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UPSCALING ANISOTROPIC STIFFNESS AND STRENGTH PROPERTIES OF WOOD

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ABSTRACT

Wood strength is highly anisotropic: The material resistance in stem direction is about an order of magnitude higher than that orthogonal to the stem. Obviously, this anisotropy stems from the intrinsic structural hierarchy of the material. Wood is composed of wood cells, which are hollow tubes oriented in the stem direction. The cell wall is built up by stiff cellulose fibrils with crystalline cores and amorphous surfaces, which are embedded in a soft polymer matrix composed of hemicellulose, lignin, extractives, and water. The constituents of the wood cell wall exhibit tissue-independent stiffness and strength properties and, thus, are elementary components of wood. The orientation of cellulose fibrils and tubular holes and the spatial gradation of porosity lead to the anisotropy and the inhomogeneity of the macroscopic material behavior.

The relation between (macroscopic) elastic material properties of wood and physical quantities at lower length scales was successfully expressed by the authors in the framework of continuum micromechanics [1]. We here extend these investigations to tissue-specific anisotropic strength properties in the sense of elastic limit states. Experimental investigations showed that (macroscopic) elastic limit states of wood are frequently initiated by shear failure of lignin in the wood cell wall [2,3]. Macroscopic elastic limit states are governed by strain peaks in the material microstructure, which can be suitably characterized by quadratic strain averages over material phases, being effective for material phase failure [4,5]. This leads to a relation between the local strain at failure of lignin and the corresponding macroscopic strain, depending on the chemical composition and on 'universal' morphological patterns. This allows for estimation of limit surfaces for arbitrary deviation between the principal material and loading directions and for assessment of the relevance of lignin failure for macroscopic strength properties. The micromechanics model needs only species-dependent volume fractions of the universal constituents and tissue-dependent porosity as input, which are easily accessible.

Model validation is based on two independent sets of experimental data: Tissue-dependent stiffness and strength values predicted by the micromechanics model (*'model output'*) on the basis of tissue-independent stiffness and strength properties of the universal constituents of wood (*experimental set I*) for tissue-specific composition data (*experimental set IIa, 'model input'*) are compared to corresponding experimentally determined stiffness and strength values (*experimental set IIb*). Macroscopic stress

states estimated from local shear failure of lignin agree very well with corresponding experimental data. This expresses the paramount role of lignin as strength-determining component in wood.

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