapt the pattern to project according to the CAD definition of the part and system configuration. Hence, a projector calibration's method and a 3D pattern generator is developed to allow the projection of an adapted pattern on the surface.

Several methods are already used to calibrate a projector [2, 3], based on a pinhole model to describe the projection of the image, which usually require a camera previously calibrated to determine this model. The method used in this study is based on the CAD definition of the workpiece, here a cylindrical portion of an aircraft, and uses the Matlab calibration code of a stereo system as in Beaubier [1]. The projector is defined by a pinhole model and replaces one of the two cameras in the stereo system. To initialize the calibration of the two components, namely to establish a first estimate of the transformation matrix between the 3D-CAD frame and the 2D image frame, Beaubier's method [1] relies on a manual selection, within the two images, of 6 points whose 3D CAD coordinates are known. The determination of these 6 points for the projector is carried out by the iterative projection of dots on these points of the real part. To remove constraints related to the lighting and the color of the experiment room, the applied pattern

is made with a circular dot grid and the camera image is thresholded with the Otsu method [4] before calibration. The transformation matrix of the projector obtained by this calibration is used to adapt the projected pattern to the surface. To generate this pattern in 3D, a conformal transformation of the nominal surface is carried out towards a 2D parametric space with the LSCM method (Least Square Conformal Maps) [5], where the pattern is applied. After conducting the inverse transformation, the 3D texture thus defined can be projected in the coordinate system of the projector with the transformation matrix obtained with the calibration. The resulting image can then be projected on the workpiece.
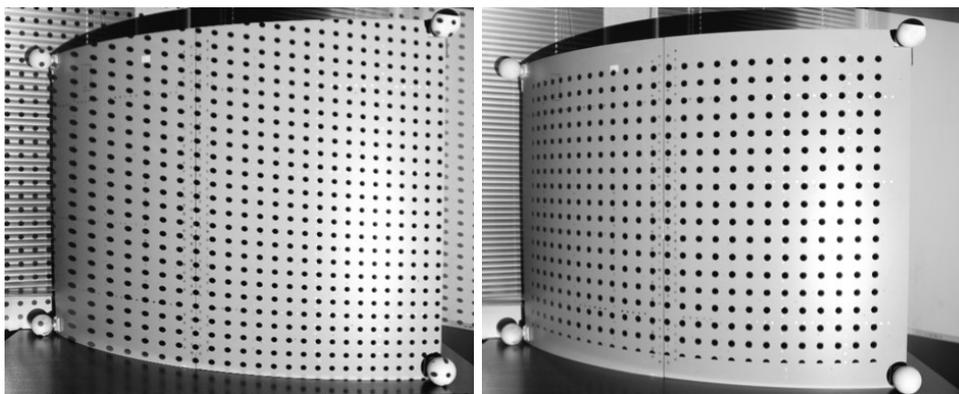

Figure 1: Pattern adaptation on a cylindrical surface

In this study, it has been shown that the regular pattern with circular shapes used to calibrate the projector can not be too small for the stereo calibration algorithm to converge. As a consequence, a random and fine speckle pattern can not be used directly and a larger pattern is needed. In addition, it has been shown that calibration with stereo DIC still works when projector rays are almost tangent to the work piece and is slightly more efficient with an adapted regular pattern. Therefore this study suggests that off-centring the projector in industrial stereo DIC systems is possible.

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DIGITAL TWIN FOR THE IDENTIFICATION OF A DISCREET SYSTEM BEHAVIOR
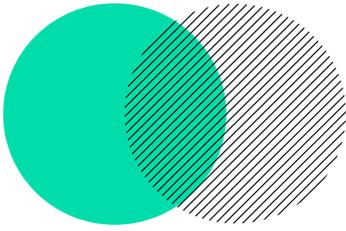
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Digital twin for the identification of a discreet system behavior

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KEYWORDS: Discret Event Sytem; Identification; Digital Twin.

ABSTRACT

Context and Objectives

The method of identification of Discret Event Sytems consists in the construction of a model of the system from the analyse of sequences representing the binary state of sensors and actuators while the system is running. The final model can be represented in a form of a Petri Net, it is a class of graph often used in the reverse engineering problems because the identified graphs are usually understandable by humans.

The aim is to find causal links between sensors and actuators in order to produce a working model of the system. The sequence used to identify a model of the system is crucial, particularly with a black-box approach because this is the only source of knowledge used in this case. The sequences length, accuracy and diversity are decisive to identify a valid model [1]. In much of the experiments, it needs to let the machine works for days and many parameters are unknown. Moreover, some active methods of identification which could artificially diversify the sequence cannot be used with a black box approach on a machine because it would damage the components.

Therefore, the use of a digital twin, a simulation of the plant combined with a Programmable Logic Controller (PLC), as shown on Figure 1, could solve these problems. During this research project we tried to implement this experiment and our will is to compare our results with an identification of the system using a real machine.

Methodology

A digital twin must reproduce, in the most faithful way, the behaviour of a system. In order to complete this task, we chose the software Factory I/O because there is a good range of actuators (conveyors, elevators, etc), of sensors (switch, size, etc) and of supplies (boxes, pallets, etc). Moreover, it performs a realistic physic simulation of the components of the system and it is possible to connect the simulation to a PLC in real time.

Then, we chose a system reproducible in factory I/O: a parcel sorter, because it is a system with concurrency (multiple sensors and actuators evolve simultaneously) which makes it harder to identify. As a PLC, we used a Controluino programmed to control the real parcel sorter.

Finally, we saved a sequence of more than 4500 vectors, each one representing a state of the system while the simulation is running. An Algorithm developed in our laboratory [2] anaylysed it and produced a graphic model (Figure 2).

