DYNAMICAL BEHAVIOR OF HARDWOOD SPECIES SUBJECTED TO CYCLIC BENDING STRESSES

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Abstract: Hardwood species as beech, maple, cherry, alder are used in common application such furniture, musical instruments, ornaments in automotive construction, panels and floors. The stresses vary in time as intensity, duration and type. From this point of view, some mechanical properties decrease conducting to strength and stability loss. In this paper, it was analyzed dynamical behavior of four hardwood species in laboratory conditions using Dynamical Mechanical Analyzer. The samples were subjected to cyclic bending in isothermal conditions (30^{o}C), with intensity force by 6 N with a frequency of 1 Hz applied on radial and tangential direction of wood structure. It was determined variation of storage and loss modulus (E' and E") and damping (tan δ). The second investigation based on temperature variation in range between 30^{o}C and 90^{o}C, it was analyzed the glass transition of wood, knowing that it is a natural lignocellulose composite.
Keywords: wood, dynamical mechanical analyzer, complex modulus, glass transition, damping

1. INTRODUCTION

Wood is one of the most spectacular manifestations of matter, is the structure of pulsating life, emotion, courage and prosperity. From the mighty tree is processed beams, timber, wood chip boards, plywood, glued laminated timber, pulp and paper, and modern technologies of thermo-chemical mechanical resulted in over 10000 wood-based products. Wood is a wonderful complexity of the microscopic and submicroscopic structure. The macro and microscopic structure, natural wood is a composite material consisting of fibers (tracheids at resins wood, vessels - from hardwood) and the matrix (lignin) [2, 3, 4]. Research on wood microstructure revealed that the wood cells forming irregular honeycomb structure (honeycomb) – in cross section and a prismatic tube structure in longitudinal section. The added value of the wood used in various applications is given by the following aspects: the material is renewable and recyclable; reduce energy consumption and acoustic-thermal insulating properties leading to low energy consumption; is a clean material both during processing and in use, compared with other materials of construction such as steel, concrete, composite materials based on synthetic resins; is an economical material as its aesthetic valences lead to reduced consumption of finishing materials; is the only fully exploited material – waste as sawdust, wood flour, chips, fibers and chips be used in the production of lignocellulosic composite materials (fiber board, chip board, OSB, MDF, etc.) or in the form of briquettes and pellet combustion, either for the extraction of cellulose or in agriculture to achieve compost [6, 7, 9, 10].

Challenges researchers in the use of wood in construction, furniture, automotive, aviation, boats, musical instruments, sports are given by anisotropy of wood structure, dimensional variation due to variation of moisture contents, negative influence of wood moisture on the mechanical properties, natural defects caused by insects, decay of wood and flammability.

The paper presents experimental results of dynamic mechanical analysis carried out for hardwood samples.

2. MATERIALS AND METHODS

Method of dynamic mechanical analysis (DMA) consist of applying a oscillating force at a frequency of 1 Hertz (1 cycle per second), in isothermal or variation temperatures for 10 minutes, producing sample strains [1, 2, 8]. The device returns the response of the material as a function of temperature and frequency, that depending on the visco-elastic nature of the material. Corresponding deformation of a viscoelastic deformation can be separated into in-phase and out of phase, the two components being given by the relations: $\varepsilon' = \varepsilon_0 * \sin\delta$ și $\varepsilon'' = \varepsilon_0 * \cos\delta$.

The sum vector of the two components is complex strain denoted with E^* and the terms E' are called conservation modulus and E'' loss modulus. The ratio of loss modulus and the storage is damping or capacity material to store strain energy. The wave response of deformation depends on the characteristics of the material, namely its elastic properties. Expressing the deformation as a function of time, follows: $\varepsilon(t) = E^*\sigma_0^* \sin(\omega t)$, where ε is the strain at time *t*; *E* – elasticity modulus, σ_0 - maximum stress; ω - frequency of oscillation. In Figure 1 the dynamic responses of different types of materials are presented: the case of perfectly elastic material a), viscous material b) and the case of visco-elastic c).

