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# COMPARISON BETWEEN A FINITE ELEMENT MODEL BASED ON GRAIN ANGLE DETECTION AND FULL-FIELD MEASUREMENTS OF TIMBER IN BENDING

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**ABSTRACT:** Strength grading is dependent of the predictions accuracy of the bending modulus of elasticity and bending strength. Different model based on grain angle measurements have already proved their efficiency for strength grading purpose. This study proposes a way to improve those models thanks to a better understanding of the phenomenon that occur due to the presence of singularities in wood using the comparison of full-field measurements by Digital Image Correlation and a Finite Element Model. First results seem to show that the two strains fields in the longitudinal direction are highly similar and are influenced by the presence of knots. Further results are waited on other specimens and in other directions of the strain field.

**KEYWORDS:** Digital Image Correlation, Finite Element Model, Grain angle, Strength grading

## 1 INTRODUCTION

Timber used for structural purposes must be graded: density, bending modulus of elasticity (MOE) and bending strength have to be predicted thanks to non-destructive measurements.

Hu et al. [1] compared the MOE obtained with an analytical model based on grain angle measurement to digital image correlation (DIC) measurements. They observed that the predicted local MOE match well with the local MOE measured by DIC in some region of the board, but not in other regions. The causes may be clear wood MOE longitudinal variation and/or knot clusters in the longitudinal direction that induce strains that cannot be taken into account in their Euler-Bernouilli based model.

To overcome this limitation of analytical model, in the present study a finite element model based on local grain angle measurement is proposed and compared to DIC.

## 2 MATERIALS AND METHODS

### 2.1 SAMPLING

A plain sawn Douglas fir board of a cross section of 40x100 mm and a length of 3 m is selected for its knottiness. As a plain sawn board, its wider face represents the longitudinal-tangential (LT) plane.

### 2.2 NON-DESTRUCTIVE MEASUREMENTS

#### 2.2.1 Modulus of elasticity estimation

The board's MOE on a global level is estimated using its relation with the boards' resonance frequency under longitudinal vibration. The MOE is then calculated using equation (1) with $\rho$ the density, $L$ the length and $f$ the first natural frequency under longitudinal vibration.

$$MOE = 4\rho f^2 L^2 \quad (1)$$

#### 2.2.2 Grain angle measurement

The grain angle is measured using the tracheid effect, by projecting a dot line laser on the surface of the board. Due to the wood's anisotropic light diffusion properties, the observed pattern on board's surface is elliptic. The ellipses main axis is oriented in the same direction as the fibre orientation. The measurement is conducted on the two wide faces of the board.

### 2.3 DESTRUCTIVE TESTS

Four point bending tests have been performed according to EN 408 [2] using a distance equal to 18 times the specimen's height between the support and 6 times between the loading heads (i.e. respectively 180 cm and 60 cm). As board's length was 3 m, the longitudinal position was chosen in order to have the more knotty area between the two central loading heads. The test was then conducted in order to obtain the local MOE as defined in EN408 and the modulus of rupture.

The bending test was filmed with a 12 bits CCD camera in the central part in pure bending between the loading heads. The observed area of the board was 400x2048 pixels, corresponding approximately to 10x51 cm. This part of the boards was painted with a speckle pattern in order to performed digital image correlation. 7D digital

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correlation software was used [3] with a size of the zone of interest (ZOI) fixed at 10 pixels. To avoid the apparition of numerical noise, a smoothing of the displacements is applied thanks to a moving average in a zone of three ZOI around the smoothed ZOI. The Green-Lagrange deformations were then computed by differentiation of these full displacement field (Figure 1b).

### 2.4 FEM MODEL

The finite element model developed in this study simulates the four point bending test in two dimensions (i.e. under plane stress conditions). Four nodes elements have been used, each element has its own elementary stiffness matrix depending of the local grain angle measurement.

Firstly, the elementary stiffness matrix, without considering the local grain angle, is calculated using relationships between $E_L$ and other elastic constant as in [4]: $E_T$ is considered equal to $E_L/20$ and $G_{LT}$ to $E_L/12.8$ and the Poisson's ratio $\nu_{LT}$ is considered constant and equal to 0.45. $E_L$ is taken equal to the MOE measured with the vibrational method described previously.

Secondly, to take into account the local grain angle orientation ($\theta$) at the element location, the elementary stiffness matrix is transformed using equation (2):

$$[\bar{C}] = [T]^{-1}[C][T^t]^{-1} \tag{2}$$

with

$$C = S^{-1} = \begin{bmatrix} 1/E_L & -\nu_{LT}/E_L & 0 \\ -\nu_{LT}/E_L & 1/E_T & 0 \\ 0 & 0 & 1/G_{LT} \end{bmatrix}^{-1}$$

and

$$T = \begin{bmatrix} \cos^2\theta & \sin^2\theta & 2\sin\theta\cos\theta \\ \sin^2\theta & \cos^2\theta & -2\sin\theta\cos\theta \\ -\sin\theta\cos\theta & \sin\theta\cos\theta & \cos^2\theta - \sin^2\theta \end{bmatrix}$$

As stated earlier, the local grain angle is available on the two wide faces of the board; it has been chosen to define the final elementary stiffness matrix as the mean of those calculated on each faces. By taking into account the same longitudinal position of the loading heads in the model as in the experimental test, it is possible to compare the strain fields obtained by full field measurement and modelling.

## 3 RESULTS

The comparison on the selected board is given in Figure 1 for the longitudinal strains. The knots can be observed in Figure 1a which shows the real photography of the board between the loading heads. Those knots are responsible of the observed perturbations on the longitudinal strains both in Figure 1b (obtained by DIC) and Figure 1c (obtained with the FEM model). Those strain fields are similar both quantitatively and qualitatively. Interestingly, the higher strains are located in the same region around the knot, where the grain angle is the most disturbed. This observation supports the base principle of the model that relies on grain angle measurement.

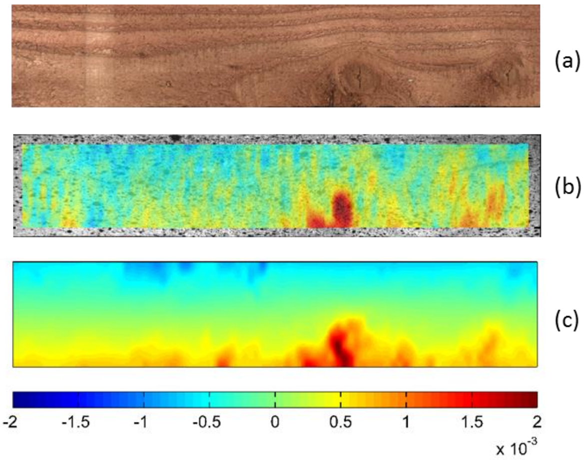


***Figure 1:*** ***From top to bottom: photography of the board*** *(a)*, ***longitudinal strains obtained with DIC*** *(b)* ***and longitudinal strains obtained by the FEM model*** *(c)* ***for a total load equal to 1kN.***

## 4 CONCLUSIONS

The comparison of DIC and an FEM model based on grain angle measurements gives satisfying results on the longitudinal strain on this particular board. Further results are waited on other boards and in other directions of the strain field. It is expected that the use of a finite element model can give better results in the case of more complex knot geometry than the analytical model of [1] and/or help to understand the limits of grain angle measurements to predict the MOE.


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