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Identification of Thermo-Mechanical Properties of Natural Polymers with a Hybrid Method

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This article presents the results of experimental research into beech wood shearing. The applied research methodology has made it possible to obtain average values of basic strength parameters of wood: ultimate strength, yield point and the Kirchhoff's shear modulus. In order to investigate the phenomenon of wood damage resulting from shearing forces, the attempt has been made to use the hybrid method. It combines the advantages of experimental research with a detailed investigation of the phenomenon by means of FEM analysis. The wood shearing tests have been recreated in Abaqus software in order to identify the areas in wood specimens where damage stresses appear first. The article contains sample results of experimental and numerical research with their comparative evaluation.

Key words: shearing, FEM analysis, experimental research.

1. Introduction

This article concerns thermo-mechanical properties of non-classical construction materials such as wood, oriented towards the needs of designing machines that carry out the process of shaping parameters of the surface and structure. One example of this kind of process is hot rolling of wood (Fig. 1a). This process enables the surface layer of the material to achieve greater density, which gives the surface better aesthetic and practical properties. Additionally, it is more weather resistant. In modelling the processes of plasticization and densification of materials such as wood we are interested mostly in material effort under which the plastic flow starts. The value of this strain is dependent on complex thermo-mechanical properties that characterize wood. Recognizing these properties, in so far as is necessary to formulate the yield criterion of the region characterized

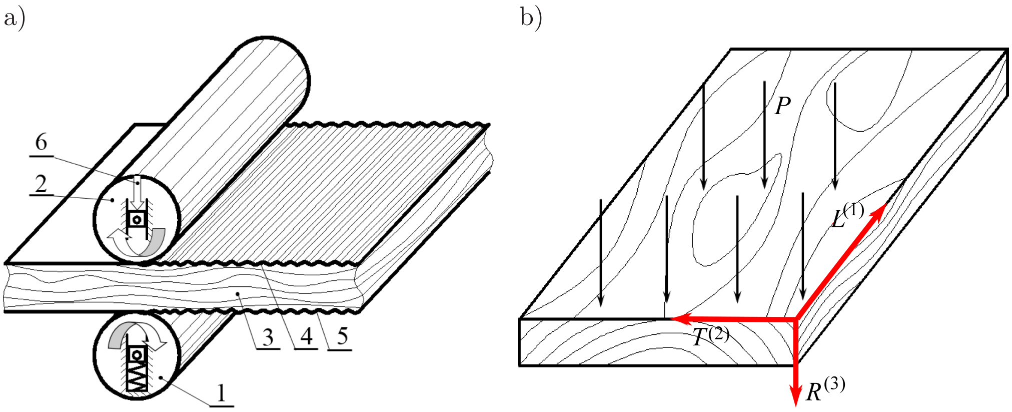

Fig. 1. a) Treatment of the surface layer of natural material by hot rolling: 1 – bottom roller, 2 – top roller, 3 – chipboard, 4, 5 – top and bottom layers of natural veneer, 6 – applied force, b) orientation of wood fibres (anisotropy): P – load, L – longitudinal direction, parallel to fibres, and two directions perpendicular to fibres: R – radial and T – tangent.

by porosity and anisotropy and accounting for the impact of temperature and moisture, is the main objective of these experimental tests.

The analysis of the material structure is the basis for determining important parameters in the process of shaping its geometric and construction properties, in connection with its specific composition and recognized properties. The profile of the properties of a material such as wood is determined by default by two categories: thermal and mechanical. In the thermal category these properties are mainly: thermal conductivity coefficient l, specific heat c_p and density ρ directly dependent on porosity. These parameters determine diffusivity of the material in Fourier equation describing heat conductivity. In the mechanical category these properties are yield point dependent on orientation of fibers (Fig. 1b), temperature and moisture.

2. Study objectives

The results of the tests of thermo-mechanical properties of wood are used to formulate constitutive equations describing the process of its plasticization with a full and comprehensive description of the influence of temperature. On this basis, it is possible to determine the effective limit load [3, 4, 6]. Specified stresses and force limits are the values that are accounted for in design assumptions and the formulated models are used in simulations and numerical calculations [1, 2, 5].

