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RESEARCH REGARDING THE COMPLEX MODULUS DETERMINED WITH DYNAMIC MECHANICAL ANALYSIS (DMA) IN CASE OF BEECH (FAGUS SILVATICA L.) AND ALDER (ALNUS GLUTINOSA GAERTN)

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Abstract:

Wood as a performance material, know an increasingly and wider applications in various fields. Due to macroscopic, microscopic and chemical structure, it is a material with important rheological properties. Knowledge of the rheological behavior helps engineers and researchers to predict lifetime of wooden structures, the strains and their stability over time.

The paper aims to determine complex elasticity modulus and damping which expressed the rheological behavior of two wood species (alder and beech). The samples were subject to cyclic stresses under the same conditions (constant temperature, constant load, frequency and duration) using dynamic mechanical analysis device (DMA). To emphasize the different behavior of wood on different section, it was considered four cases of load. Results indicated that dynamic modulus is lower than one determined at static bending, but in correlation with main section of wood. This means that in real condition of applications, it is recommended to take into account the rheological behaviour of wood and the elasticity of them to cyclic stresses. Secondly, the wood recorded different behaviour in accordance with direction of force/moment related to fibres directions. Damping is higher at beech wood compare to alder in case of longitudinal flexure; the values of beech damping δ varied between 0.088 and 0.102, and for alder, 0.0748 to 0.095.

Key words: *dynamic mechanical analysis (DMA); rheological behaviour; complex modulus; damping; strain.*

INTRODUCTION

Wood as a performance material, know an increasingly and wider applications in various fields. Due to macroscopic, microscopic and chemical structure, it is a material with important rheological properties. Also, because of its inhomogeneous structure, wood is one of the most representative anisotropic materials with different mechanical and physical properties on the three main sections: longitudinal (L), radial (R) and tangential (T). Knowledge of the rheological behavior of wood is important for life prediction of wooden structures, the strains and their stability over time. Researches have shown that slow flow phenomenon of wood is characterized by three periods: at first, primary flow occurs where strain rate decreases; than secondary flow occurs when the strain rate remains constant - the phenomenon is carried out consistently and for a long time, depending on the strain; latest stage is characterized by tertiary flow with relatively high strain rate, which accelerates as it approaches the breaking (Curtu and Ghelmeziu 1984).

In order to explain the phenomenon of flow and relaxation of solid wood, its structure is simplified using rheological models of elasto - viscoplastic bodies that takes into account the moisture content gradient in wood, the effect of external load, and a threshold viscoplastic (permanent) strain which is dependent on stress level and time (Moutee 2006). A number of rheological models of wood drying have been proposed during the last two decades (Rice and Youngs 1990, Ranta-Maunus 1990, 1993, Pang 2001). Rice and Youngs (1990) mentioned that the Burger model used for describing viscoelastic strain could not fully account for the observed stress levels in the timber. The Kelvin model, or *N* Kelvin associated elements model, has been the most commonly used mechanical analogue to describe viscoelastic behavior in wood (Moutee 2006). However, using *N* Kelvin elements model increases the number of rheological parameters that need to be computed, thus bringing more difficulty into the solution or more dispersion in the solved rheological parameter values (Moutee 2006).

The paper presents experimental research on determining the rheological behavior of wood specimens of beech and alder to cyclic stresses by measuring the storage modulus (denoted E’) which is a measure of the elastic response of a material but not the same as Young’s modulus and the loss modulus (E’’) - a measure of the viscous response of a material, also called the imaginary modulus. The experiments were performed using dynamic testing and the data were processed by means dynamic mechanical analysis (DMA) (Menard, 2008).

THEORETICAL BACKGROUND

A material under sinusoidal stress is characterized by strain at the peak of the sine wave and an angle defining the lag between the stress sine wave and the strain sine wave. Based on this, the storage or elastic modulus E’ which is equivalent to Young Modulus can be calculated (Menard 2008):

$$\mathrm{E}' = (\sigma_0/\varepsilon_0)\cos\delta = (f_0/bk)\cos\delta\ , \qquad (1)$$

Where σ_0 is the maximum stress at the peak of the sine wave, in MPa;
ε_0 –the strain at the maximum stress;
δ – the phase angle;
f_0 –the force applied at the peak of the sine wave, in N;
k –the sample displacement at peak;
b –the sample geometry term.

