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TENSILE PROPERTIES OF NATIVE WOOD FIBRES

***Michaela Eder[1], Stefanie Tschegg[2] and Ingo Burgert[1]**

[1] Max-Planck Institute of Colloids and Interfaces, Dept. of Biomaterials
D-14424 Potsdam
michaela.eder@mpikg.mpg.de;
www.mpikg.mpg.de

[2] BOKU – Dept. of Material Sciences and Process Engineering, Peter-Jordan-Straße 82, A-1190 Wien
stefanie.tschegg@boku.ac.at;
www.boku.ac.at

[3] Max-Planck-Institute of Colloids and Interfaces, Dept. of Biomaterials
D-14424 Potsdam
ingo.burgert@mpikg.mpg.de
www.mpikg.mpg.de

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ABSTRACT

Biological materials are built using a minimum of resources, they are hierarchically organised and show outstanding mechanical properties when related to their densities [1, 2]. Five hierarchical levels can be identified in wood: the integral level of the entire trunk, the macroscopic and microscopic level dealing with tissue and cell structures, the ultrastructural level of cell wall organisation and the molecular level [3]. The different levels cover length scales from up to 100 meters to a few Angström. Changes at any level of hierarchy are reflected directly in the mechanical response of the “material” wood when subjected to loads. Contributions to a better “understanding” of such biological materials require studies at different length-scales. Within the scope of the present work, structural and mechanical properties were studied at the micro- and ultrastructural level. For this purpose single wood cells (also termed “fibres”) were isolated mechanically with the aid of very fine tweezers in order to not modify the cell wall assembly. The measured tensile properties of the single cells were discussed with respect to structural differences and varying moisture contents. In determining the material properties at the micro- and nanoscale it was also intended to provide raw data to a database which can serve as a basis for simulations of material behaviour. for further material simulations. Attempts for integrating the micro- and nanostructure into models which should finally predict the macroscopic behaviour of wood are a matter of interest e. g. for the construction industry [4]. Furthermore, the data concerning properties and mechanics of the raw material 'wood fibre' might be of interest for fibre-related industries, e. g. pulp and paper, fibreboard.

In a first step, mechanical and structural properties of wood cells of adult Norway spruce were investigated. To examine the changing material properties of wood across a growth ring at high resolution, single wood fibres were isolated from the earlywood towards the latewood of one tree ring. Mechanical properties (uniaxial tensile tests) and structural parameters (fibre size and shape, microfibril angle) were discussed with respect to the local positions of the fibres in the growth ring. It was shown that the mechanical properties of the fibres were changing gradually from early- towards

latewood. However, the stiffness, calculated on the basis of cell wall cross sectional areas, remained almost unchanged across the growth ring. Mainly the cell size varied during the growth period to facilitate water transport or mechanical stability and changes in cell wall stiffness played a minor role. In contrast, the ultimate stress of the cell wall was almost twice as high for latewood as for earlywood. Observed minor changes in the cellulose microfibril angle could not explain the drastic changes in ultimate stress between early- and latewood completely.

To shed light onto this remaining question, *in-situ* experiments in an Environmental Scanning Electron Microscope (ESEM) were performed. The ESEM is well known to be a powerful tool in biomaterials science due to its applicability in observing the biological sample in a wet state at high magnifications. For the study of the deformation behaviour of wet single wood fibres a specially designed tensile testing stage with a cooling device was built. The experiments revealed differences in the deformation behaviour of the thin-walled early- and the thick-walled latewood fibres: tension buckling appeared to be a common failure mechanism in thin-walled cells. With increasing cell wall thickness, tension buckling became less important for crack initiation, whereas structural weak points such as pits or pitfields were more relevant.

In a second step the influence of moisture content on the stiffness of the single fibres with different microfibril angles was studied. From literature it is well known that the elastic modulus of bulk wood is decreasing with increasing moisture content [eg. 5], and likewise the fracture toughness is decreasing [6]. The data of our single cell experiments showed, that the decrease in stiffness of the fibres with high microfibril angle compared to the dry cells was more pronounced than for the cells with a lower microfibril angle.

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