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Micromechanical modelling of degradation processes in wood

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Deterioration activity of fungi plays a major role among the degradation processes of all biological materials in nature and, thus, also for wood. As a consequence of fungal decay, the inherent microstructure and the composition of wood are modified, which causes changing mechanical properties. Herein, we aim to model these structure-function relationships by means of micromechanical approaches. Depending on the fungal species different degradation strategies are followed [1]. While white rot fungi degrade all major wood polymers, brown rot fungi only degrade wood polysaccharides. The mechanical properties of wood are determined by its inherent hierarchical microstructure and composition [2]. Thus, due to changing microstructure and composition, fungal degradation affects the mechanical properties of wood differently, depending on the specific fungus-host combination. Macroscopically loss of stiffness and strength has been reported upon fungal degradation, but its relation to microstructural alterations is still not fully explored [3]. Thus, investigations at the cell wall scale might give enhanced insight into effects of fungal decay on mechanical properties of wood. In order to test for hypotheses on fungal degradation mechanisms and their effects on the wood cell wall stiffness, a multiscale micromechanical model for the estimation of wood stiffness [4], using the framework of continuum micromechanics, is applied. This model is extended accordingly to be able to predict stiffness of the S2 layer and the middle lamella and to account for degradation specific processes [5]. Experimentally determined earlywood and latewood specific composition and microstructural data of Scots pine sapwood, degraded by either brown rot or white rot fungi serve as input data [6]. The model predictions for the cell wall stiffness will be expressed in terms of a predicted indentation modulus M_{PRED}, using anisotropic indentation theory [7], to be able to compare model predictions with experimentally observed indentation moduli M_{EXP} [6].

In case the observed mass loss during fungal decay is considered via cell wall thinning, i.e. no porosity evolves in the cell wall, M_{PRED} lies well within the reported range of M_{EXP} for both cell wall layers, namely the S2 layer and the middle lamella. This is exemplarily shown for brown rot in Figure 1, but is also true for white rot (not shown). The fact that the experimentally observed increase of M_{EXP} in the middle lamella during degradation could be predicted by the model can be explained by the decrease of pectin, which is a low stiffness compound in the middle lamella. In the S2 layer, comparison of experimental and numerical results between different degradation stages is more difficult due to the dependency of M on the microfibril angle (MFA) [7]. Samples with similar MFA showed also increased M_{EXP} during degradation [5] and these trends could also be depicted by the model [6]. In case the mass loss is considered via cell wall porosity, the micromechanical model distinctly underestimates M_{EXP}. Thus, we suggest that no mechanically relevant porosity evolves during fungal degradation. At first glance, it seems that increasing stiffness of the cell wall during degradation contradicts the observed decrease in stiffness at the macroscopic scale [3]. However, due to a mass loss, there is less but probably stiffer bulk material in the cellular wood, which macroscopically gives an overall decrease [5].

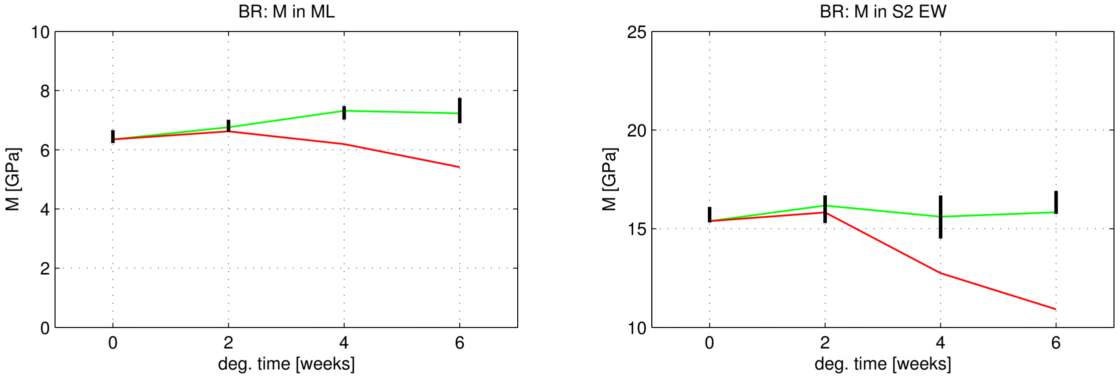

Figure 1: Model predicted indentation moduli M_{PRED} over degradation time (brown rot) in the middle lamella (left) and in the S2 layer of EW cell walls (right); green: modelling without porosity, red: modelling with porosity, black: range of experimentally determined M_{EXP}.

In addition to cell wall porosity, also other hypotheses related to degradation strategies of fungi and corresponding changes in the microstructure, including stiffening of individual polymers, e.g. lignin, changes in cell wall crystallinity during decay, and the influence of the MFA on M_{PRED} were tested by means of the micromechanical model [5].

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