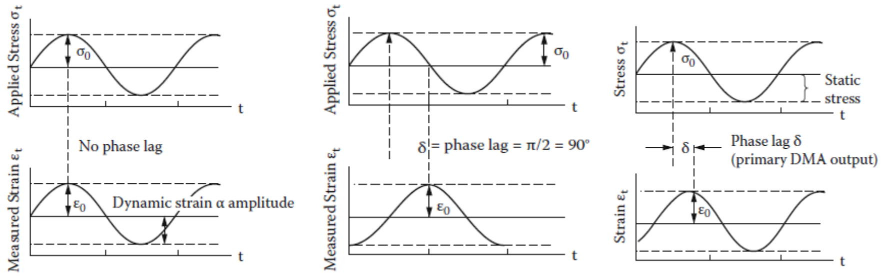
The energy lost to friction and internal motion is expresses as the loss modulus, E” called the viscous or imaginary modulus. It is calculated from the phase lag between two sine waves:

$$\mathrm{E}'' = (\sigma_0/\varepsilon_0)\sin\delta = (f_0/bk)\sin\delta\ . \qquad (2)$$

Damping of material called tan δ indicates how efficiently the material loses energy to internal friction and is calculated as the ratio of the loss to storage modulus:

$$\tan\delta = E''/E'\ . \qquad (3)$$

Graphic representation of previous relationships for elastic, viscous and viscoelastic materials, made by Menard (2008) is presented in Fig. 1.



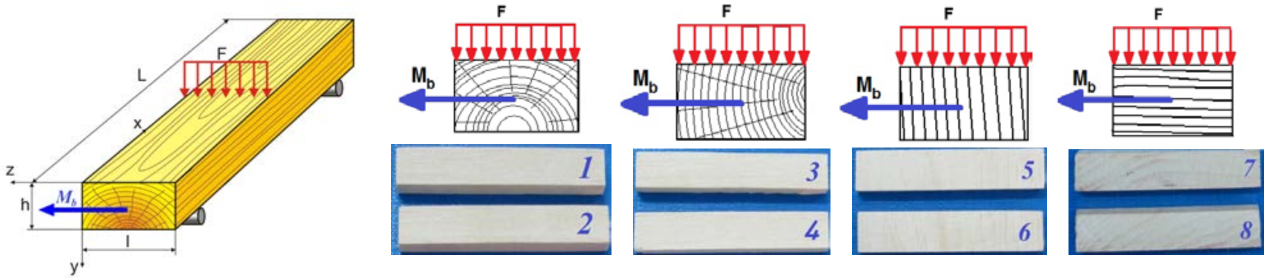
a. b. c.

Fig. 1

Correlations between applied cyclic stresses and corresponding strain depending on the type of material (Menard 2008): a - elastic material; b- viscous material; c- viscoelastic material.

MATERIALS AND METHOD

Samples as bars with 50x10x5mm^3 made from alder (Alnus Glutinosa Gaertn) and beech (Fagus Silvatica L.) solid wood were taken in study. Knowing that wood is an orthotropic anisotropic material were studied four cases of orientation force and bending moment reported the main sections of wood as can be seen in Fig. 2 and in Table 1. In Table 1 are summarize the values of input data for each tested sample, in terms of moisture content, density, sizes, force, duration of test, temperature from inner oven of test device.

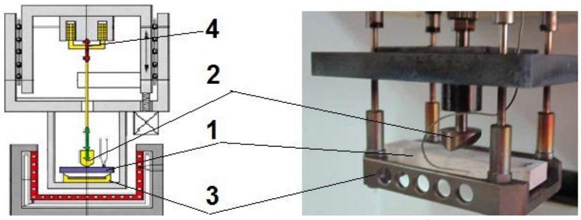


a. b. c. d. e.

Fig. 2

Load direction reported to wood structure for studied samples:
a – Set-up of beam for dynamic bending test according to ASTM D5023 – 07; b – case 1 (Tangential Bending Moment M_{bTg}, Longitudinal Flexural); c – case 2 (Radial Bending Moment M_{bR}, Longitudinal Flexural); d – case 3 (Transversal Bending Moment M_{bTr}, Radial Flexural); e – case 4 (Longitudinal Bending Moment M_{bL}, Tangential Flexural) (see Table 1)

The three points bending flexural test under force was performed. Bending moment (M_b) is orthogonal to force direction as can be seen in Fig. 2a. Four cases of load were considered in accordance with type of flexural and disposal of bending moment to wood fibres. The storage modulus E', loss modulus E" and damping tanδ have been determined using Dynamic Mechanical Analyzer DMA 242C- Netzsch Germany (Fig. 3). The device consist of: 1 – sample, 2 – head of bending, 3 – sample support for three points bending, 4 – electronic system for cyclic load.



a. b.

