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Identification of orthotropic elastic properties of wood by a synthetic image approach based on digital image correlation

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Abstract — This work aims to identify orthotropic linear elastic constitutive parameters of *Pinus pinaster* Ait. wood through the Finite Element Model Updating (FEMU) methodology. The approach is validated using both FE and synthetic image data. In the latter, digital image correlation is carried out on synthetic images deformed according to a 2D FE model. A systematic comparison is carried out. The identifiability for the four orthotropic material parameters on the radial-tangential (RT) plane is discussed regarding robustness and relative errors.

Keywords — Full-field measurements, DIC, Synthetic images, Parameter identification, FEMU, Wood

Introduction Wood and wood-based products have been gathering interest due to policies of sustainability and green economy. The mechanical properties of wood are to be measured along the three orthotropic material directions, longitudinal (L), radial (R) and tangential (T). The experimental characterisation, however, poses several challenges due to the inherent hierarchical, heterogeneous and anisotropic modelling behaviour of such biological materials.

Due to recent progress on digital technologies, there has been an exponential growth in the use of novel testing methodologies coupling full-field measurement techniques, such as digital image correlation (DIC) [1], which are capable of providing full-field data. To take advantage of such kinematic fields over a whole region of interest, novel inverse identification method has been proposed [1].

This work adresses the characterisation of radial-tangential (RT) orthotropic elastic properties of *Pinus pinaster* Ait. wood, being modelled as a linear elastic, homogeneous and orthotropic material, based on 2D DIC and Finite-element model updating (FEMU) method using: (i) a FE-based and (ii) a synthetic image-based approaches.

Methods Wooden specimens were cut from a *Pinus pinaster* tree on the RT plane using two (0° and 60°) off-axis angles, with nominal dimensions of 20.5(R)$\times$10.5 (T)$\times$4.5(L) mm^3. Uniaxial compression test were carried out under quasi-static loading conditions. The experimental tests were coupled with 2D DIC in order to measure full-field data and the load was measured by a load cell. A speckle pattern was applied to the surface of the specimens by means of an airbrush, with suitable size, isotropy and contrast.

DIC setting parameters have a relevant impact on the full-field measurements, in particular, in the presence of heterogeneous fields generated by the material meso structure. As such, the selection of these parameters is a key issue regarding this technique [2]. The DIC setting parameters were chosen taking into consideration a parametric analysis carried out on MatchID DIC software, using the Performance Analysis module: Subset size - 17; Step size - 5; Correlation coefficient - ZNSSD; Interpolation order - Bicubic splines; Shape function - Quadratic; Strain window size - 9; Strain interpolation - Q4; Strain convention - Green-Lagrange.

Results The identification process was performed using FEMU, through the minimization of an objective function considering the difference between reference and iterative strain fields and applied load. Firstly, to validate this methodology, a FE-based approach was developed using a FE model with the DIC experimental boundary conditions and reference properties for *Pinus pinaster*. Secondly, a synthetic image-based approach was used. The synthetic images were built using nodal displacement from the reference FE model (with reference properties), further being processed by the DIC alghorithm. Similarly, the full-field measurements and load were used on the identification process using FEMU.

The convergence of the identified parameters to the reference values is shown in figure (1), while the identified values and the error involved in this methodology is summarised in table (1).

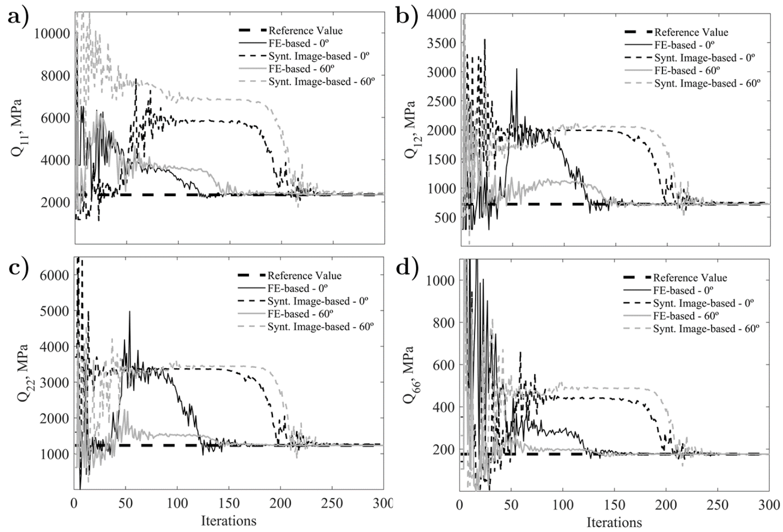


Figure 1: FEMU results for 0° and 60° RT oriented specimens: (a) Q_{11}; (b) Q_{12}; (c) Q_{22}; (d) Q_{66}.

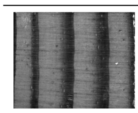
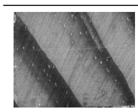
			Q_{11} (MPa)	Q_{12} (MPa)	Q_{22} (MPa)	Q_{66} (MPa)
Reference parameters			2335.68	723.01	1233.81	176.00
	FEA-based	Id. Value	2335.68	723.01	1233.81	176.00
	Synthetic image-based	Id. value	2355.18	750.08	1267.86	175.08
		Error (%)	0.84	3.74	2.76	0.52
	FEA-based	Id. value	2335.73	723.02	1233.86	176.00
	Synthetic image-based	Id. value	2428.39	734.33	1233.79	175.33
		Error (%)	3.96	1.57	0.00	0.38

Table 1: Parameter identification: 0° and 60° RT specimens based on FEMU.

Discussion and Conclusion The proposed FEMU methodology proved to be effective in the identification of the four RT orthotopic elastic parameters. The integration of the DIC measurement chain in the identification approach by means of synthetic images yielded a maximum relative error under 4%. The Q_{66} parameter is well identified in both FE-based and synthetic-based approaches and for both 0° and 60° orientations, with a maximum error of 0.52 %. However, it is noted that Q_{11} property was better identified using the 0° specimen while the Q_{22} and Q_{12} identifications showed to be better on the 60° specimen, which suggests that there might be a dependency on the off-axis angle and the identifiability of certain material parameters. There are various uncertainties that can affect this error, such as the DIC setting parameters. An extension of this approach to experimental data is currently under analysis.

References

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