The limit load appointed in a layer of porous and anisotropic materials, may be used:

- for optimisation of processing the material to achieve the required geometrical parameters,
- to formulate the design assumptions and of constructions.

The obtained results of the experimental tests give insight only into average values of basic strength parameters, such as: ultimate strength, yield point and the Kirchhoff's shear modulus.

3. Research methodology

Research concerned the common beech (*Fagus silvatica*). Specimen dimensions are presented in Fig. 2a. In Fig. 2b edges of shearing are marked in relation to fiber direction. Research was conducted for 3 temperatures: 20°C, 50°C and 80°C and for 3 moistures: 9%, 18% and 27%. In order to achieve the right level of moisture, specimens were seasoned in special desiccators and the climate chamber [2]. Figure 3 presents the research workstation consisting of the MTS

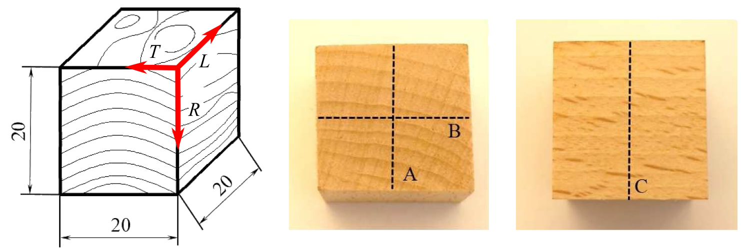

Fig. 2. a) Dimensions of specimen, b) edges of shearing: A – radial direction, B – tangential direction, C – longitudinal direction.

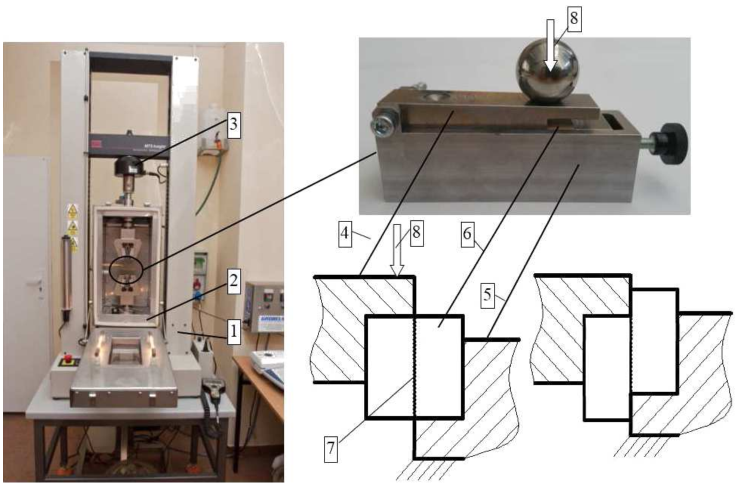

Fig. 3. MTS strength tester including climate chamber: 1 – strength tester, 2 – climate chamber, 3 – load cell (measuring the applied force), 4 – movable jaw of shear test device, 5 – fixed jaw of shear test device, 6 – specimen, 7 – surface of cutting, 8 – load of strength tester.

strength tester with the enclosed climate chamber. A special device ensuring adequate fixing and loading of the specimen was used in shearing research.

4. Results

The stress-strain curves were obtained for each shear test on the basis of extensometer displacement. The cross-sectional area of specimen was determined before the test. The other input parameters, namely temperature and percent moisture were measured right after the test. An example of a typical curve obtained from a shear test carried out on a specimen of beech wood in radial direction is presented in Fig. 4. The whole series of curves is presented in Fig. 5. Table 1 presents an example of a single test record sheet from a shear test carried out on a beech specimen of 18% moisture at 20°C. Figure 6 present the curves relating the yield point of beech wood to the temperature gradient for radial direction and three moisture content levels respectively [2].