Results and Conclusion

First of all, we succed to identify a working model of the system, therefore the method of the digital twin is feasible. Even better, it allowed us to repeat the experiment really easily and to try different scenarios of working. Moreover, with a digital twin, the experiment can be running as long as necessary. Consequently, many vectors are observed what ensure the quality and the understandability of the obtained models.

Nevertheless, this method limits the complexity of the system, firstly because of the limited range of actuators and sensors of the software, secondly because many parameters of the experiment cannot be defined (temperature, wear of the components, etc). Moreover, we should use the identified model of the real system to precise the parameters of the simulation (conveying speed for example) to ensure that our systems are comparable.
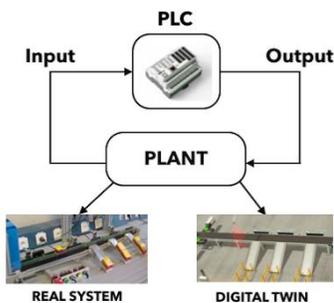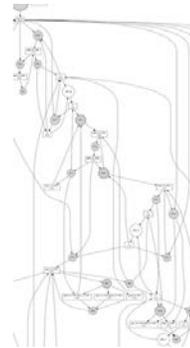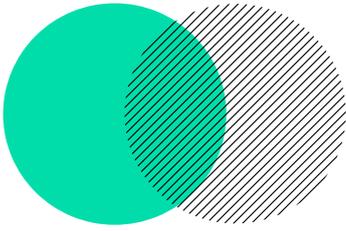

Figure 1: The use of a digital twin

Figure 2: A part of the Petri Net identified with the digital twin

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MOBILITY INDICATORS : DATA EXTRACTION AND TRANSFORMATION FOR HABITS IDENTIFICATION IN SMART HOME

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Mobility indicators : data extraction and transformation for habits identification in smart home

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KEYWORDS: Automation; Data extraction; Smart House.

ABSTRACT

1 Introduction

Domotic fields such as home automation are thriving. Due to the ageing of the population, current research are carried on, with the aim to develop a powerful and efficient system for elderly security and health risk detection using non-intrusive material to respect private life.

In 2008, Martin Floeck and Lothar Litz, worked together on two approaches that can be used to condense the raw data information into more significant information: the activity and inactivity profile and further research describe a probabilistic method to raise an alarm when the inactivity profile is abnormal.

In this study based on the previous work of Mathilde Cavero and Victor Paredes, we aim at analysing data from an existing person in order to determine new information on its behaviour and detect potential health problem.

Our database includes timed and anonymous data from presence and contact sensors installed in apartments located at La Reunion. Each data is json rawdata and each line of the file corresponds to a raising edge or a falling edge of the sensors.

2 Analysis of the raw data

The goal is to create a modular structure program that can be used as a base for future developments. To do so we created a parser that could convert the log json file into a class object program that represent the apartment and organise the different information of the log intelligently.

This way, we could access rapidly specific information. One that can next be used by other programs that aim at analysing the patient behaviour. Thought, we converted already existing functions written by Mathilde Cavero and Victor Paredes and adapted it to work with the new modular system. Those functions were used to determine the inactivity of the patient, using the Floeck and Litz's theory. We then developed new functions that allowed us to determine approximately the patient speed and its position in the apartment.

3 Creating raw data

However, we rapidly encountered a problem concerning those data and its analysis. On one Hand, the Company that was due to provide us new data failed to do so, on a second hand, due to the enormous amount of data, we were unable to verify if our analysis of the log were correct. That is why the study took a shift and mainly focused on the development of a flat/inhabitant simulator that could realistically reproduce its behaviour and the data outcome of an equipped apartment.

To do so, we decided to create a modular structure of an apartment that can be adapted to any kind of apartment and easily upgradable. We build it around the concept of room class, door class, sensor class and others with different properties to manage its interactions with the simulated inhabitant.

Then, to create a daily routine that could fit any profile, we establish scenarios such as breakfast or lunch time, which the launch depends on the hour and the inhabitant state such as his level of hygiene, his hunger or his need of sleep. Once a scenario is played the inhabitant is moving in the virtual apartment and virtual sensors send us log like real sensors would do in the real world.

4 Conclusion and future work

Our method allows to simulate a simple model of habits that can be easily updated: it switches between three scenarios and when interrupting with an emergency button, the alarm is triggered within the limit. We can have access to different characteristics of the simulated person and compare the result of our analysis algorithms with the information of the simulator. This should allow us to verify the well functioning of our algorithms. However, further research is needed to see how to better use this data for medical purpose.

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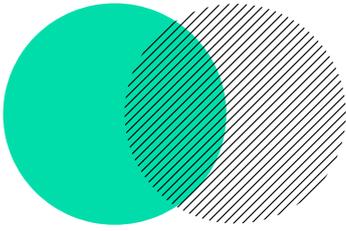
TESTS UNDER RICH BOUNDARY CONDITIONS

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Tests under rich boundary conditions

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KEYWORDS: metamaterials; higher-order effects; higher-gradients; optimization.

ABSTRACT

At the beginning of the 19th century, Cauchy developed a theory of continuum mechanics. Although it can describe the behaviour of a number of materials, it was not suitable for modelling structures with significant scale ratios (metamaterials). Then, new models were established at the end of the 20th century to describe behaviours that were not highlighted by the classical field theory. However, at that time, the available technical means did not allow to simulate numerically the behaviour of such materials, nor to test them experimentally, and not even to produce them.

