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IDENTIFICATION OF IN SITU LIGNIN STRENGTH BASED ON MICROPILLAR COMPRESSION AND MICROMECHANICAL MODELING OF WOOD CELL WALLS

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Many biological materials feature a hierarchical architecture with remarkable mechanical properties combining low weight with both toughness and strength. In order to better understand the mechanisms leading to this unusual combination of traits, structure-property relationships have to be assessed on all length scales. Wood is such a hierarchical material. Its cell walls feature semi-crystalline cellulose fibrils embedded in an amorphous polymer network that are aligned at an angle to the cell main axis resembling a fiber reinforced composite.
Continuum micromechanics can predict mechanical behavior on a higher length scale based on the composition, microstructure, and properties of the individual phases. However, the experimental data for yield properties at the microscale is sparse making an identification of phase properties and validation of yield predictions difficult. Specifically, the lignin shear strength in wood remains to be measured, which proves to be difficult due to the intermixed nature of the polymer network and the small length scales involved. Inverse determination of phase properties from experiments on a higher length scale is possible using continuum micromechanics, if composition, microstructure, and boundary conditions are sufficiently well understood. An experimental setup for micromechanical testing with well-defined boundary conditions is micropillar compression. Micron sized pillars are eroded from bulk cell wall material using a focused ion beam and compressed uniaxially using a flat punch indenter. Due to the mostly homogeneous and uniaxial loading conditions, the experimental data may be combined with micromechanical modeling to access phase properties at a lower length scale.

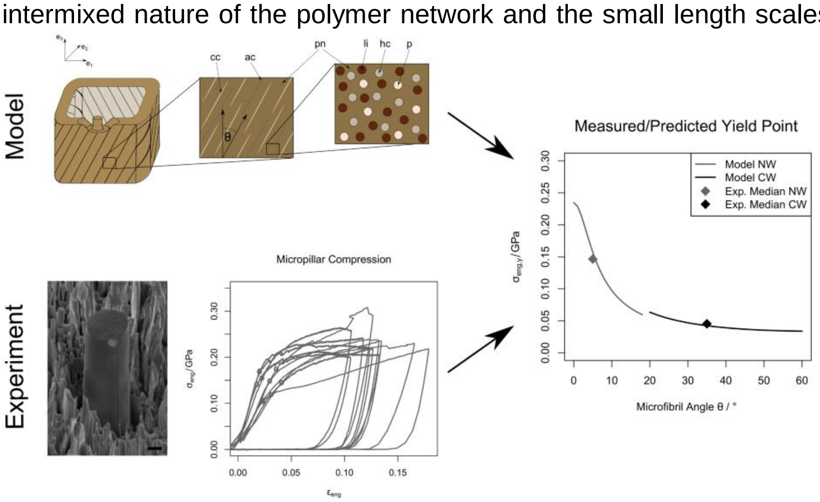

Figure 1: A combination of continuum micromechanics and micropillar compression allows measuring the yield strength of lignin. cc & ac - crystalline & amorphous cellulose, pn - polymer network, li – lignin, hc – hemicellulose, p – pore space

The aim of this work was to perform micromechanical tests leading to homogeneous and uniaxial stress fields on a single cell wall layer for normal (NW) and compression wood (CW) of Norway spruce. Additionally, the chemical composition was determined by wet chemical analysis and the cellulose fibril angle distribution was measured using wide angle XRD. Subsequently, a continuum micromechanics model for elastic limit states was used to explain the measured properties and to relate them to species-independent phase properties on a lower length scale, more specifically the lignin yield stress.
The study demonstrates a novel approach for measuring phase properties of inhomogeneous materials by a combination of continuum micromechanical modeling and micropillar compression experiments inside a scanning electron microscope under controlled conditions. The mostly homogeneous and uniaxial stress state in this experimental setup allows to identify yield stresses at the microscale and to assess phase properties on a lower length scale with high accuracy and reproducibility if the microstructure and the inelastic deformation mechanisms

of the tested material are well understood. This could be an interesting approach for validating multiscale models or identifying phase properties for other nanostructured materials in the future.