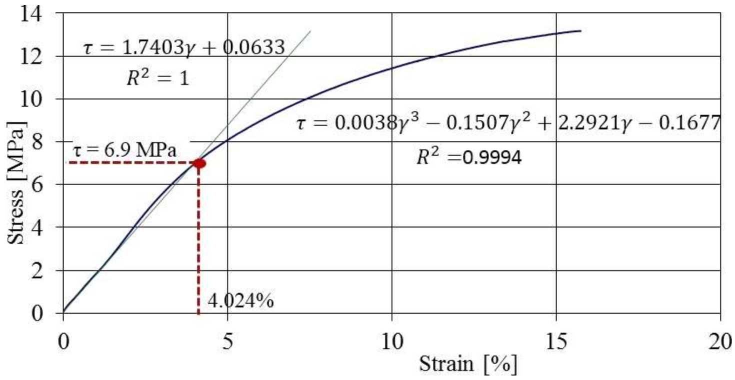

Fig. 4. The stress-strain curve for beech specimen sheared in radial direction at 20°C and 18% moisture.

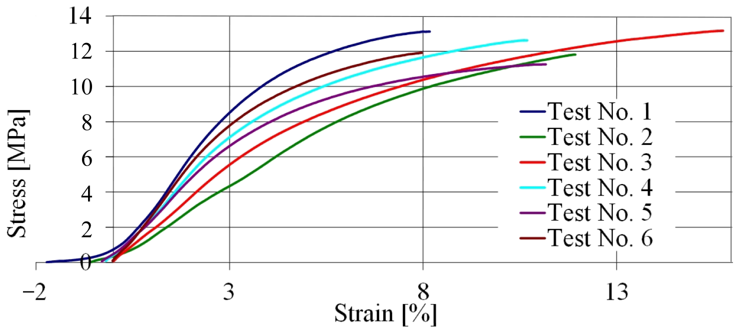

Fig. 5. The stress-strain curves for six beech specimens sheared in radial direction at 20°C and 18% moisture content.

Table 1. Single test record sheet (shear of beech in radial direction, 18% moisture, 20°C).

Wood variety	beech	Test No. 3
Direction in relation to grain	radial	
Moisture content [%]	18	
Temperature [°C]	20	
Cross-section area [mm^2]	420.25	
Kirchhoff's modulus G_r^T [MPa]	174.87	
Shearing force [N]	5534.272	
Shear stress [MPa]	13.169	
Strain	0.15748	

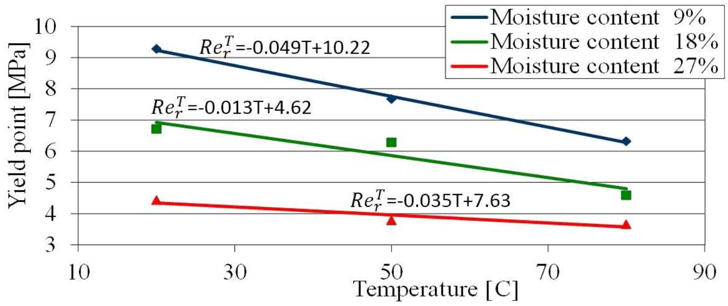

Fig. 6. Yield point vs. temperature for three moisture content levels – beech, radial direction.

5. FEM simulation results

In order to better understand wood damage phenomena resulting from shear forces, the experiment presented in chapter 3 was recreated using FEM analysis. The objective was to determine strains at which first damage stresses being to appear. Dangerous values of stresses first appeared in the top layers of the material, to a varying degree depending on fiber direction in the material. Figures 7a and 7b present stress – strain curves for two sample fiber directions: radial and longitudinal. Additionally, images are supplied showing stress at a given stage of specimen strain. The wood material was modelled as anisotropic for the FEM analysis taking into account appropriate values of strength parameters for given moisture and temperature. A broader discussion of the modelling process of beech wood based on the results of experimental research is presented in the article [2]. Figures 8a and 8b present stress curves as a function of specimen thickness along the edge of shearing. The results for the specimen sheared in radial and longitudinal direction are also presented.

