Study and Analysis of Micromechanical Properties of Timber for Wood Based Applications.

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Abstract

The paper deals with the determination of nano- and micro structural, and micromechanical properties of timber. This was done by means of optical and electron microscopy, atomic force microscopy (AFM) and nanoindentation. These methods can define the parameters of individual phases within a composite, which is important for development of micromechanical models. These can be used for design and optimization of materials, such as various wood-based products. Our study provides information about the micromechanical properties of early and late spruce cells.

***Keywords**:* timber, mechanical properties, atomic force microscopy, nanoindentation, spruce cells

1. INTRODUCTION

Timber is one of the most popular building materials and it has been extensively used since the ancient times. Celtic people successfully built relatively lightweight structures made of timber before the 4th century BC. Nowadays its popularity is still increasing even in developed countries, because it is renewable material and its production is eco-friendly. Timber is used in civil engineering for load-bearing structures, such as floor beams, as well as for the auxiliary structures and claddings, and sometimes it is even used as a fire protection.

From the micromechanical point of view timber, or wood in general, is composed of three basic components: 1. celulose (35–55 %), 2. hemicelulose (15–35 %), and finally 3. lignin (15–30 %) [1, 2]. For the purposes of construction industry the timber produced from coniferous trees is most popular, in particular from spruce. It can be split without troubles, reaches quite high elastic deformation, it has relatively low bulk density and it can be easily glued. Therefore, it is often used for the production of wood-based composite products and glued-laminated beams, known as glulams.

Mechanical properties of wood at macro-level are closely connected to the properties of wood cells at micro-level. The cell structure of wood is relatively complicated, there are several cell types and this diversity is mainly caused by the different growth and development of cells in spring (earlywood) and summer (latewood). The structure of latewood is denser because the cells are thick-walled around a cavity called lumen, and it has strengthening function while the earlywood forms a weaker layer within the annual ring and its main purpose is to transport the nutrients through big lumens. The size of cells and their walls is very limited and therefore the evaluation of mechanical properties can be done only on the micro level, for instance by means of nanoindentation.

2. EXPERIMENTAL METHODS

The investigated sample was extracted from a glulam beam composed of spruce lamellas [1]. An internal structure of the wooden cells for spring and summer growing season was monitored using AFM. It is shown in Fig. 1a and 1b. It is clearly visible that the earlywood cell is thin-walled, having the wall thickness between 2 and 3 μm and being equipped by a large lumen. The latewood cell is thick-walled and its thickness ranging between 3 and 7 μm [1, 4].

Nanoindentation tests were performed using a Hysitron Tribolab system® at the Faculty of Civil Engineering, CTU in Prague. Intrinsic elastic properties of individual cells were evaluated by statistical nanoindentation [2] at this level. The properties of lumen were tested only on the earlywood cells since the lumen of latewood cells was usually damaged as documented on the cross-sections in Fig 1a and 1b, and only the cell walls were indented on the latewood cells.

