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NANOINDENTATION AND MICROMECHANICAL MODELING TO EXPLORE THE MECHANICAL PERFORMANCE OF DETERIORATED SOFTWOOD

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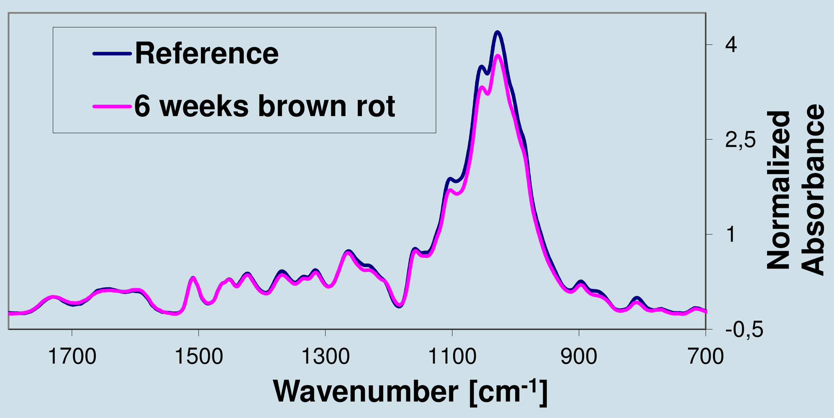
Motivation

The aim of the presented project is to further enhance the current understanding of the effects of fungal decay on the wood microstructure and, in consequence, on the micromechanical material behavior of wood. There are two main types of basidiomycete fungi degrading wood, causing either white rot or brown rot. Brown rot fungi degrade wood polysaccharides, leaving behind a lignin rich microstructure. White rot fungi are able to degrade all major wood components. The starting point of this project are Scots pine (*Pinus sylvestris* L.) sapwood samples, degraded by one fungus causing white rot (*Trametes versicolor*) and one fungus causing brown rot (*Gloeophyllum trabeum*) from an earlier study [1]. Out of this set, undegraded reference samples and white rot and brown rot samples, exhibiting a mass loss of 1%, 5% and 10%, are considered. As a novel aspect, the growth ring specific combination of mechanical with chemical and spectroscopic test results will enable us to elucidate the interrelation of structure and micro-mechanical performance of degraded wood. These relations will also be formulated by means of a micro-mechanical model.

Methods – Experimental program and micromechanical modeling

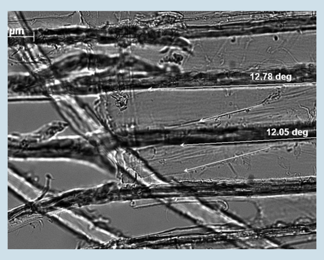
MICROSTRUCTURAL CHARACTERIZATION

FT-(N)IR spectroscopy, FT-(N)IR microscopy, wet chemical analyses



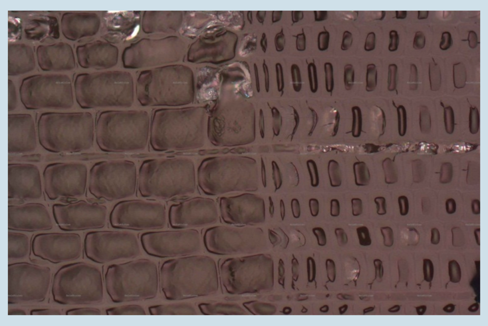
chemical composition: hemicelluloses, lignin, cellulose

Light microscopy



MFA on a thin section

microfibril angle (MFA)