It is only recently that we have begun to experiment with these materials in the context of statics, in order to highlight their generalized non-standard behaviour. Obviously, the response of the material depends on the boundary conditions. However, in our study, boundary conditions may be more complex in nature than for standard materials (e. g. local rotations). Previously, works on this subject on a flexcore plate [1] showed that the 1st gradient (in displacement) behaviour laws do not accurately describe the material's response. Indeed, there is a gap between the prediction of displacement by the 1st gradient theory and the displacement measured by digital image correlation [2]. In order to specify this difference, our predecessors decided to use a 2nd gradient model. Nevertheless, the determination of this model requires the identification of all the coefficients of the behaviour matrix, which is impossible given the experimental tests conducted.
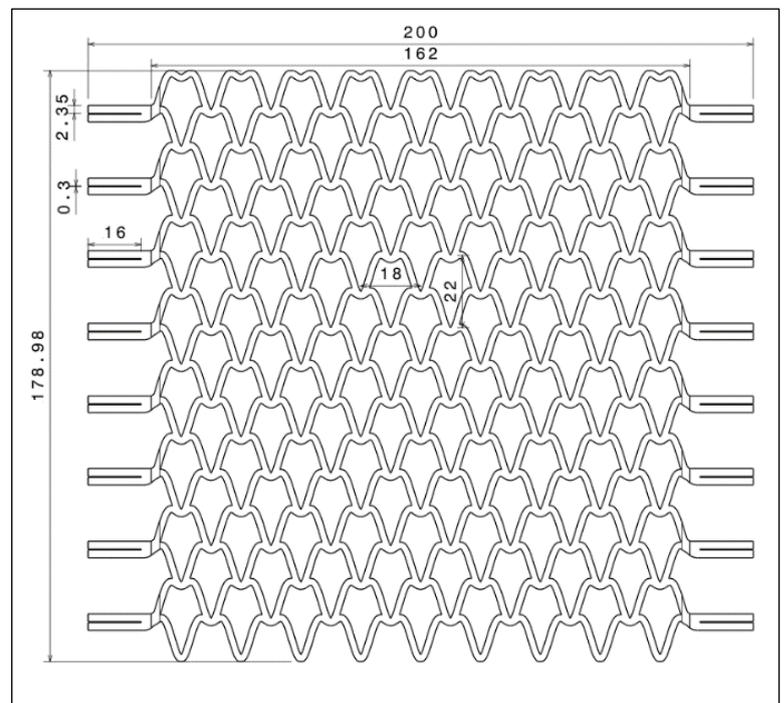

FIGURE 1 – FLEXCORE 2D

As part of our Study and Research Work (TER), we have decided to focus our research on the study of a 1D bar-type model. As a result, the coefficients of the behaviour matrix are identifiable from an experimental test [3]. First, we extracted a column from the flexcore plate, thus constituting a 1D specimen. A modeling under

CatiaV5 and a tensile test were carried out in order to identify the 2nd gradient effects. However, for the tested geometry, these effects are very slight. In line with previous works, we observed that the soft separation of the meso and macro scales of the material was (among other things) a necessary but not sufficient condition for observing such effects.
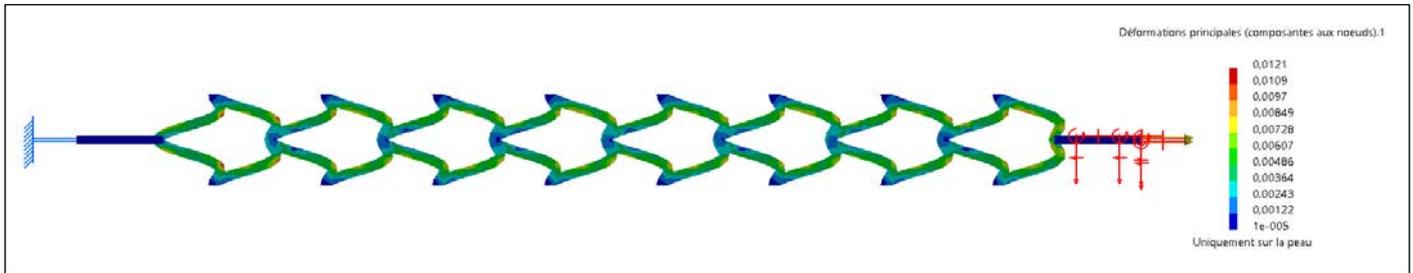

FIGURE 2 – SIMULATION UNDER CATIAV5 OF A TENSILE TEST ON A 1D FLEXCORE

Thus, the problem lies in the optimization of geometric and stiffness parameters (a, b, c, k_1, k_2, k_{12} and k_{21}, see figure 3) of a 1D material maximizing the effects of the 2nd gradient. For this purpose, a multi-solids modeling was established, representing the material as the repetition of an elementary section consisting of bars and torsion springs.
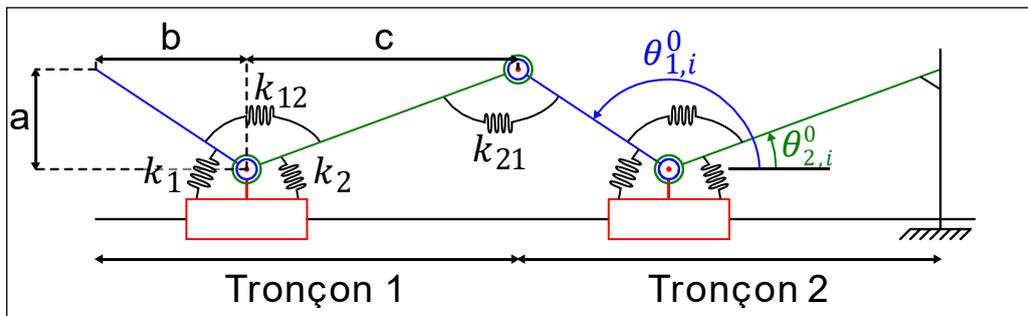

FIGURE 3 – MULTI-SOLIDS MODELING IN THE PARTICULAR CASE OF TWO SECTIONS

It is then a question of solving a non-linear static problem in order to calculate the displacement at each points of the mechanism. For this purpose, we have chosen to use a Newton-Raphson algorithm, giving an approximation of the static solution of the problem. Then, we try to maximize the residue between the simulated displacement and a linear regression of the latter by a particle swarm optimization [4]. After obtaining an optimized set of parameters, we will machine our material by water jet cutting, perform the tensile test and measure the displacements by digital image correlation. Finally, we will identify the coefficients of the behavioural law from the 1D analytical law provided by previous research [3].

