TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

INSTITUTE FOR MECHANICS OF MATERIALS AND STRUCTURES

MOISTURE-DEPENDENT MECHANICAL PROPERTIES OF SOFTWOOD AND HARDWOOD CELL WALLS: A NANOINDENTATION STUDY

L. Wagner†, C. Bos‡,†, T. K. Bader†, J. Eberhardsteiner†

†Vienna University of Technology, Institute for Mechanics of Materials and Structures; ‡Karlsruhe Institute of Technology, Institute for Applied Materials

Motivation

Wood is a **hygroscopic material**. In moist conditions, water is incorporated in the wood cell wall. With **increasing moisture content (MC)** the **macroscopic mechanical properties** of wood are known to **decrease** [1]. However, since other influences on macroscopic mechanical properties of wood, such as mass density, may override the effect of moisture, investigations at the cell wall scale may contribute to an enhanced insight into moisture-mechanics relationships. Wood cells are composed of several different cell wall layers. Of these, the **secondary 2 (S2) cell wall layer** and the **middle lamella (ML)** dominate the macroscopic mechanical properties of wood. The S2 layer can be envisaged as a reinforced polymeric material with inclined cellulose fibrils reinforcing a lignin and hemicellulose matrix and can be assumed to behave transversely isotropic. The ML consists of a lignified pectin network which can be assumed to be isotropic. In order to investigate **mechanical properties of wood cell walls, nanoindentation** has established itself as useful tool in wood science [2,3]. Elastic material properties and the hardness of the S2 layer and the ML can be measured by means of this technique. In this study, wood of two **hardwood** species and three **softwood** species, growing all over Europe, is investigated. Mechanical properties of the S2 layer as well as of the ML are determined at **different relative humidities (RH), i.e. at different MC.** These investigations are expected to deliver new insights into moisture-mechanics relationships of wood.

Material and Experimental Methods

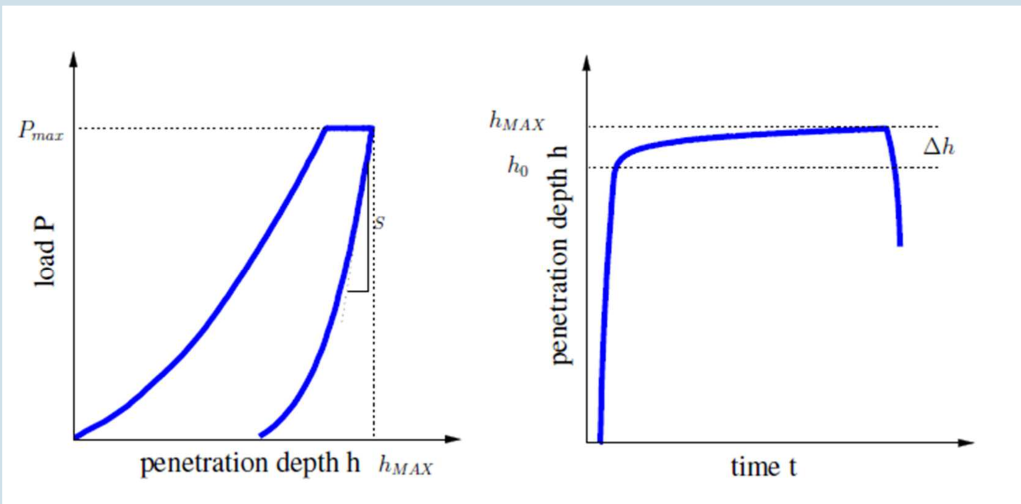
Material [4]

Softwood:
- Scots pine (*Pinus sylvestris* L.)
- Norway spruce (*Picea abies* [L.] Karst.)
- European yew (*Taxus baccata* L.)

Hardwood:
- European beech (*Fagus sylvatica* L.)
- European oak (*Quercus rubor* L.)

Nanoindentation Tests

Indentation in **S2 cell wall layer** of latewood cells and **ML** in-between them at:
- **22°C / 10-40-60-80 % RH** and **under water**, i.e. fiber saturation point (FSP)