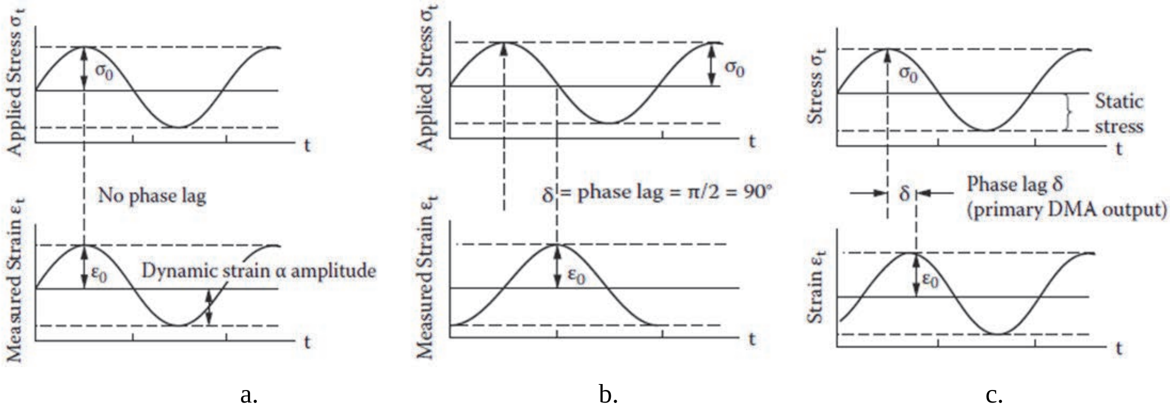


Fig. 1. Correlations between applied cyclic stresses and corresponding strain depending on the type of material:
a – elastic material; *b* – viscous material; *c* – viscoelastic material.

Different hardwood samples: beech, maple, cherry and alder were tested in dynamic mechanical analysis. Figure 2 presents the test equipment [11]. Specimens with dimensions of 50×10×5 mm, were loading with a force (*F* = 6 N, with frequency *f* = 1 Hz) perpendicular to the length of the specimen, applied midway between supports, support spacing being 45 mm. The maximum displacement was 30 μm. The samples were cut in different directions of wood: longitudinal - radial, longitudinal - tangential, transversal and tangential, yield many results (Figure 3).

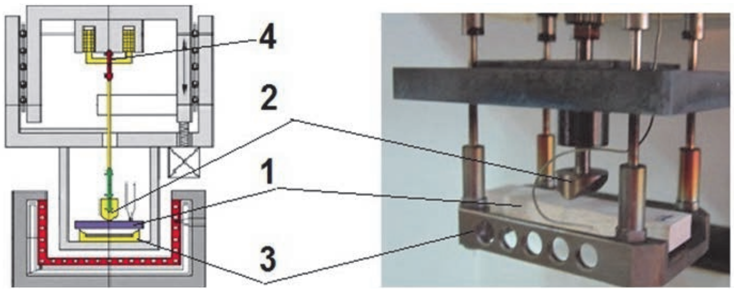


Fig. 2. Set-up of beam for dynamic bending by a central load DMA 242C
(*1* – sample, *2* – force device, *3* –supports, *4* – electronic system to oscillate force).

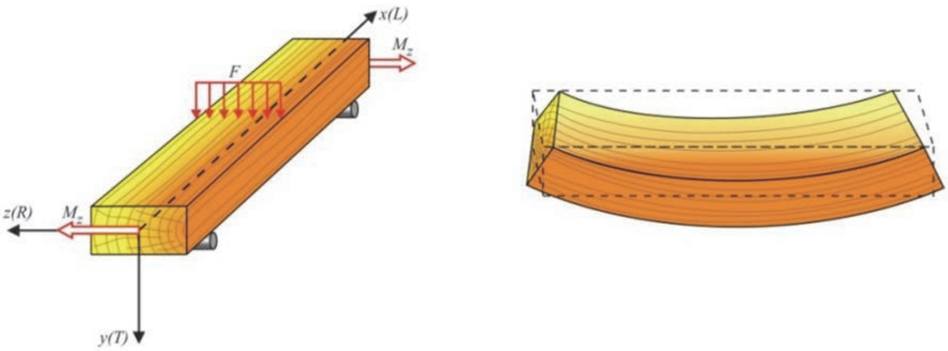
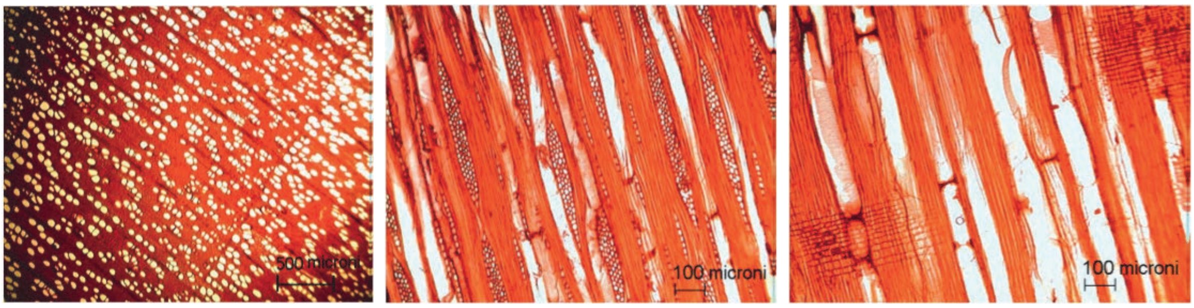
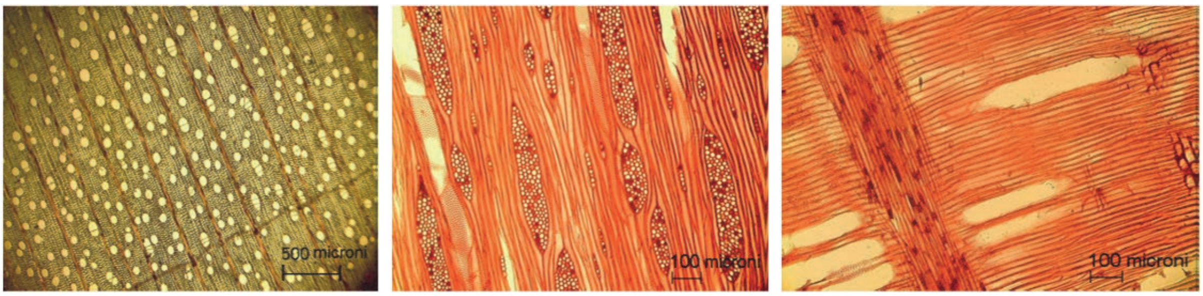