To conclude, although 1D analytical resolution and parameter identification is easier, it does not seem trivial to find a 1D geometry that highlights the 2nd gradient effects. For the moment, the multi-solids numerical model allows us to highlight the 2nd gradient effects. It remains to be seen whether these effects, once maximized, will always be significant on the machined material.

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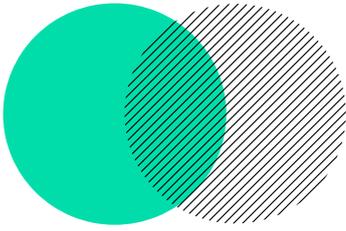
AUTOMATIC DETERMINATION OF MECHANICAL PATTERNS FOR PARSIMONIOUS MODELING OF COMPOSITE MICROSTRUCTURES

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Automatic determination of mechanical patterns for parsimonious modeling of composite microstructures

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Keywords : Pattern, Microstructure, PCA, GFEM

Abstract :

Context/Aim

Ceramic matrix composites (CMCs) have drawn considerable attention and countless applications in the aerospace industry. The mechanical properties are directly linked to the microstructure, which is due to manufacturing processes. When ceramic matrix composite is observed under a microscope, one can see that the distribution of fibers is quite aleatory, but can be divided into geometrical patterns. Patterns are typically one isolated fiber or a group of two or three united fibers. If geometric patterns of fibers leading to the best mechanical properties were able to be generated precisely in the manufacturing process, the mechanical behavior of the structure would be enhanced.

Finite elements modeling of the heterogeneous structure of CMCs induces an important computational cost and gives a large amount of data. Therefore, we will use Generalized Finite Elements Method [1] and apply principe of Virtual Works in order to calculate a good approximation of the solution at a lower cost. From the displacement data calculated to determine the most descriptive local displacement proper functions needed in the GFEM, we develop a technique in this paper to recognize automatically the mechanical behavior of classical geometric patterns in the CMC.
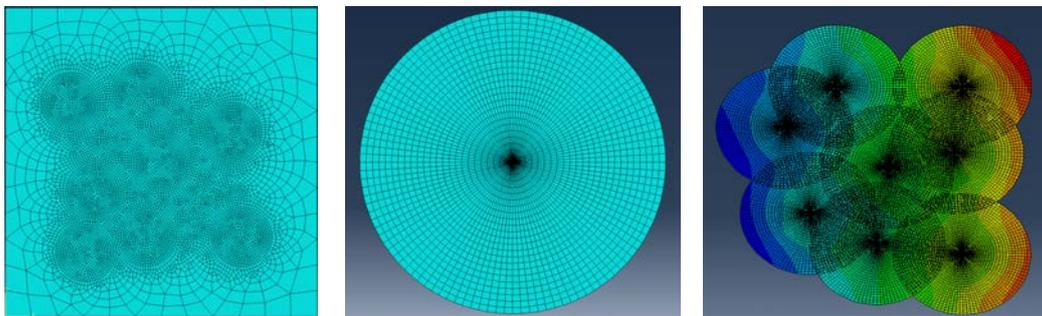
Fig 1- Generation and mesh of the microstructure, axi-symetric mesh to compare each displacement field, extraction of patches

Methodology/ Tools

First, we needed to generate all the database necessary for the research.
We created and mesh on Abaqus five Elementary Representative Elements (ERVs) containing randomly generated circular fibers, with fixed volume fraction in it in order to make three loading cases, two tensile tests and one shear test. On every fiber, the initial displacement has been interpolated on the axi-symetric one to be able to compare adequately the displacements on each fiber. Then, the displacements on every node for the five models and the three load cases were collected.

Secondly, Principal Component Analysis was used over straightened fields and non straightened fields to find a finite dimension basis of local displacement proper functions to approach quickly and easily the solution. The Principal Component Analysis allows to make displacement and deformation data less redundant. This statistical method has three steps. First, we center and reduce the data in the dataMatrix, then its biggest eigen value is calculated and gives the solution of the optimization problem according to the Eckart-Young theorem. By displaying the displacement fields of the data matrix, we could observe that some of them were identical except from one angle. In order to avoid them being taken into account as two different fields, the fields have been straightened with respect to a given criterion.

The following rectification criterion has been chosen : the mesh line with nodal displacement vector biggest norm is considered to be the horizontal direction. To calculate the stress and deformation over each element of the mesh, form functions have been implemented. Once the new basis of local displacement proper functions has been calculated, each mode can be analyzed separately in order to bring to light interactions between fibers.

Results

The PCA has proven that 90 % of the data is contained by the first mode, and that almost 10% is contained by the second mode. Contribution of different modes in the Rectified and non rectified fields are quite similar (Fig 2).
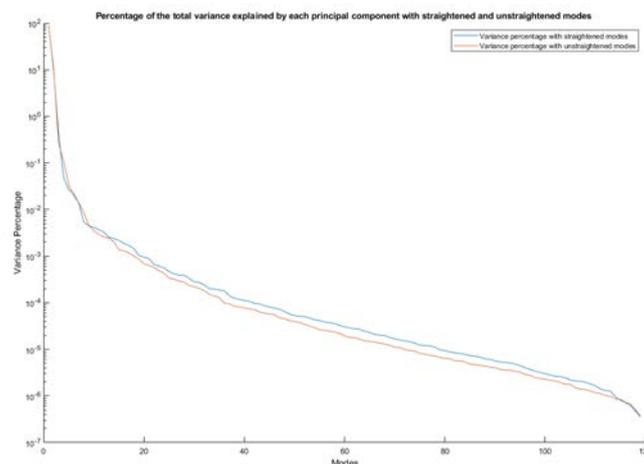