Evaluation of nanoindentation tests: [5]

$$S = \frac{\partial P}{\partial h}\Big|_{h=h_{max}}$$

$$M = \frac{\sqrt{\pi}\, S}{2\sqrt{A_C}}$$

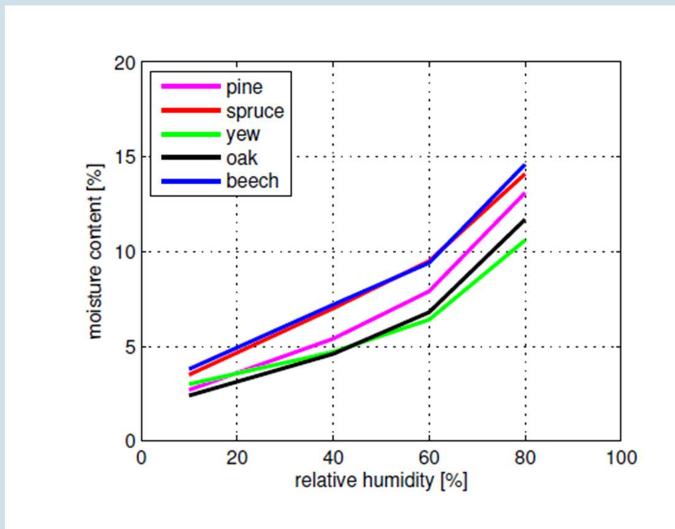
$$H = \frac{P_{max}}{A_C}$$

$$C = \frac{\Delta h}{h_0}$$

A_C… contact area
M… indentation modulus
S… initial unloading stiffness
P… load
h… penetration depth
C… indentation creep
H… indentation hardness

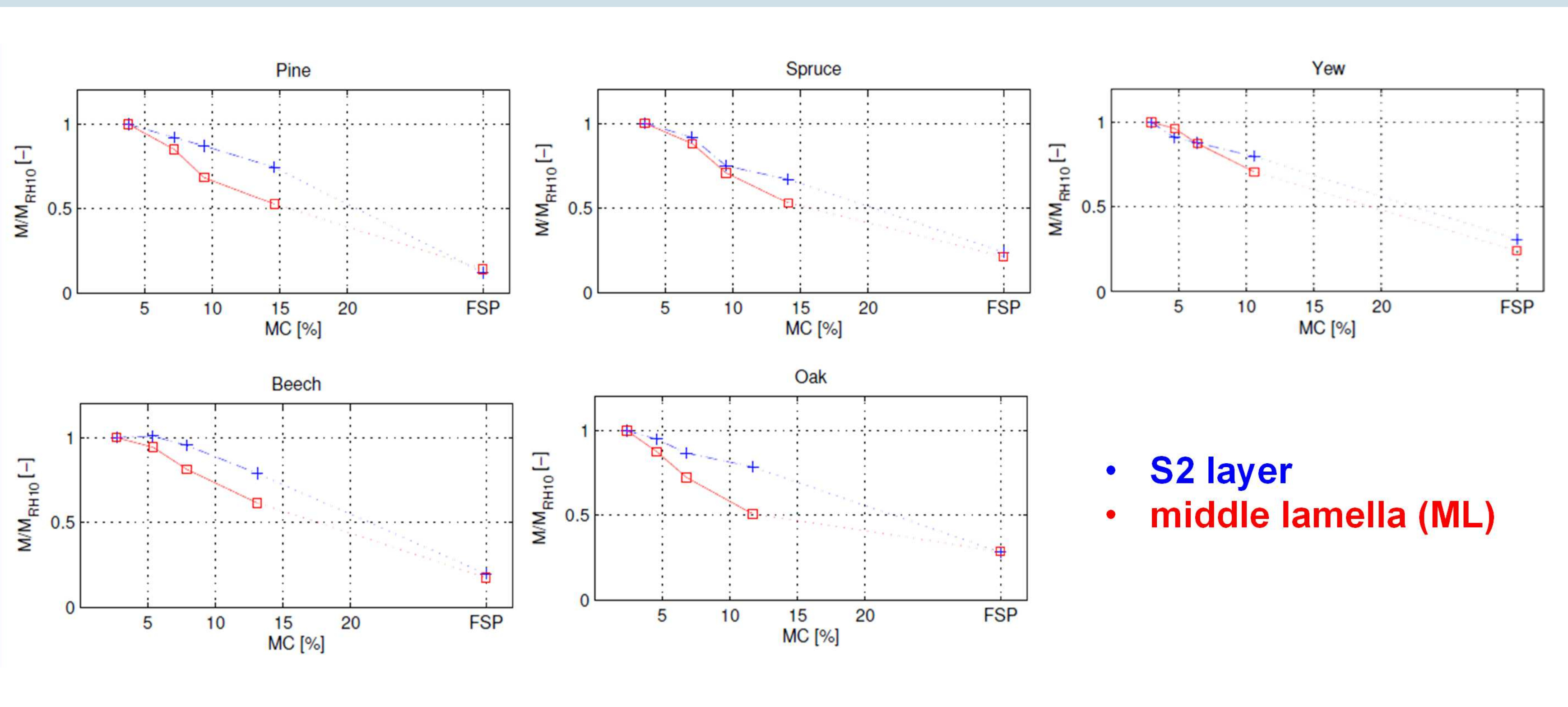
Sorption behavior

Dynamic vapor sorption (DVS) measurements:
•**22°C / 10-40-60-80 % RH**
yields MC at different conditions