Fig. 3. Loading samples on longitudinal–radial direction.

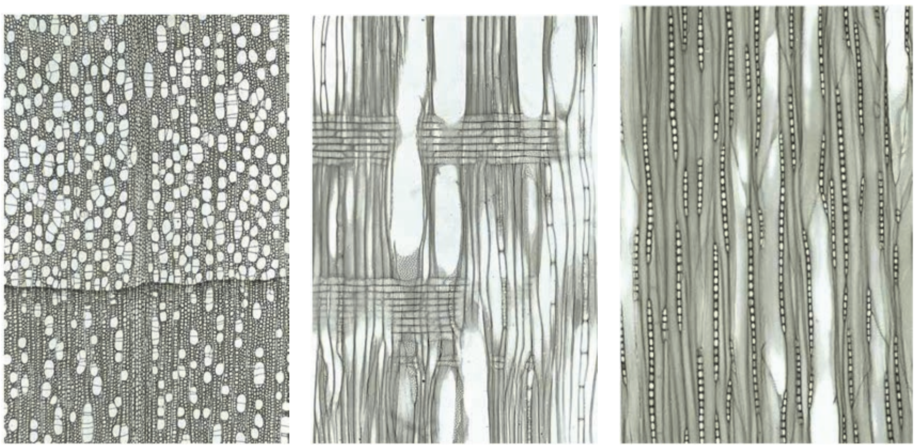
Wood from chemically point of view, is composed of cellulose, hemicellulose (galacto-glucomanan, arabinoglucuronoxylan, glucuronoxylan, glucomannan), lignin and extractive substances (waxes, fats, tannins, resins, etc.). Formation of the cell wall is achieved by the aggregation of all structural elements made of cellulose: from cellulose macromolecular chains of the micelle (crystallite) consists of macromolecular chains of cellulose about 100 to microfibrila micelles formed from about 10 to 24, to 2000 macromolecular chains of cellulose, the 250 fibrils composed of about 5000 microfibrils, about 500 000 or macromolecular micelles chains thus constituting secondary cellulose wall interspersed with pectic substances. Microfibrils are arranged in the form of laminae with different orientations to the longitudinal axis, thereby composing the cell wall structure like a layered composite material. In Figure 4 are presented the wood anatomy of studied species.



a. b. c.



d. e. f.