Fig 2- Percentage of the total variance explained by each principal component

With or without rectification over the fields, even if the contribution of the several modes is the same, modes can easily be different (Fig 3,4).
However, even if some shapes of the modes do not seem to represent a physical information that can be easily understood.
The 8th and 10th modes on straightened displacement data may represent interaction between fibers because of their asymmetric behavious, but this is only an assumption (Fig 5).
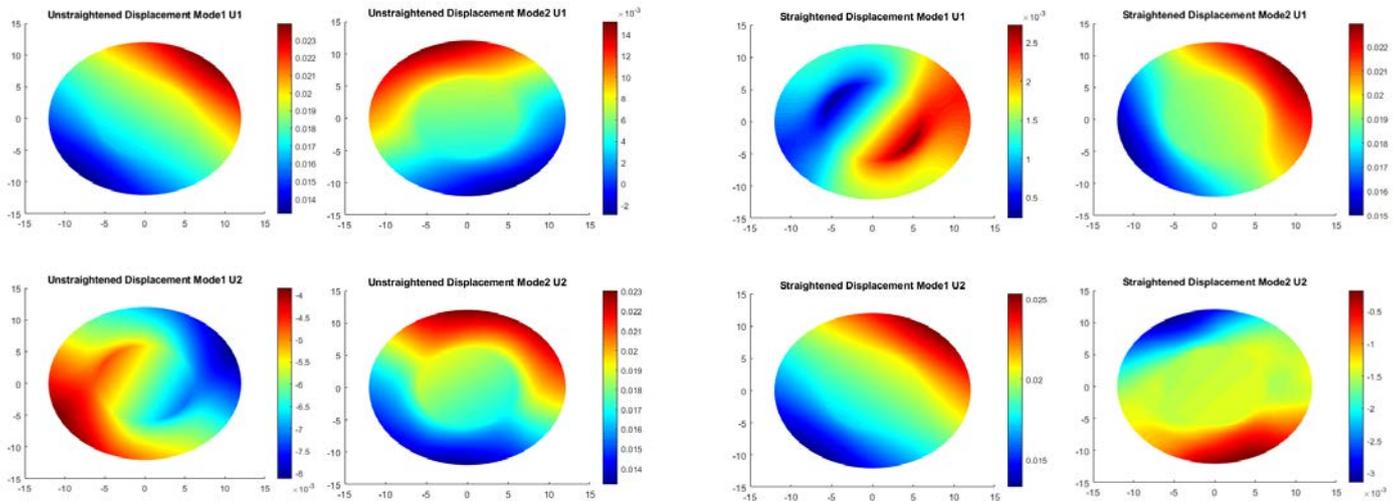

Fig 3- Unstraightened modes 1 and 2 along both directions

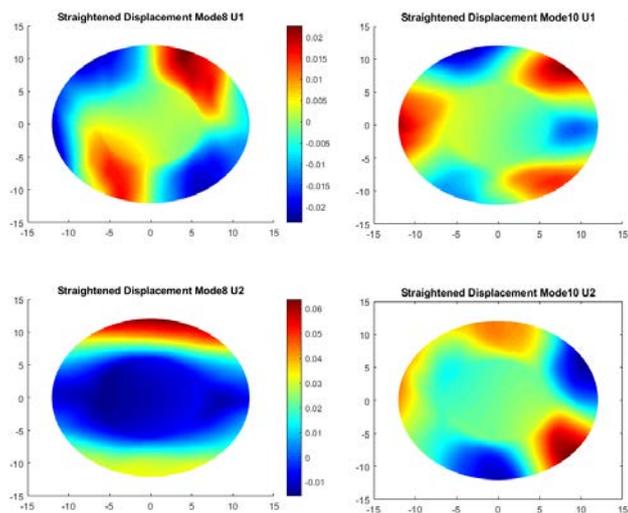**Fig 4- Straightened modes 1 and 2 along both directions**

Fig 5- Straightened Displacement of the 8th/10h modes

Conclusion

-A Matlab code has been implemented and can be re-used with ease for any other microstructures.
-The choice of rectification criterion has a lot of importance when it comes to physical comprehension of the several modes.
It would be necessary to know how to choose it for longer study (a possibility could be to weight displacement near the wedge of the fiber, for example).
-Independent Component Analysis [3] would bring to light the perturbation fields, but this has not been developed in this project.

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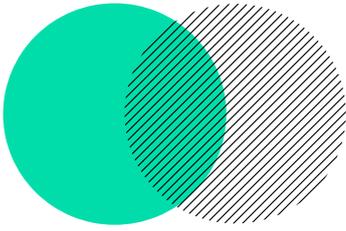
INNOVATIVE STRATEGIES FOR MONITORING REFRACTORY CRACKING

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Innovative strategies for monitoring refractory cracking

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KEYWORDS: Castable Refractory; Digital Volume Correlation; Tomography; Wedge Splitting Test; X-FEM simulations.

ABSTRACT

Refractory materials are frequently used in industry for their high thermomechanical resistance in extreme conditions such as high temperature applications or corrosive environments. Because of their widespread use, understanding how these materials break is essential. This project aims at performing an in situ test in a lab tomograph allowing for stable crack propagation. The acquired scans are used to measure displacement fields via digital volume correlation. The final goal is to analyze the cracking mechanisms of the studied material and to simulate crack propagation.