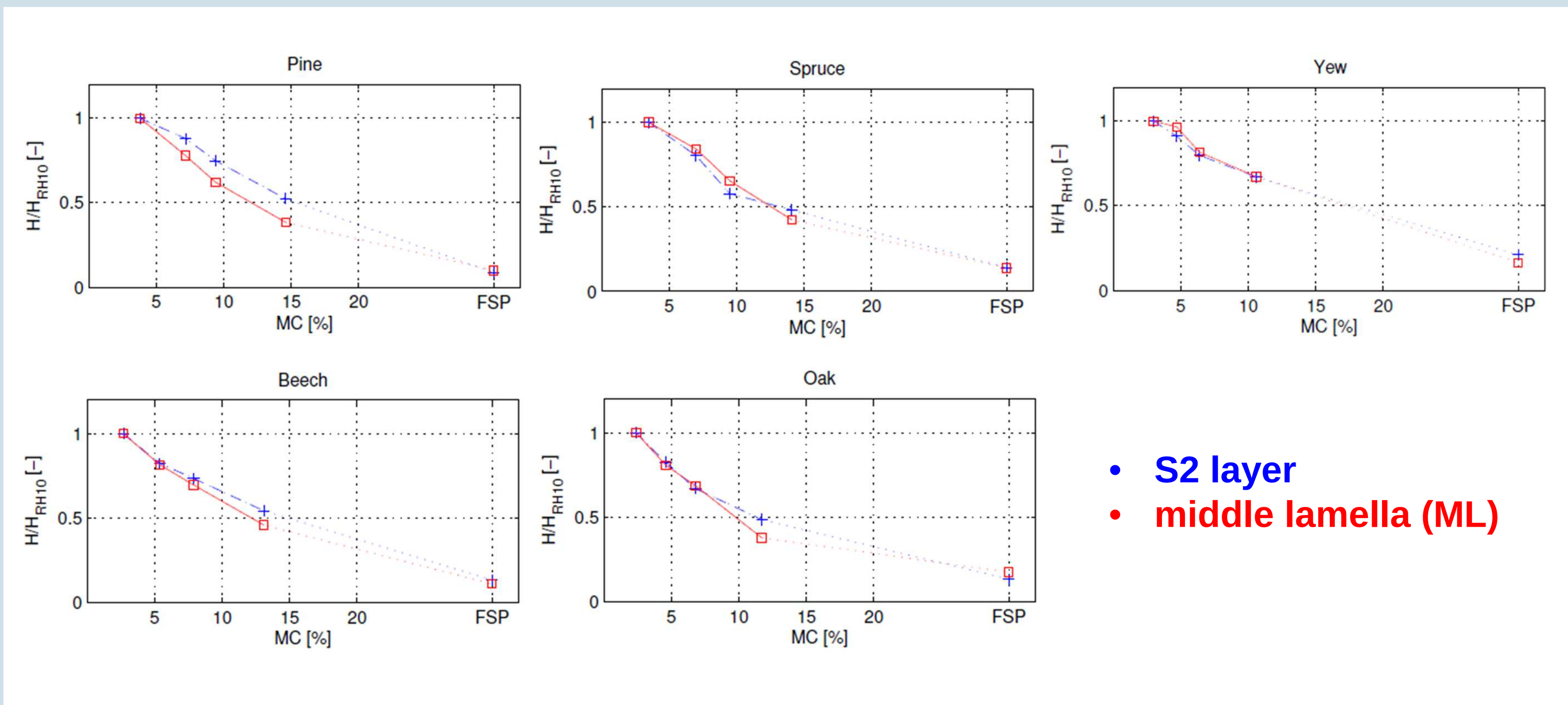


Results & Discussion

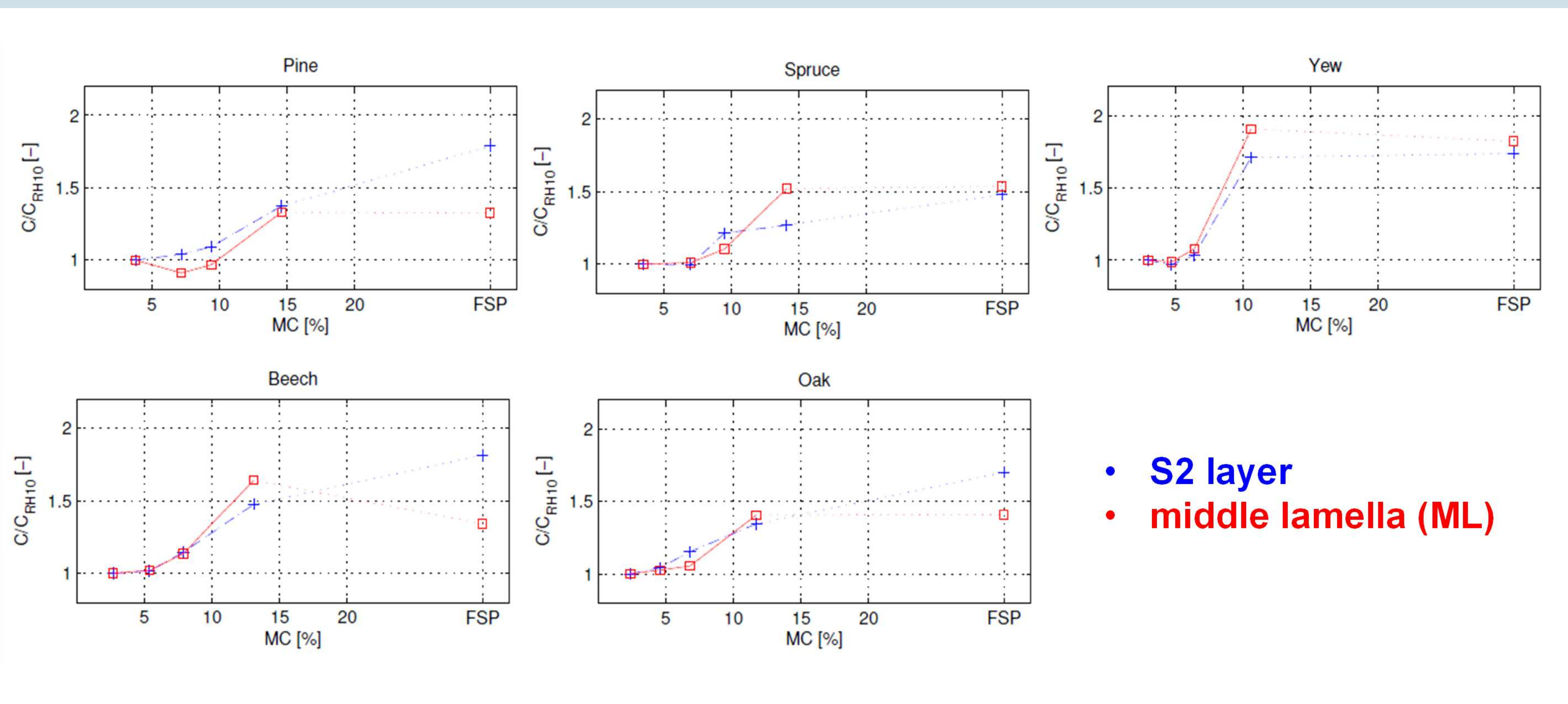
Indentation Modulus



Indentation Hardness



Indentation Creep



Conclusions

All measured properties showed moisture dependent behavior. The **indentation modulus M** initially showed **higher losses** with increasing MC **in the ML than in the S2 layer.** Later at the **FSP**, the losses of M in the ML are again **similar** to those in the S2 layer. For the indentation hardness H no such differences could be observed. Regarding the **indentation creep C**, relatively **constant** values were determined for the ML and the S2 layer **below 10% MC**, whereas an **increase** by 50% **towards higher MCs** could be seen. In the **S2 layer** a **further increase towards the FSP** was detected whereas no such increase was found in the ML. At **lower MCs (<10%)** the **cellulose in the S2 layer** seems to have a **restraining effect**, as reflected in the results of M and C. The similar losses of H in the S2 layer and ML indicates that **H** is **governed by** the properties of the **hemicellulose-lignin matrix.**

References:
[1] Gerhards (1982) *Wood Fiber Sci* 14:4-36
[2] Wimmer et al. (1997), *IAWA J*, 18(1):77-88
[3] Wagner et al. (2013), *J Mat Sci* 49(1):94-10
[4] Wagner et al. (2014) *submitted*
[5] Oliver&Pharr (1992), *J Mat Res* 7(6):1564-1583

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