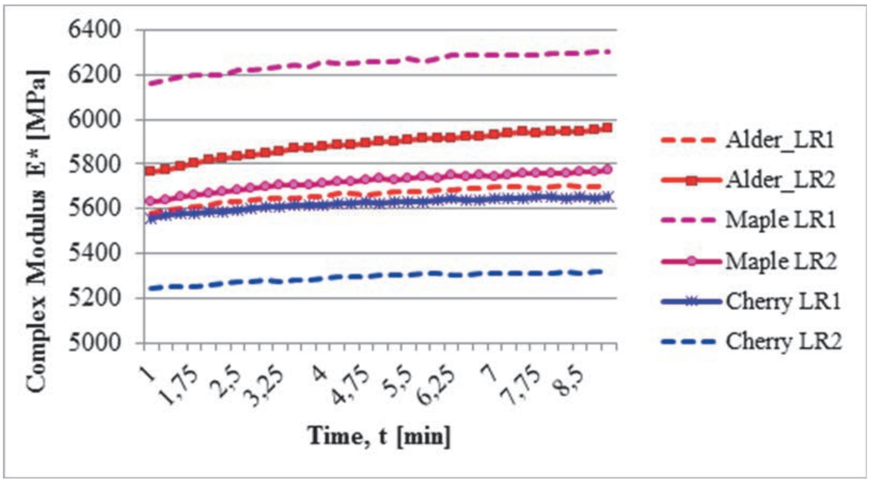


g. h. i.

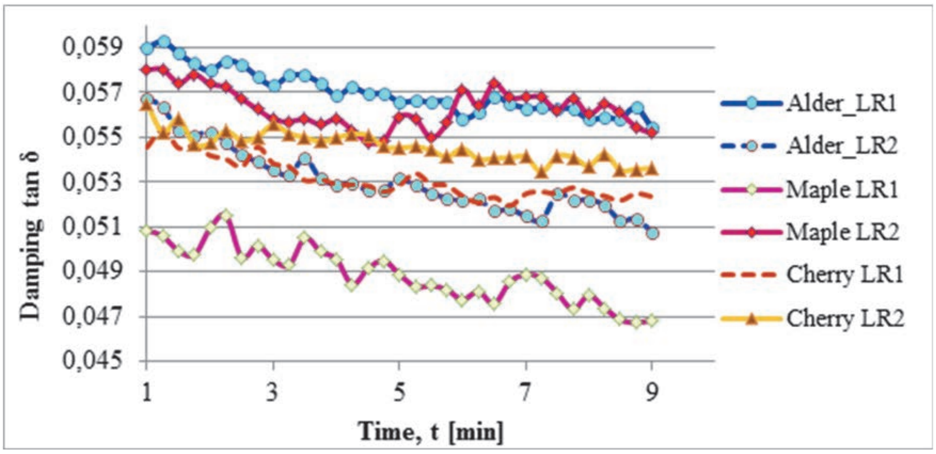
Fig. 4. Microscopic views of wood samples: cherry wood (*a* – cross section; *b* – longitudinal - radial section; *c* – longitudinal tangential) [12]; maple (*d* – cross section; *e* – longitudinal - radial section; *f* – longitudinal tangential) [12]; alder (*g* – cross section; *h* – longitudinal – radial section; *i* – longitudinal tangential) [13].

3. RESULTS AND DISCUSSION

Following experimental investigations have resulted in numerous data on the rheological behavior of different tested species. Thus, there were storage modulus values E ', loss modulus E "and the damping tanδ, under isothermal conditions and the variation of the temperature, for a constant load. A loading in radial longitudinal direction of the specimen produces a radial bending moment. During cyclical, wood tends to store increasingly more energy due to internal friction occurring in wood as shown in Figure 5, a, but decreasing the damping capacity of the wood over time, regardless of species (Figure 5 , b). Due to its macroscopic structure (corrugated fiber), wood maple shows a different behavior even if the specimens were taken from the same tree. Species such as alder and cherry presents a high damping coefficient. Analyzing curves tanδ damping coefficient is observed viscoelastic character of the wood.



a)



b)

Fig. 5:
a – variation of complex modulus *E** in time, under constant oscillating force and temperature;
b – variation of damping tanδ in case of radial-lomgitudinal samples.

With increasing temperature, the energy storage capacity of deformation decreases regardless of the wood species, but the slope varies from one species to another (Figure 6). It is noted that each species is characterized by the same variation of storage modulus with respect to temperature gradient. Maple wood is most influenced by temperature, storage modulus decreased with approximately 483 MPa compared with cherry wood (187 MPa) and alder (35 MPa). Following variation of damping coefficient *tanδ* with respect to temperature (Figure 7) it can be observed that all alder specimens has a similar behavior: high damping capacity and internal friction. With increasing temperature, the damping coefficient increases for all species up to a maximum value, then the tendency of damping is to decrease. Cherry wood, radial longitudinal direction has a maximum at around 63-75 °C, maple wood - the temperature between 46-57 °C, and alder - between 64-84 °C. In the literature it is considered that the peak damping coefficient corresponding glass transition temperature (glass transition) and represents the temperature at which chemical changes occur in the structure of lignin and cellulose. Unlike composite wood which by its nature is a natural composite shows a gradual transition from one chemical state to another.