Fig. 3

Set-up of beam for dynamic bending by a central load:
a - Dynamic Mechanical Device; b - Details during the experiments

The measurement conditions were: isotherm measurement at 30±0.1^{0}C, frequency 1Hz, the amplitude of force 6N and maximum deflection 30µm. Table 1 presented input data concerning each studied cases and samples.

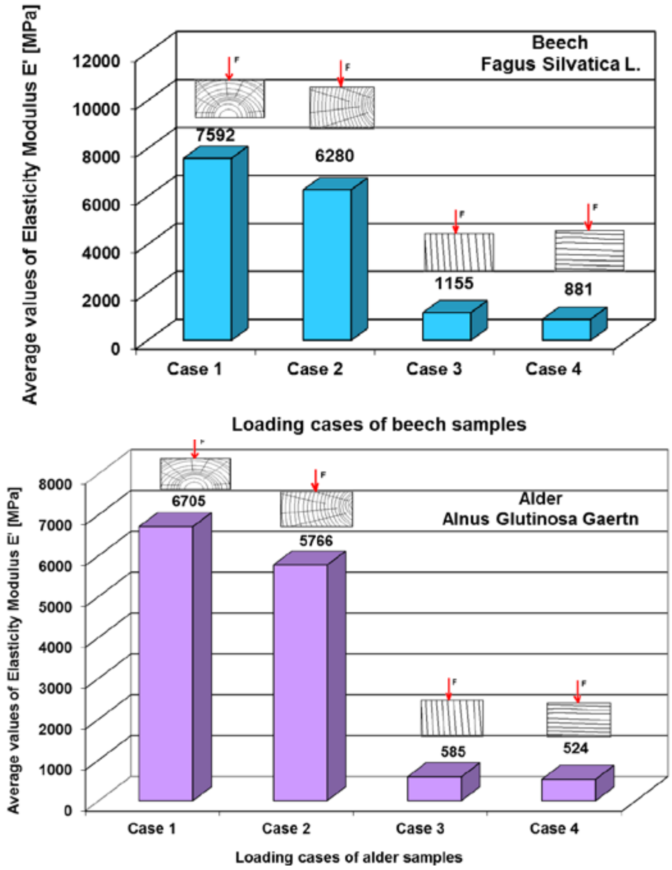
Table 1

The input data for samples and load

Cases **Load direction reported to wood structure**	**Samples**	**Moisture Contents %**	**Density ρ [g/cm^3]**	**Sizes [mm]**			**Force [N]**	**Time t [min]**	**Temperature T [^{0}C]**	**Frequency f [Hz]**
				L	*l*	*h*				
Case 1 Tangential Bending Moment (**M_{bTg}**) Longitudinal Flexural	Alder 1.1.	14.8	0,542	50	9.73	4.92	6	10	30	1
	Alder 1.2.	14.1	0,520	50	9.80	4.94	6	10	30	1
Case 2 Radial Bending Moment **M_{bR}** Longitudinal Flexural	Alder 2.1.	14.8	0,517	50	9.74	4.75	6	10	30	1
	Alder 2.2.	14.7	0,525	50	9.84	4.97	6	10	30	1
Case 3 Transversal Bending Moment **M_{bTr}** Radial Flexural	Alder 3.1.	14.0	0,539	50	10.67	4.83	6	10	30	1
	Alder 3.2.	14.6	0,514	50	10.66	4.96	6	10	30	1
Case 4 Longitudinal Bending Moment **M_{bL}** Tangential Flexural	Alder 4.1.	14.9	0,568	50	9.86	4.90	6	10	30	1
	Alder 4.2.	14.8	0,532	50	9.82	4.91	6	10	30	1
Case 1 Tangential Bending Moment (**M_{bTg}**) Longitudinal Flexural	Beech 1.1.	13.9	0,851	50	10.63	4.95	6	10	30	1
	Beech 1.2.	14.2	0,742	50	10.73	4.97	6	10	30	1
Case 2 Radial Bending Moment **M_{bR}** Longitudinal Flexural	Beech 2.1.	13.7	0,748	50	10.70	4.90	6	10	30	1
	Beech 2.2.	13.9	0,669	50	10.66	4.99	6	10	30	1
Case 3 Transversal Bending Moment **M_{bTr}** Radial Flexural	Beech 3.1.	14.1	0,764	50	9.68	4.98	6	10	30	1
	Beech 3.2.	14.3	0,802	50	9.56	4.96	6	10	30	1
Case 4 Longitudinal Bending Moment **M_{bL}** Tangential Flexural	Beech 4.1.	13.7	0,884	50	9.5	4.97	6	10	30	1
	Beech 4.2.	13.8	0,801	50	10.72	4.85	6	10	30	1