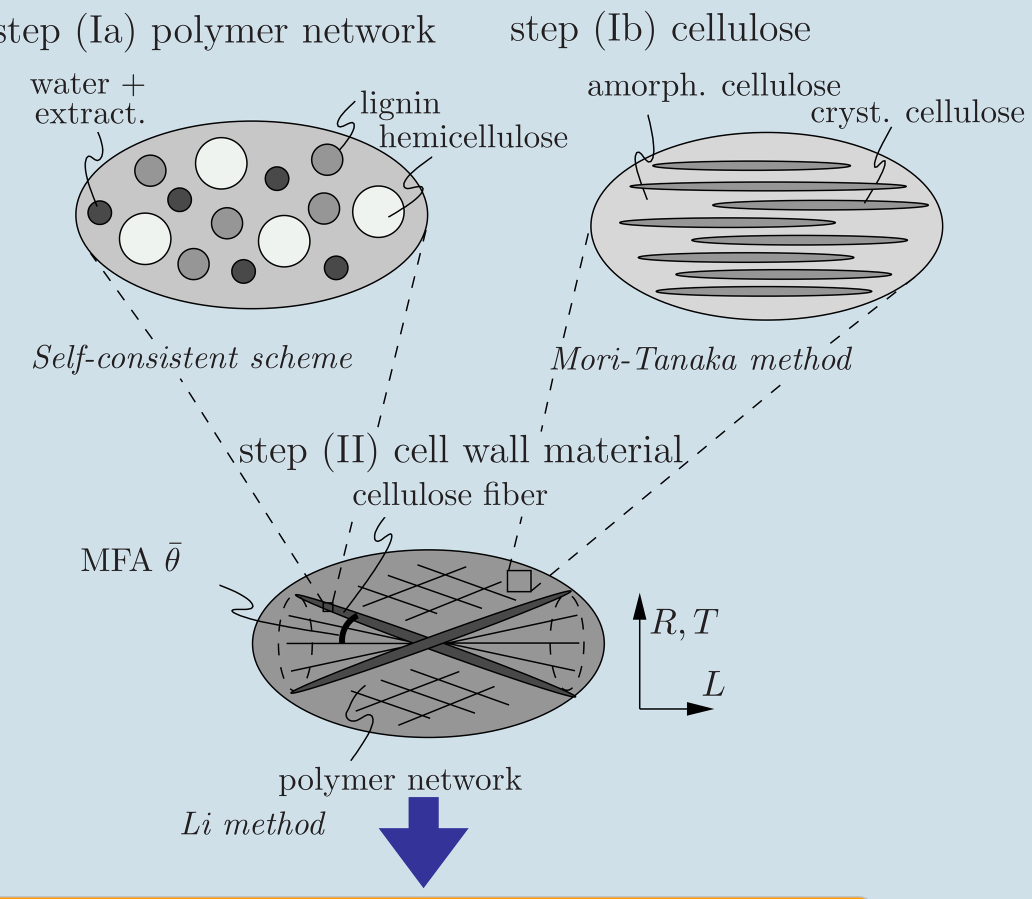
cell geometry from NI sample

wood cell geometry, earlywood and latewood content

Solid wood properties

mass density

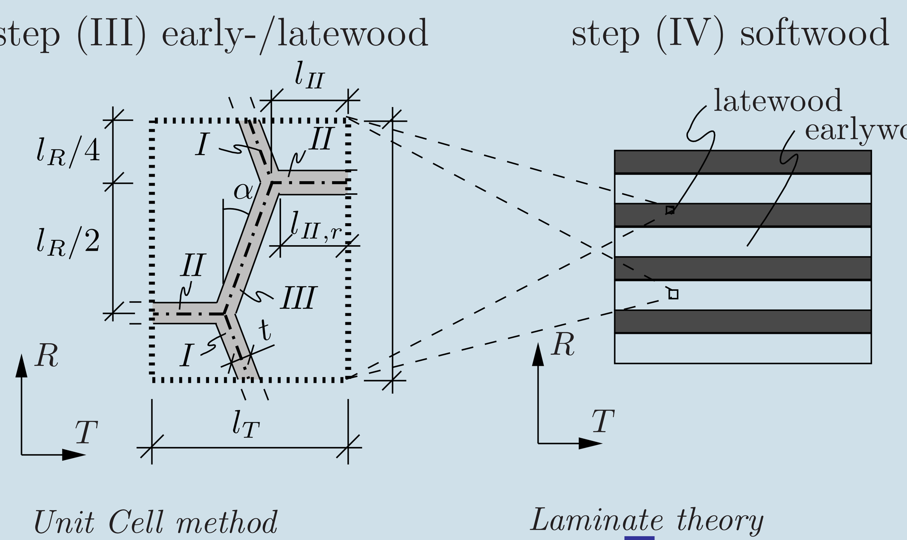
MICROMECHANICAL MODEL [2,3]



predicted cell wall stiffness C^{hom}_{CWM}

Anisotropic indentation theory [4]:
Indentation modulus as function of orientation of cellulose microfibrils and stiffness tensor of the cell wall material:
$M_{pred}=\mathcal{F}(MFA, C_{11}, C_{22}, C_{12}, C_{13}, C_{44})$