Method Tomography was used to monitor crack propagation in the tested sample. X-rays were transmitted through the material and acquired by the detector. While the tomograph emitted x-rays, the sample was rotated from 0 to 360° and series of radiographs (900 in the present case) were acquired. Then the reconstruction code processed all 2D frames to obtain a 3D image. A stable crack propagation had to be observed during the test, especially during the various acquisitions. It was achieved by using the so-called wedge splitting test (WST [1], Fig. 1(a)). This setup involved a low elastic energy stored in the testing machine and the sample, which made stable propagation easier.

To measure the displacement fields induced by the propagating crack, Digital Volume Correlation (DVC) was used. This method registered two volumes, namely, that of the sample in its reference configuration (i.e., before the crack had propagated), and another one acquired during crack propagation. A particular DVC approach is the so-called global method, which uses finite element discretizations [3]. In this project, global DVC was run with a matlab code that minimized the correlation residuals and returned the measured nodal displacements and the correlation residuals. Considering the needed memory, the Fusion cluster was selected (i.e., the mesocenter for CentraleSupelec and ENS Paris-Saclay). In order to simulate crack propagation, the extended finite element method (X-FEM) was used [2].

Results In the present case, the standard displacement uncertainty is equal to 0.16 voxel. In light of the measured displacement levels obtained for the three studied steps, the results

of the DVC analyses are considered to be reliable. The crack has grown in the volume and almost split the sample in two. Looking at the 3D images, there was only one crack and not several of them. The 3D renderings of measured displacement fields (Fig. 1(b-d)) confirmed this statement. The gray level residuals (Fig. 1(e)) showed that the crack had bifurcated and was very rough. X-FEM simulations were run in which the measured boundary conditions were applied to the numerical model. Crack bifurcation was also observed (Fig. 1(f)). Further simulations will allow the propagation parameters such as the cohesive strength and displacement to be calibrated so that the fracture energy will be estimated.
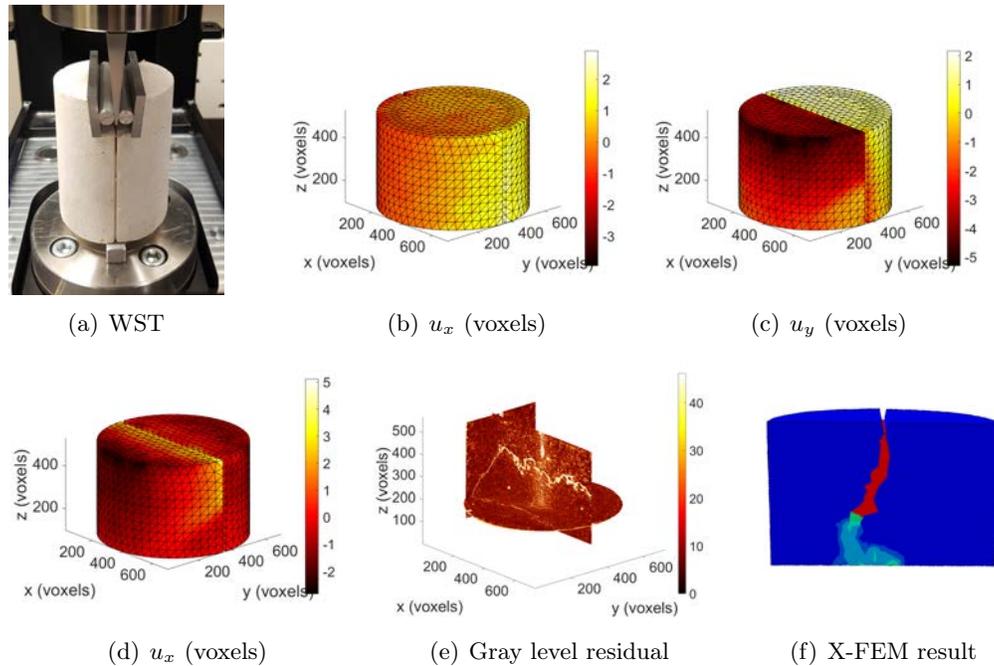

(a) WST   (b) u_x (voxels)   (c) u_y (voxels)

(d) u_x (voxels)   (e) Gray level residual   (f) X-FEM result

Figure 1: Major results of the project. (a) In situ WST on castable refractory. (b-d) Measured displacement fields via DVC. (e) Gray level residuals. (f) X-FEM result of the simulated test (the red elements depict the fully cracked surface).

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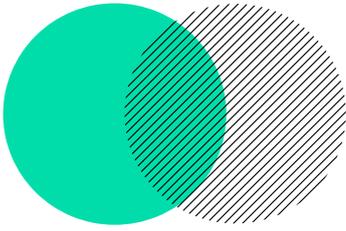
MOBILITY INDICATORS : DATA EXTRACTION AND TRANSFORMATION FOR BEHAVIOUR IDENTIFICATION IN SMART HOUSES

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Mobility indicators : data extraction and transformation for behaviour identification in smart houses

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KEYWORDS: Automation; Data extraction ; Smart House.

ABSTRACT

1 Introduction

Domotic fields such as home automation are thriving. Namely, security systems for elderly people have undergone an important development due to the ageing of the population.

In 2008, Martin Floeck and Lothar Litz, worked together on two solutions that can be used to condense the raw data information into more meaningful information : drawing activity profile and drawing inactivity profile.

To the best of our knowledge, these methods are considered as the most advanced solutions to identify habits with sensors. Nevertheless, they have not used the full potential of raw data that could lead to determine the inhabitant's average speed of walk, and indications on his or her current health : exhaustion, abnormal repetitive activity...

In this study, we seek to implement the Floeck and Litz's solution as a work basis in order to suggest other solutions to accurately assess the inhabitant's health condition and detect accidents.

2 Technology

Our database includes data from apartments located at La Runion. Each data is json raw data : each line of the file corresponds to a raising edge or a falling edge. Moreover, they are timed and anonymous.