RESULTS AND DISCUSSIONS

After applying the experimental method of determining the complex modulus E*, respective storage E' and loss modulus E'', and damping tan δ, the results were processed and plotted in Fig. 4…8. All results represent the rheological response of wood to cyclic stresses on all cases of load. The values of storage modulus determined in case of 4 are 9 - 10 times lower at beech and 10 - 11 times lower at alder than in case 1 as can be noticed in Fig. 4. Also, the storage modulus E' in case 2 are with 17…18% lower than case 1, beech and 14…15% for alder.



a. **b.**

Fig. 4
Average values of storage modulus E' in all case of load
a – Beech; b – Alder.

In all cases of stresses, alder wood has more elasticity compare with beech. The E' values are lower for alder as follows: 1,12 times in case 1; 1,09 in case 2; 1,97 in case 3; 1,68 in case 4. DMA method proved that dynamic modulus in case of longitudinal bending is much larger than the transverse bending (radial / tangential). The transverse bending deformations are much larger than the longitudinal, consequently, the elasticity is higher, but resistance is much lower. In Fig. 5 is presented the correlation between storage and loss modulus for longitudinal flexural of alder. It can be noticed that during the cyclic stresses, wood tends to storage more and more energy due to internal friction and responds of them is measured in higher permanent deformations. The longer stress is higher, dynamic modulus E increasing and damping decreases (Fig. 6). Damping differs in accordance with type of flexural – is lower for longitudinal flexural (case 1 and 2) and is higher for transversal one (case 3 and 4). This behaviour is more obviously in case of beech (Fig. 7).

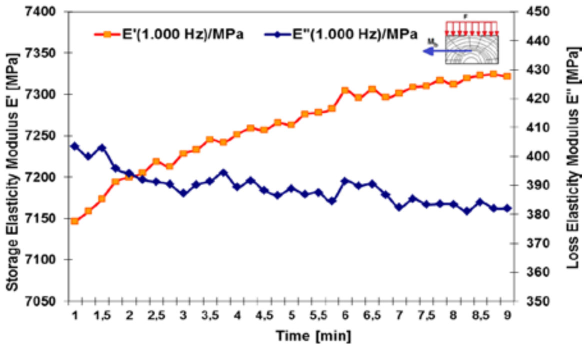


Fig. 5
Correlation between storage and loss modulus of alder versus time, in case 1.