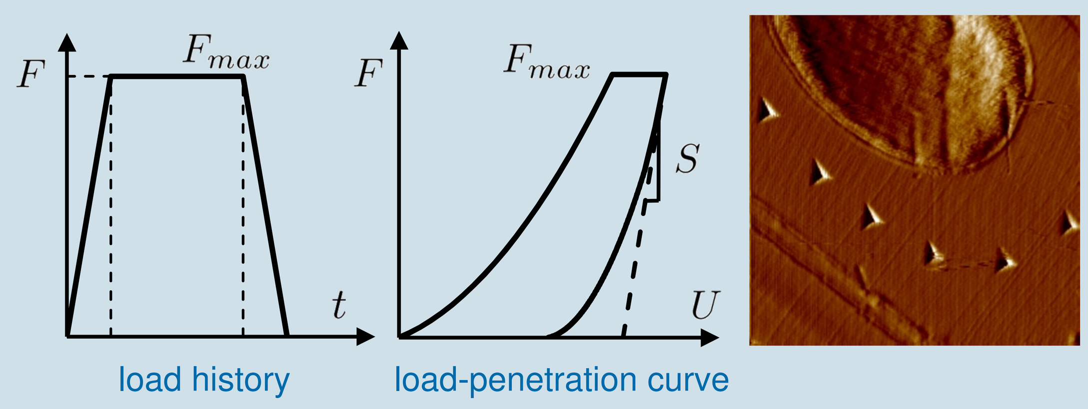
predicted indentation modulus M_{pred}



predicted softwood stiffness C^{hom}_{SW}

MECHANICAL CHARACTERIZATION

Nanoindentation (NI) [5]



from initial slope of unloading curve

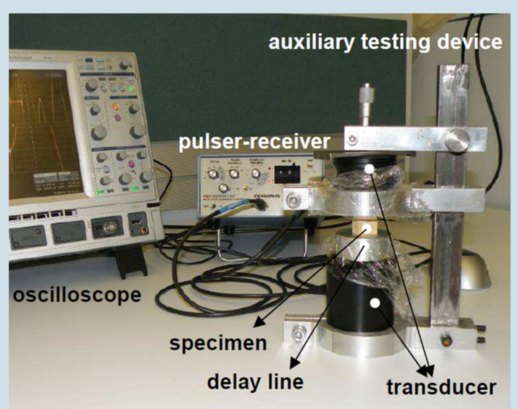
$$S = dF\,/\,dU|_{U=U_{max}}$$
$$M = \sqrt{\pi}/(2\sqrt{A_c})\,S$$

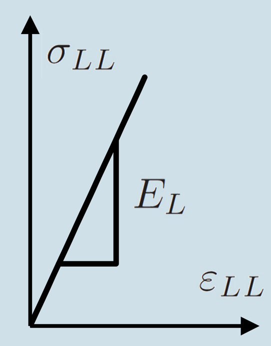
A_c … contact area
U_c … contact depth

experimental indentation modulus M_{exp}

Ultrasonic (US) tests [6]