To be able to use those data, we first developed client-server scripts based on Python and PhP.

3 Analyse of behaviour

Once raw data were processed, an algorithm based on the Floeck and Litz's studies has been developed.An other algorithm was used to simulate the sending of data from an apartment. It allowed us to plot the 'inactivity rate profile' of the inhabitant.

To go further and create new solutions such as an indicator for general deterioration, we needed a much larger database. We decided to keep analysing behaviour in order to create meaningful raw data that we could use to assess the efficiency of our analyse method.

4 Creating raw data

A configurable software was then designed to generate raw data. To create a daily routine that could fit any profile, activities were divided in different elementary actions : going to something, waiting some time, using an object. Each activity is based on a finite number of these part and is being associated with a probability distribution and one or several gauges.

Once a activity is happening it could be still interrupted by an other activity with higher importance and higher probability. The degree of emergency of the activity 'Opening the door' is considered as 'High' where as the one of 'Having dinner' is 'Medium' and for 'Reading a book' it is assessed as 'Low'.

Our method allows to simulate a simple model of habits : it switches between three scenarios and when interrupting with an emergency button, the alarm is triggered within the limit.

5 Conclusion and future work

We developed a method to model the behaviour and activities of one or several inhabitants. We are able to generate meaningful logs that could be analysed with python scripts created before. However, the software still needs to be improved and new indicators are to be found.

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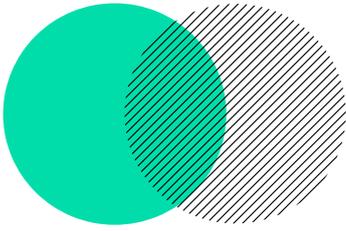
STUDY OF THE CRITICAL BUCKLING LOAD OF WOOD LAMINATES

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Study of the critical buckling load of wood laminates

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ABSTRACT

Background information

Cross-laminated timber (CLT) panel consists of an odd number of wood layers stacked in a symmetric way, where each layer is oriented perpendicular to the previous. Lightweight yet very stiff, CLT also stands out for its low environmental impact. For these reasons, CLT is proving to be a highly advantageous alternative to conventional materials, and consequently becoming increasingly used in construction industry. Nevertheless, more accurate models would enable a better design of CLT structures, thus making them more competitive. Given the buildings' height, CLT panels should be studied under compressive load. Furthermore, since the critical buckling load is close to the failure, the study of the buckling of CLT panels is fundamental to their safe use. Due to the anisotropic behavior, it seems imperative to take transverse shear into consideration, especially on account of the low slenderness of the specimens.

Methodology

The aim of the present work is to investigate the influence of different improvements in predicting the critical buckling load of laminates. In particular, the importance of taking shear stress into account will be evaluated and the relevance of adding a shear correction factor assessed. In order to obtain analytical results, beam models were employed.

Since Timoshenko beam theory takes shear strain into account, it is suitable to describe the behavior of thick beams. Nevertheless, a shear correction factor should be added so as to satisfy the equilibrium equation. Indeed, the simplified beam kinematics leads to inaccurate shear stresses.

The corrected shear stress operator is obtained by imposing the stationarity of the Hellinger-Reissner functional [1] with regard to shear force. To evaluate the sensitivity of the critical buckling load to transverse shear, the critical loads obtained considering shear force as well as a corrected shear stress operator were compared to Euler's load. Moreover, a sensitivity study was performed regarding geometrical and material properties. Finally, our results were confronted with experimental data obtained in [2].

Results

The evolution of the shear correction factor for a three-layer sandwich beam versus both the ratio of the core's Young modulus to the skin's one and the ratio of the core's thickness to half of the total thickness is reported in Figure 1. These results indicate that the shear correction factor is highly variable and reaches its minimum when the thickness ratio is close to 0.8 and the core's Young modulus is the lowest.
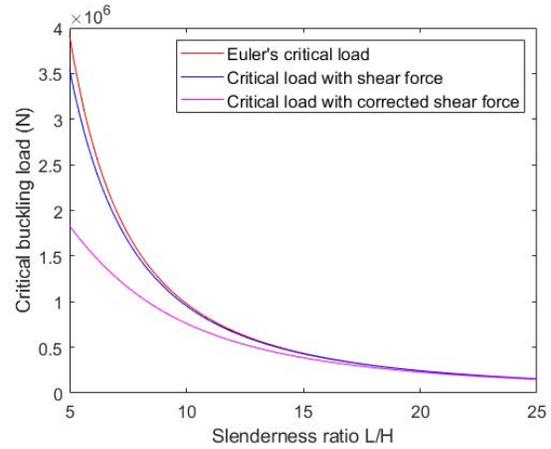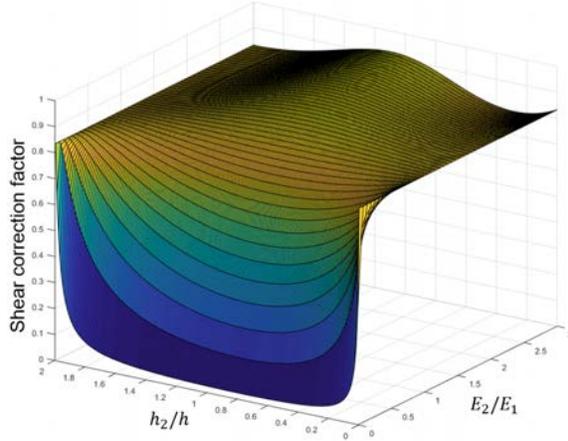

Figure 1: Shear correction factor for a sandwich beam vs. thickness and Young modulus ratios

Figure 2: Critical buckling load for a sandwich beam vs. slenderness ratio with different models

