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Influence of morphology on effective hygro-elastic properties of oak wood

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ABSTRACT

A multi-scale framework is presented for the prediction of the macroscopic hygro-elastic properties of oak wood. The distinctive features of the current multi-scale approach are that: i) four different scales of observation are considered, which enables the inclusion of heterogeneous effects from the nano-, micro-, and meso-scales in the effective constitutive behaviour of oak at the macro-scale, ii) the model relies on three-dimensional material descriptions at each considered length scale, and iii) a moisture-dependent constitutive assumption is adopted at the nano-scale, which allows for recovering the moisture dependency of the material response at higher scales of observation. In the modelling approach, oak wood is considered homogeneous at the macro-scale. The meso-scale description considers the cellular structure of individual growth rings with three different densities. At the micro-scale, the heterogeneous nature of cell walls is described by the characteristics of the primary and secondary cell wall layers. Finally, the nano-scale response is determined by cellulose micro-fibrils embedded in a matrix of hemicellulose and lignin. The oak properties at the four length scales are connected via a three-level homogenization procedure, whereby, depending on the geometry of the fine-scale configuration, an asymptotic homogenization procedure or Voigt averaging procedure is applied at each level to determine the effective hygro-elastic properties at the coarse scale. In addition, the moisture adsorption isotherms at each scale are constructed from a volume-weighted averaging of the moisture adsorption characteristics at the scale below. The computational results demonstrate that the macro-scale moisture-dependent, hygro-elastic behaviour of oak wood is predicted realistically, thereby revealing the influence of the material density, the micro-fibril orientation, and the hygro-elastic properties from the underlying scales. The computed macro-scale properties of oak are in good agreement with experimental data reported in the literature.