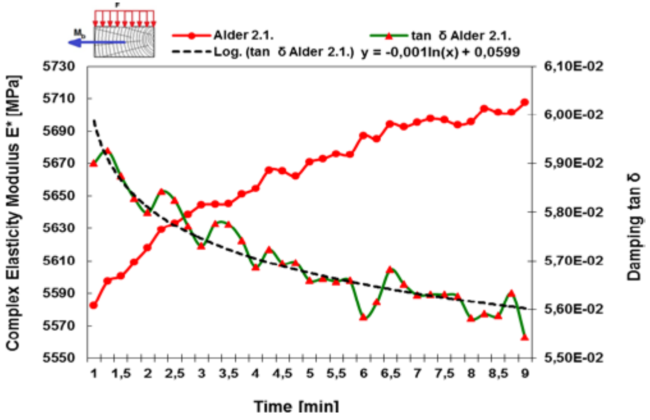
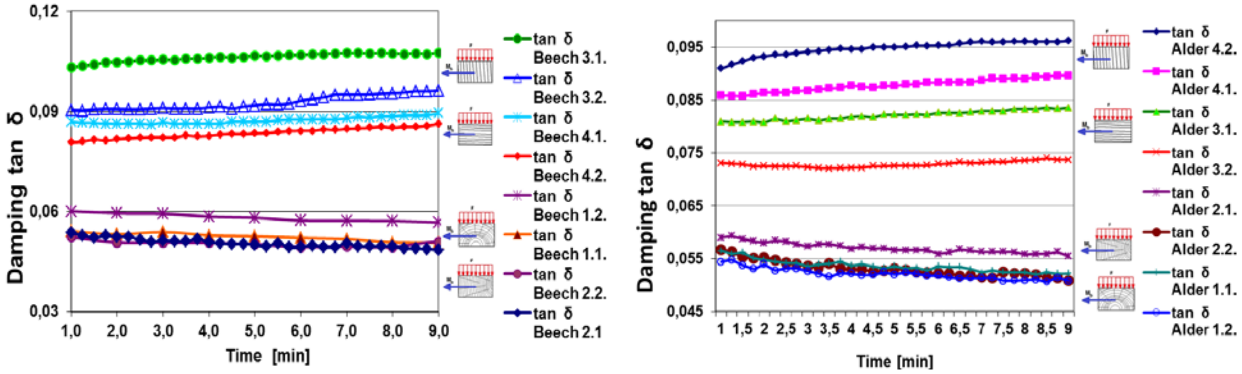


Fig. 6

Correlation between complex modulus E* and damping tan δ of alder versus time, in case 2.



a. **b.**

Fig. 7

The damping curves for beech samples in all tested cases: a - Beech; b- Alder.

With DMA research, dynamical modulus of elasticity is lower than statical one regardless of loading. For example, in case of longitudinal flexural, statical elasticity modulus is 1,48 times higher than elasticity modulus determined with ultrasound method and 1,68 times higher than diynamic modulus with DMA (Curtu 1984, Bucur 2006, Grimberg *et al*. 2011).

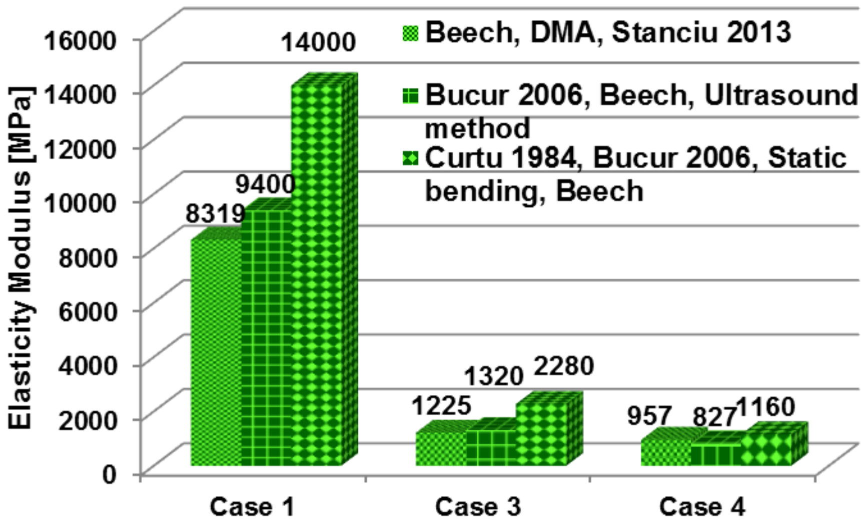


Fig. 8

Comparison of Elasticity Modulus values determined by means different method (static bending, ultrasound and DMA).

CONCLUSSION

It can be concluded that dynamic mechanical analysis is one of the future tool to predict the rheological behaviour of different materials. In this study, two main wood properties were determined in cyclic stresses conditions: damping and complex modulus (with its components). Also, it was considered two species of wood – alder which is a relatively soft hardwood and is moderately lightweight with medium density and beech characterized by relatively high density. Both types of samples were tested in similarly condition. Firstly, the dynamic elasticity modulus determined for different cases of load are strongly lower than static one. This means that in real condition of applications, it is recommended to take into account the rheological behaviour of wood and the elasticity of them to cyclic stresses. Secondly, the wood recorded different behaviour in accordance with direction of force/moment related to fibres directions. Damping is higher at beech wood compare to alder in case of longitudinal flexure; the values of beech damping tan δ varied between 0.088 and 0.102, and for alder, 0.0748 to 0.095.

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