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MODAL ANALYSIS OF LIGNOCELLULOSES BASED COMPOSITE MATERIALS

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Abstract: *The paper aims to present few of the experimental research results from acoustic testing of various lignocelluloses based composite materials used in environmental architecture, such as solid wood, chipboard, composite panel, fibreboard. To determine the acoustical parameters such as resonance frequency, damping coefficient, modal shapes, the Pulse soft and Bruel & Kaer equipments were used. The influence of wood species, moisture content, thickness, material structure of samples on their acoustic characteristics were the main objectives of this research. In accordance with physical and chemical properties, the panels made from lignocelluloses materials were designed to be used for different applications such as automotive industry, soundproofing panels for highway, in concert halls architecture, sound insulation of buildings.*
Keywords: *lignocelluloses, frequency, damping, lignocelluloses*

1. INTRODUCTION

One of the main objectives of sustainable development is based on using and recycling waste. Lignocelluloses based composite materials from different structures (plates, beam, solid) are made from sawdust, fibres, wood chips with different sizes, all being residues resulted from primary and secondary wood processing [7]. Mixture of the resin and matrix leads to obtain materials with new properties and with improved statically and dynamical behaviour [3-5]. The acoustic qualities of a mechanical structure are intrinsically linked to the material they are made of and also linked to own elastically properties [6], [12]. The influence of wood species, moisture content, thickness, material structure of samples on their acoustic characteristics was the main objective of this research.

A simple and efficiently method for measuring fundamental frequency and damping coefficient of the sample is described in the paper. The wood's behaviour under the acoustic waves depends on the one hand on the sound energy which makes contact with it and on the other hand it depends on the nature and the state of the wooden material, respectively on the macro and microscopic structure of the wood – the structure of the cellular membrane, the fibres' dimensions and cohesion, the presence of some own chemicals, the wood's humidity, the temperature of the wood, the elastically properties, and it also depends on the structure's layout in proportion to the sound source (longitudinal, transversal, radial, tangential, complex) [8-12].

Depending on moisture content, microscopic structure, sized (thickness), section, wood and lignocelluloses materials can be used in applications that are designed to isolate noise and vibrations (sound absorbing panels in civil, social, cultural, industrial, automotive, paving, etc.) or the construction of musical instruments. The herein paper presents the results of applying a non-destructive evaluation method based on vibration tests with flexible supported plates. The measured natural frequencies and damping coefficients were compared with theoretical results obtained from the finite element method.

2. MATERIALS AND EXPERIMENTAL SET-UP

The lignocelluloses plates were made from plywood and having the physical and elastically features listed in Table 1. The layers of veneers have $[0^0/90^0/0^0]_S$ disposal, being fabricated for experimental investigation. Four type of spruce quality were used, the difference between them being the regularity of annual rings and the annual ring width. The other ones were made from hornbeam and lime. Before the effective tested, it was measured the moisture content of wood and the thicknesses of plates in 7 points, using the ultrasound moisture meter type Merlin PM1-E [5, 8].

Table 1. The physical features of tested plates

Materials of plates	Thickness *h [mm]*	Length *L [mm]*	Width *l [mm]*	Moisture content *U [%]*	Density ° [kg/m^3]
Sample 1 Spruce Picea abies Karsten	2	530	415	8.7 %	638,781
Sample 2 Spruce *Picea abies Karsten*	2	530	415	7.4 %	641,054
Sample 3 Spruce *Picea abies Karsten*	2	530	415	6.6 %	645,601
Sample 4 Spruce *Picea abies Karsten*	2	530	415	9.7 %	627,415
Sample 5 Hornbeam Carpinus betulus L.	2	530	415	7.0%	795,635
Sample 6 Lime *Tilia cordata Mill*	2	530	415	8.9 %	709,252

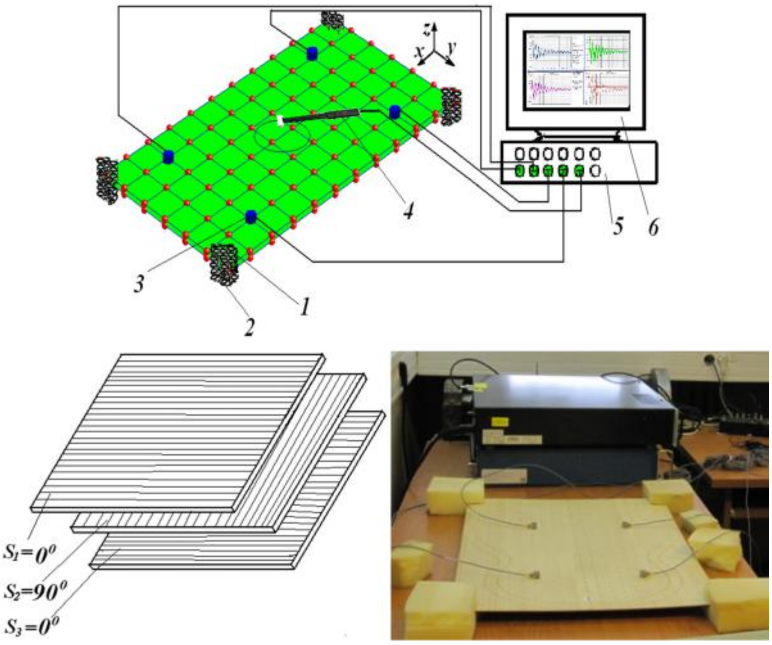


Figure 1. The experimental set-up (1- studied sample, 2 - yielding seat, 3 - accelerometer (s), 4 - impact hammer, 5 - Pulse hardware, 6- Pulse software)