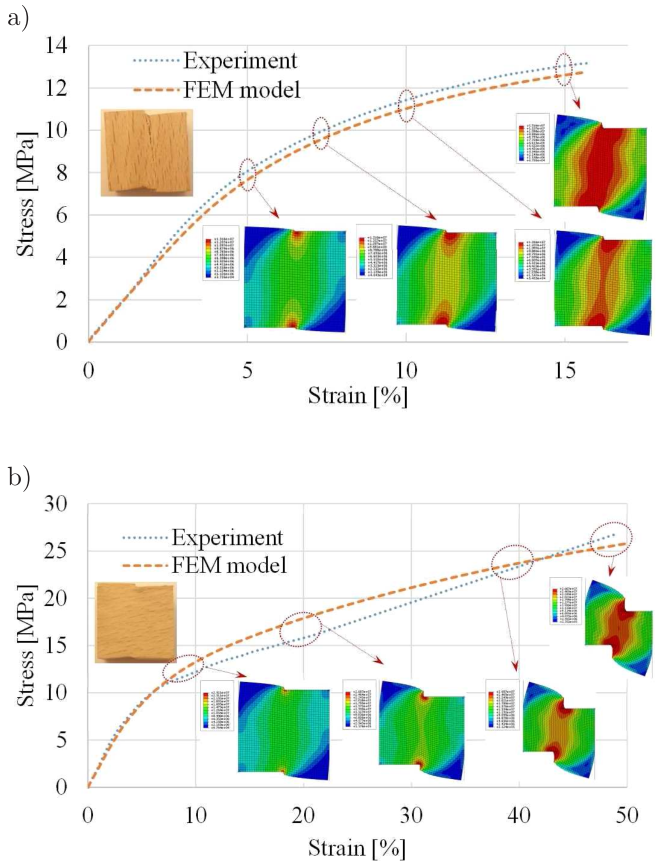

Fig. 7. a) The stress-strain curves for beech specimen sheared in radial direction at 20°C and 18% moisture, b) the stress-strain curves for beech specimen sheared in longitudinal direction at 20°C and 18% moisture.

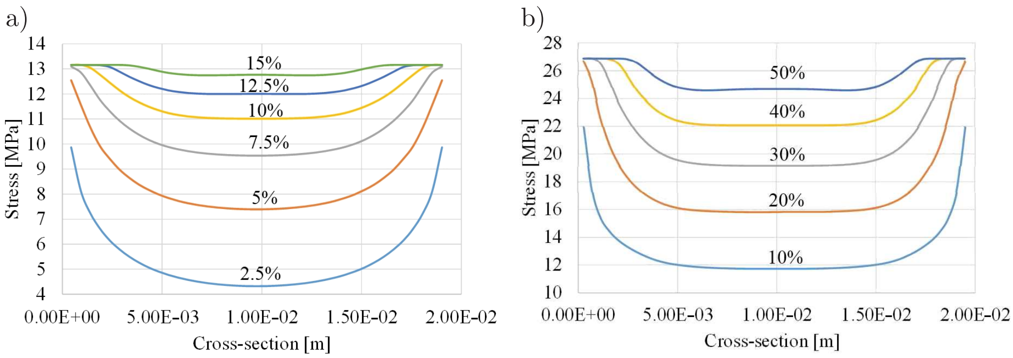

Fig. 8. a) The stress-cross-section distance curves for beech specimen sheared in radial direction, b) the stress-cross-section distance curves for beech specimen sheared in longitudinal direction.

It can be read from the graphs presented in Fig. 8 at what strain, relative to ultimate strain, stresses with values approaching damage stresses being to appear.

6. Conclusion

Taking into account the results of research of shear stresses on this type of materials, even with a limited scope of deformation, it is possible to identify areas in the external parts of the material where stresses exceed the failure point. It is closely related to the direction of the wood fibers. In the case of the radial direction, after exceeding 50% of the full deformation scope the damage stress occurs in the surface parts of the material. In the case of the tangential direction it is about 60% of the full deformation scope, while for the longitudinal direction it is only 40%. The presented research results make it possible to bring more detail to the assumptions in the construction of mathematical models related to the industrial processing of wood.

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