Considering a shear correction factor κ, the critical buckling load for a simply-supported beam taking transverse shear into account is given by :

$$P_c = \frac{<EI>}{L^2}\pi^2\left(1 + \frac{\pi^2}{L^2}\frac{<EI>}{\kappa <GS>}\right)^{-1}$$

According to this equation, a small correction factor could decrease significantly the buckling load. Results of the sensitivity study reveal that the slenderness is the most influential parameter to the difference between the critical loads predicted with considered models. The maximum difference is attained for the lowest slenderness (see Figure 2, obtained with a three-layer sandwich beam, whose characteristics are $E_{core} = 400MPa$, $E_{skin} = 12000MPa$, $h_{core} = 20mm$, $H = 100mm$). After calculating the critical loads for the specimens used in [2], the comparison points out that the effective critical buckling loads were systematically overestimated. Given these results, a model considering an initial defect in the beam has been investigated. In this case, a sideways displacement occurs prior to reaching the critical load, thus inducing a shear force. Therefore, the failure could rather be due to reaching a critical shear stress than a critical buckling load. Currently, applications of fracture mechanics to delamination [3] are being studied since this work will be pursued in internships on both buckling and delamination.

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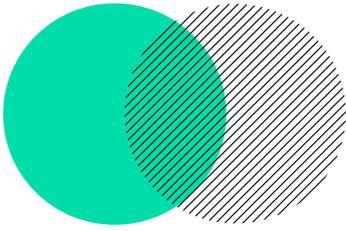
A VIRTUAL/REAL DIALOGUE TO SET UP, CONTROL AND OPTIMIZE A SINGLE CAMERA DIGITAL IMAGE STEREO-CORRELATION TEST

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A virtual/real dialogue to set up, control and optimize a single camera digital image stereo-correlation test

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KEYWORDS: digital image multi-view correlation ; virtual testing ; Optimization ; buckling test.

ABSTRACT

The term "digital image stereo-correlation" (DIC) refers to the non-contacting technique based on the acquisition of digital images of an object which, through image registration, extracts 3D shapes and full-field motion measurements [1]. It is a recent method that relies on a projection model at different viewpoints and their consistency with a single 3D shape. The significant benefits that the full-field character entails as compared to the use of strain gauges make its use very appealing in the industry: the information gathered is global and continuous rather than local and discrete. Its implementation requires at least two cameras that are fixed and each calibrated [2]. The positioning of those cameras is chosen in order to offer a correct angle of view but in practice remains mostly empirical. Such a setup lacks flexibility, may be time consuming and shows no tolerance to imperfection. Tests involving multiple view points are feasible but very demanding.

It is proposed in this study to develop and optimise the stereo-correlation method with a single camera mounted on a robot arm to gain flexibility in its positioning (Figure 1, left). This setup enables the camera to capture the specimen to be tested under a large variety of angles but it leads to new issues, among them the accuracy and the repeatability of the positioning of the robot. Tests are made to assess these characteristics. The robot arm is a source of positioning uncertainties but the position of the camera can be calculated with a dynamic calibration on a target provided for that purpose. It is set up next to the test piece in order to constantly be in the field of view. This calculated position is therefore chosen over the commanded position for the stereo-correlation method.

The test piece was designed to maximise out-of-plane deformations during a tensile test (Figure 1, right). By minimising the bending elastic energy of the surface, an exact analytic solution has been obtained for the out-of-plane buckled geometry as a function of the imposed elongation. The calculation is based on the assumption that the membrane is inextensible. That solution is used as a reference of the 3D displacement of the test piece.

The software *Blender* [3], which can simulate the real experimental environment, is used to shorten the test development time by virtually setting up the test within a 3D environment
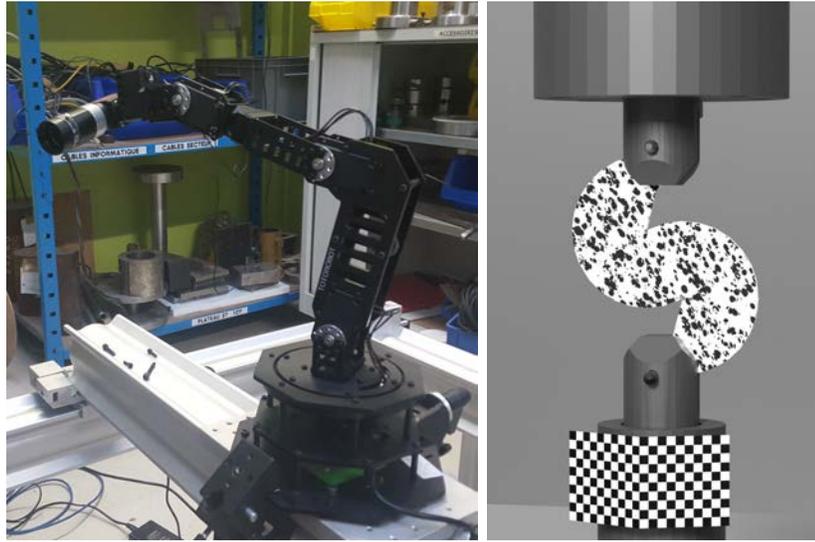
Figure 1: Camera mounted on a robot arm (left) and *Blender*-generated render of the specimen designed in *CATIA* and target for the tensile test (right).

(using the virtual design approach [4]) and then avoiding a trial and error method. A 3D virtual model of the test is generated and the camera positions are optimised, in the software, in order to offer a wide coverage and to minimise the measurement uncertainty. Rather than adjusting the test setups on the real system, they are adjusted in *Blender* offering a faster and more accurate algorithm. The objective criteria that are implemented solve the problem of empirical positioning.

Finally a tensile test was performed to determine the displacement of the test piece. The software *EikoTwin* provides this information from pairs of images taken with the robot arm. These displacements are compared to the analytic solution. This comparison assesses the effect of errors in robot positioning that were calculated with a calibration.

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