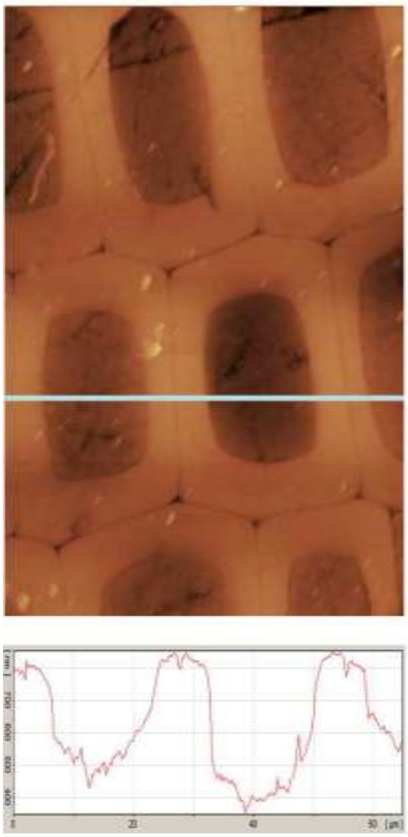

Figure 1a AFM image of a spring wood cells 65 × 65 μm, cross section of cells

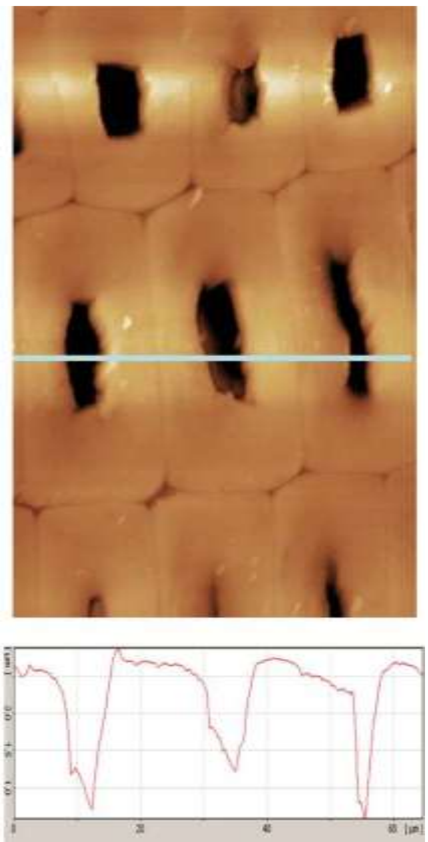

Figure. 1b AFM image of a summer wood cells 65 × 65 μm, cross section of cells

Several indents were made on both types of wooden cells at different locations of the previously polished surface of the investigated specimens. Standard load controlled test for an individual indent consisted of three segments: loading, holding at the peak and unloading. Loading and unloading of this trapezoidal loading function lasted for 5 seconds and the holding part lasted for 8 seconds. Maximum applied load was the same in both cases, equal to 400 μN. The grid of indents (4 × 5) at a single position, located by in-site imaging, is shown in Fig. 2. The indents are located in distance 3 µm to avoid their mutual influence.

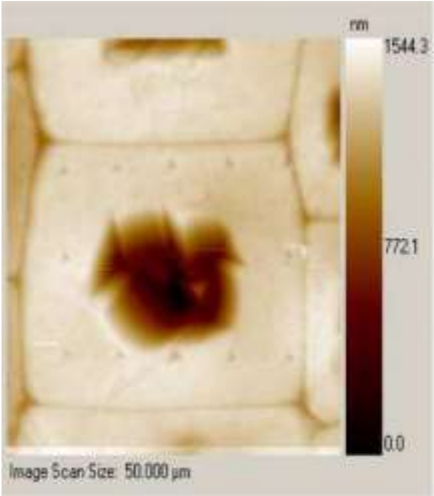

Figure. 2 Matrix of indents of summer cell wall scanned with Hysitron Tribolab®, 50 x50 µm

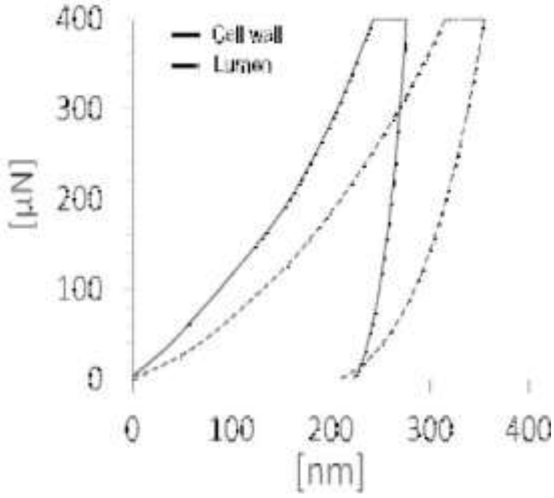

Figure. 3 Typical loading diagram of cell wall and lumen of spring wood

3. RESULTS AND DISCUSSION

The output of our measurements is the set of force displacement nanoindentation curves. These curves describe the response of the material on mechanical loading – the relationship between the loading force and penetration depth. The average penetration depth was established as 222 nm for latewood cells and 270 nm for earlywood cells. The average penetration depth in the region of lumen was 324 nm. These values are sufficient with respect to the surface roughness, but not too large to avoid interaction between phases.

Table. 1 Average values of micromechanical parameters for wood cells

Type of wood	Position	Elastic modulus	st. dev	Hardness	st. dev
		[GPa]	[GPa]	[GPa]	[GPa]
Spring	Cell wall	10.2	0.9	0.18	0.02
	Lumen	3.1	0.1	0.13	0.01
Summer	Cell wall	12.9	1.3	0.25	0.03

Typical nanoindentation load-penetration curves representing spring wood cell wall and lumen are shown in Fig. 3. Elastic modulus and hardness was evaluated for individual indents using standard Oliver and Pharr methodology [3]. The average values and standard deviations at individual positions of the measurements are summarized in Tab. 1. Such result is in good agreement with the range of experimental values reported for spruce wood e.g. by Gindl et al. [2].

4. CONCLUSIONS

The microstructure of the wood sample was studied by AFM and it revealed different cell structures of the earlywood and latewood. Mechanical properties of individual cells were assessed by means of nanoindentation. Elastic parameters of spring and summer cell walls were obtained by means of statistical nanoindentation. The elastic modulus of latewood cell wall was established as 12.9 GPa, which is 26 % higher than the earlywood cell wall modulus, equal to 10.2 GPa.

The mechanical properties of lumen were measured only on the earlywood cells since the lumen of latewood cells was usually damaged during sample preparation. The elastic modulus of lumen was established as 3.1 GPa. The obtained results are in a good agreement with the data of other researchers, reported in open literature. Further research, focused mainly on the effect of humidity on the wood structure and mechanical properties will be done in a near future.

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