Quasistatic tensile tests

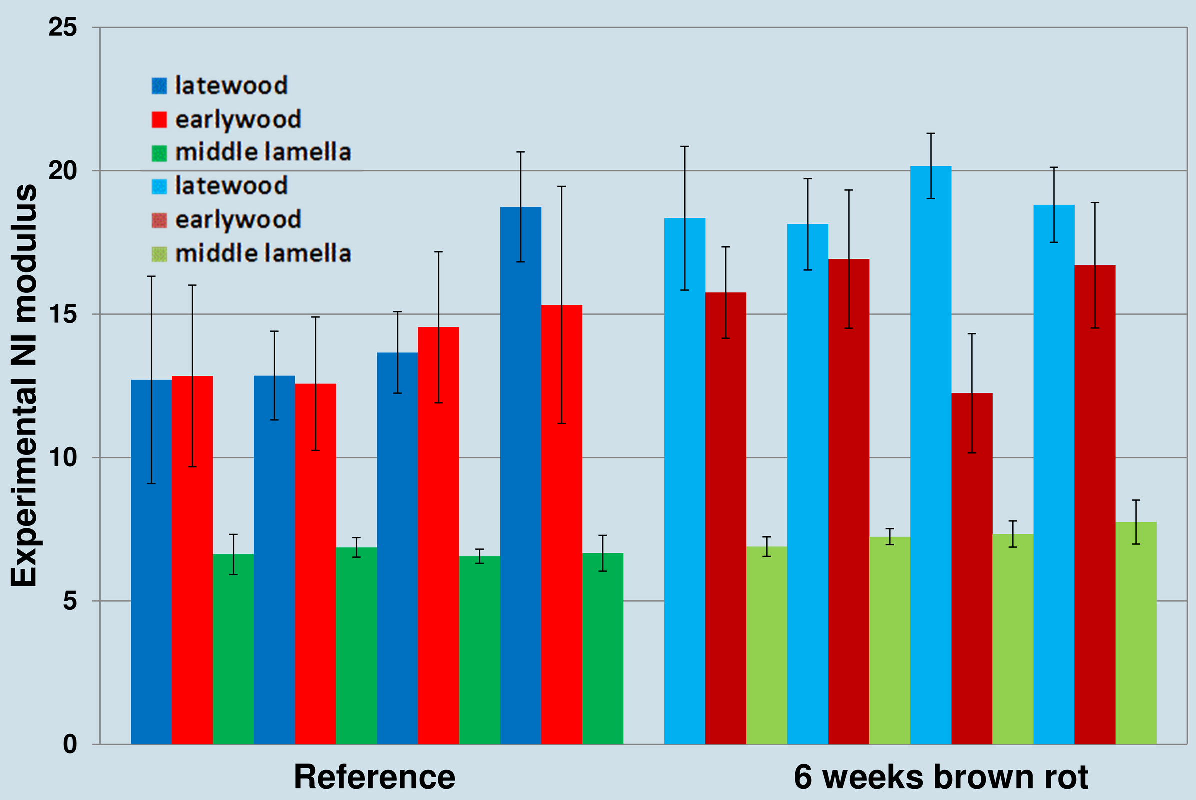




$$v_i = l_i\,/\,t_i$$
$$C_{iiii} = \rho\, v_i^2$$
$$E_L = \Delta\sigma_{LL}\,/\,\Delta\varepsilon_{LL}$$

elastic stiffnesses C_{LLLL}, C_{RRRR}, C_{TTTT} *elastic modulus E_L*

Preliminary Results



Currently, reference samples and samples after six weeks of brown rot degradation have been tested by means of nanoindentation. It can be seen that without further information about sample specific MFA and chemical composition, it is not possible to draw conclusions only from NI results.

Using ATR-FTIR spectroscopy combined with multivariate data analysis, the degradation state of the brown-rot samples (relative to the reference) could be determined. Degradation was shown to be uneven and became significant in some samples already at 1% mass loss. Brown-rot spectra indicated the depolymerisation of polysaccharides, as well as loss of hemicelluloses accompanied by a relative increase of the lignin content.

Preliminary partial least squares regression models showed good correlation between the FTIR spectra with mass loss and equilibrium moisture content. Some correlation of the spectra was also found with losses of mechanical properties (E_L-, C_{LLLL}- and C_{RRRR}-loss, but not with C_{TTTT}-loss).

References:
[1] Bader et. al. (2011), *IRG/WP 11-40570*
[2] Hofstetter et. al. (2005), *Europ. J. Mech. A/Sol*
[3] Bader et. al. (2010), *Acta Mechanica*
[4] Jäger et. al. (2011), *Composites: Part A*
[5] Oliver&Pharr, (1992), *J Mat Research*
[6] Bucur, (2006), Springer Verlag Wien, Heidelberg, New York

COST Action FP0802 Workshop "Hierarchical structure and mechanical characterization of wood", 24-25 August 2011, Helsinki, Finland