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LOCAL STIFFNESS OF SOFTWOOD BASED ON MICRO- AND MACRO-SCALE COMPUTED TOMOGRAPHY

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ABSTRACT

Wood is a discontinuous cellular structure on a microscopic scale, but its mechanical behaviour resembles a continuum on a macroscopic scale. The structure of both domains can be studied by X-ray computed tomography (CT). A challenge for accurate CT-based models of wood is to set the values of the orthotropic stiffness tensor locally based on density. Micro-CT scans under in-situ loading may be used to estimate local stiffness in wood, based on strain fields derived from digital volume correlation. The goal of the present paper is to study how micro-CT scans of clearwood under in-situ loading can be used to predict stiffness locally as a function of the apparent macroscopic density, to improve the fidelity of FE models based on macro-CT scans.

Keywords: orthotropic stiffness tensor, fibre orientation, digital volume correlation, finite element analysis, image analysis, in-situ scanning.

INTRODUCTION

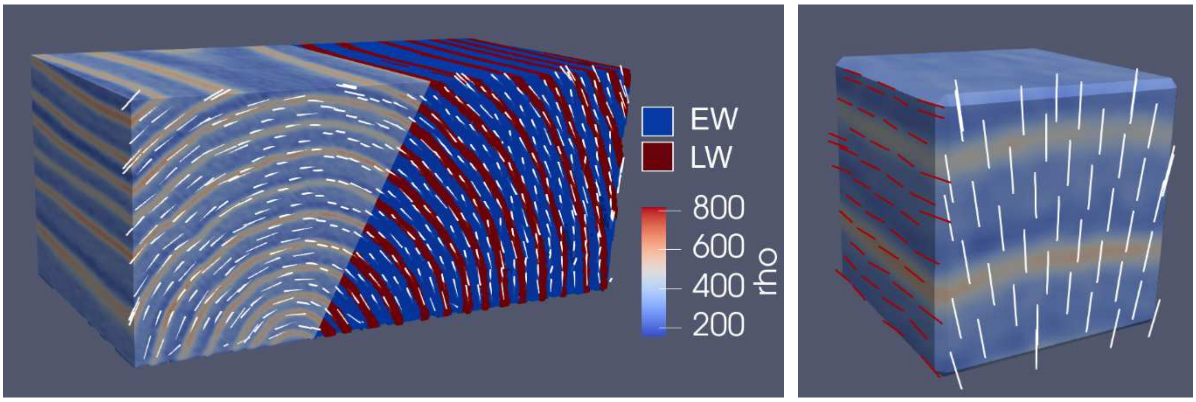
Wood is a cell-based composite structure with large natural variation. To predict the mechanics of an individual piece of wood requires detailed information on its internal structural features. On a *microscopic* scale, the cellular structure of wood looks *discontinuous*. For softwoods, the dominant cells are tracheids, which behave transversely isotropic, i.e. stiffer and stronger along their elongation than perpendicular to it. Their mechanical properties vary both on the micro-scale (cell wall thickness in early- and latewood or knots) and on even smaller scales, e.g. microfibril angles and chemical composition. In clearwood, tracheids are mostly oriented along the trunk, and they are interwoven with a smaller number of ray cells which are oriented perpendicular to growth surfaces, i.e. radially in a trunk. On a *macroscopic* scale, starting from the size of a growth ring (1-5 mm), the distinction between single cells dilutes and the collective behaviour of the arrangement of tracheids and rays resembles a *continuum* with orthotropic properties with longitudinal, radial and tangential material directions (Dinwoodie, 2000). Micro-scale changes in the cell wall thickness emerge as local density changes macroscopically.

X-ray computed tomography (CT) can reconstruct the internal structures of wood, both on the micro and macro scale. Forsberg et al. (2008) used synchrotron radiation to obtain micro-CT images of a small wood sample in-situ under three-point bending and applied digital volume correlation (DVC) to calculate the 3D strain field on a cell level. Huber et al. (2022) used macro-CT images to predict the mechanics of sawn timber in CT-based finite element (FE) models which accounted for growth rings, knots and local fibre orientations around knots. A challenge in CT-based modelling is to predict the stiffness tensor locally. Strain fields obtained from DVC on the micro-scale may be used to estimate local stiffness and could serve the calibration of models of wood based on macro-CT. The goal of the present paper is thus to study how in-situ micro-CT scans of clearwood can be used to predict stiffness locally as a function of the apparent macroscopic density, to improve the fidelity of FE models based on macro-CT scans.

RESULTS AND CONCLUSIONS

The initial specimen of this study was a 77 x 45 x 35 mm^3 piece of clearwood from Norway spruce sawn timber (Figure 1a). The specimen was oven-dried to 0% moisture content (MC). The specimen was scanned in a laboratory macro-CT scanner at a resolution of 0.3 mm in all spatial directions. The specimen was loaded elastically in uniaxial compression in an universal testing machine at the surfaces perpendicular to the longitudinal material direction and the force-displacement curve was recorded. A 10 x 10 x 10 mm^3 sub-specimen (Figure 1b) was cut out of the initial specimen and scanned in a laboratory micro-CT scanner at a resolution of 1 µm in all directions. The sub-specimen was kept at an elevated temperature during scanning to keep a low MC. A second scan was performed in-situ under uniaxial load perpendicular to the longitudinal direction and DVC was used to calculate the resulting strain field. For all CT scans, the local material directions were estimated based on the gradient structure tensor (Huber et al., 2022). Based on the strains, the measured load and the material orientation, the uniaxial stiffness properties were derived in early-, latewood and the transition in between those phases.

The stiffness tensor was subsequently modelled by scaling a reference stiffness tensor for Norway spruce (Dinwoodie, 2000) in linear, power and exponential laws as functions of local density. CT-based FE models were created for the specimens under loading to evaluate the different scaling laws. The results will be presented at the conference.



(a) (b)

Fig. 1 – 3D density image of the (a) initial specimen, including indication of early- and latewood and reconstructed tangential material direction, and (b) sub-specimen, including the radial and longitudinal directions.

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