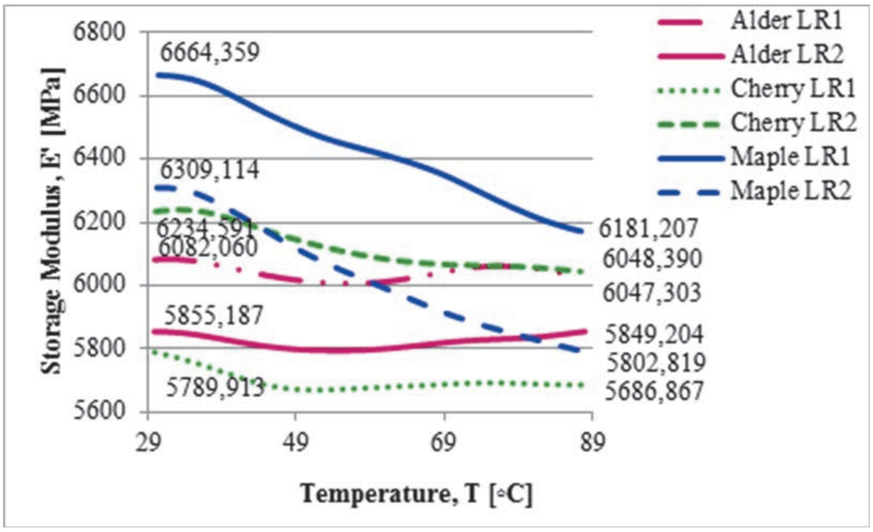


Fig. 6. Variation of storage modulus *E'* with increasing of temperature.

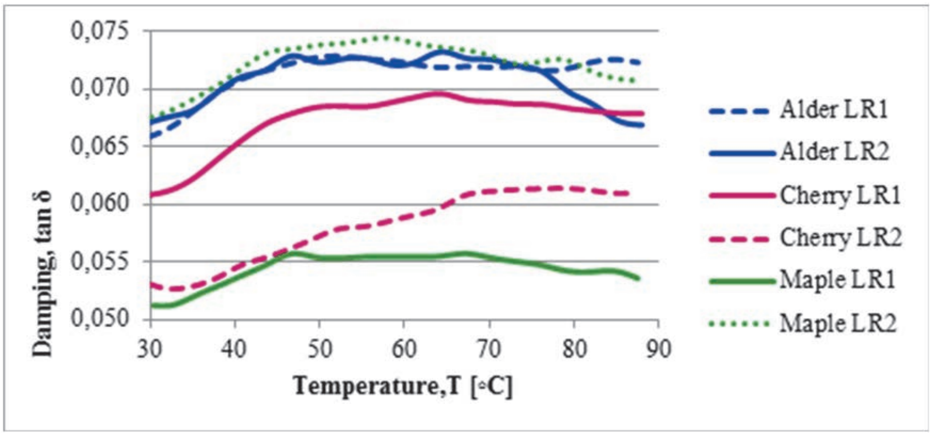


Fig. 7. Variation of damping coefficient tanδ, related to temperature.

4. CONCLUSSION

This paper aimed to analyze the rheological behavior of different hardwood species, in terms of timber capacity to store energy of deformation, strain rate at constant or variable temperature, all depend on the microstructure of wood.

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COMPORTAREA DINAMICĂ A SPECIILOR DE FOIOASE SUPUSE LA ÎNCOVOIERE CICLICĂ

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Rezumat: Specii de foioase precum fagul, paltinul, cireșul și arinul sunt utilizate în diverse aplicații cum ar fi piese de mobilier, instrumente muzicale, ornamente în construcții de automobile, panouri, pardoseli și altele. Tensiunile variază în timp ca intensitate, durată și tipuri. Din acest punct de vedere, unele proprietăți mecanice scad, ducând la pierderea rezistenței și stabilității structurilor din lemn. Lucrarea prezintă analiza comportării dinamice a epruvetelor din speciile de lemn menționate mai sus, analizate cu echipamentul de analiza mecanică în regim dinamic (DMA). Astfel, în prima etapă, epruvetele au fost testate la încovoiere ciclică, în condiții izotermice de solicitare la temperatura de 30°C, cu forța de 6 N cu frecvența de 1 Hz, aplicată pe direcție radială și tangențială. S-au determinat modulul de elasticitate dinamic în domeniul complex (modulul de conservare E` și modulul de pierdere E") precum amortizarea (tan δ). În a doua etapă a cercetării, epruvetele au fost supuse la încovoiere ciclică, în condițiile varierii temperaturii de la 30°C la 90°C, analizându-se tranzițiile înregistrate în lemn ca urmare a creșterii temperaturii.