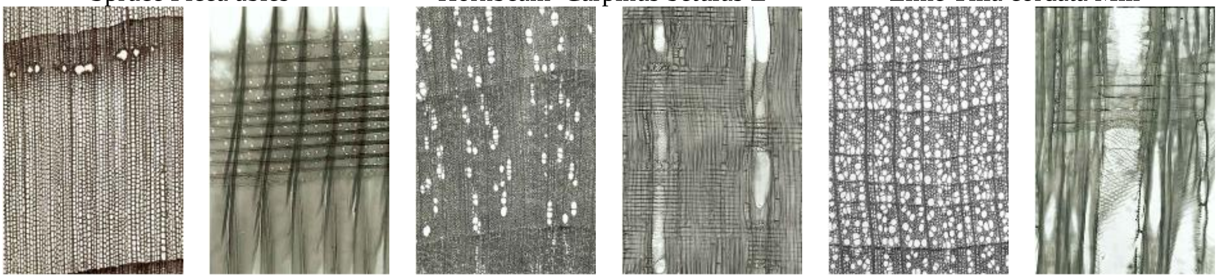
The experimental set-up was built as it can be seen in Fig. 1 (right) [15]. Each composite plate (1) was freely supported on a foam device (2) and hit with impact hammer, type B & K 8204 (4), in the central point of plate. The vibrations of plate were captured with four accelerometers type B&K 8320 (3) and transmitted to Pulse hardware and displayed with Pulse soft. The primary data were processed with ME' Scope VES 4.0 software. The light accelerometers weight did not affect the values of natural frequencies extracted from experimental tests. The devices used for simulate free boundary conditions are different as it can be found in references: foam device placed on corners, or along the edges, suspended plate, elastically support for entire surface of plate, pads or central elastic spring. After numerous tests regarding the proper type of support, was found that are negligible influences which conduct to use the foam devices placed in corner of studied plate (see Fig. 1).

3. RESULTS AND DISCUSSIONS

It is known that from microscopic point of view, spruce (in Latin Picea abies) is characterized by gradual transition between early wood and latewood, with resin canals bordered by 8 to 12 or more thick-walled epithelial cells, the longitudinal tracheids generally with uniseriate and the ray tracheids present, with smooth walls (see Fig. 2). Average ray height 10 to 15 cells, rarely up to 25 cells.
The hornbeam (Carpinus betulus L) presents diffuse-porous; the growth ring boundaries is rather indistinct and aggregate rays generally but not always are present. Libriform fibres and (only few) fibre-tracheids are present. Occasionally prismatic crystals can be noticed in enlarged ray cells. The lime (Tilia cordata Mill) have diffuse-to semi-ring-porous. Pores are often in radial oriented files and clusters, being slightly polygonal. The growth

ring boundaries are marked by 2 to 3 rows of thick-walled, radial flattened cells and distinctly flaring rays. The ray height is very variable, often up to 10 cells, sometimes up to 50 or more cells.

Spruce Picea abies | Hornbeam Carpinus betulus L | Lime Tilia cordata Mill



Transversal | Radial | Transversal | Radial | Transversal | Radial

Figure 2. The wood species – microscopic views

In Fig. 3 are being displayed the response signal acquired during the experimental testing in terms of FFT (i.e FFT – Fast Fourier Transform) and an exponential decay, leading after some computation to the possibility of retrieving the natural frequencies and damping coefficient of composite samples. The experimental results were compared with the results obtained after running some simulations based on finite element method (FEM). The plates were meshed using shell type elements with four nodes and ABAQUS as environmental software. Free boundary conditions were considered. The analysis was performed for different values of density and Young's modulus of the plate material – lignocelluloses composite has the following characteristics:

- density ρ (ρ = 600.....800 kg/m^3),
- longitudinal Young modulus E_x (E_x= 10000.....16000 MPa),
- transversal Young modulus E_y (E_y = 5000........9000 MPa),
- Poisson's coefficients $\nu_{xy} = 0.44$, $\nu_{yx} = 0.028$.

In Figure 4 are displayed the modal shapes of modal analysis for the first six modes. The modal shapes are similarly irrespectively of mechanical properties of materials, especially when values have the same size grade.

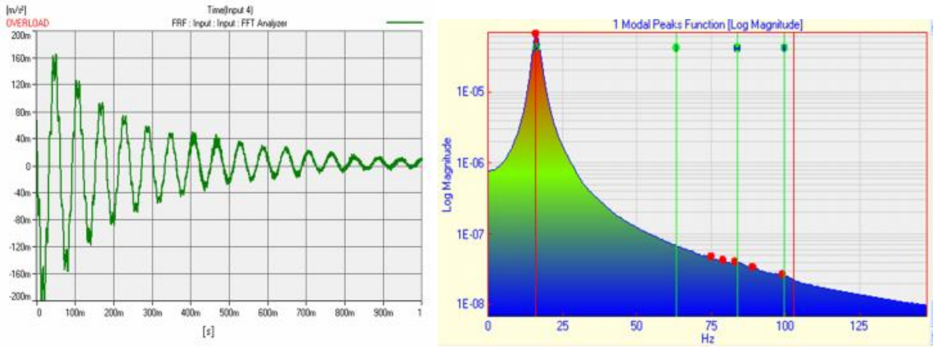
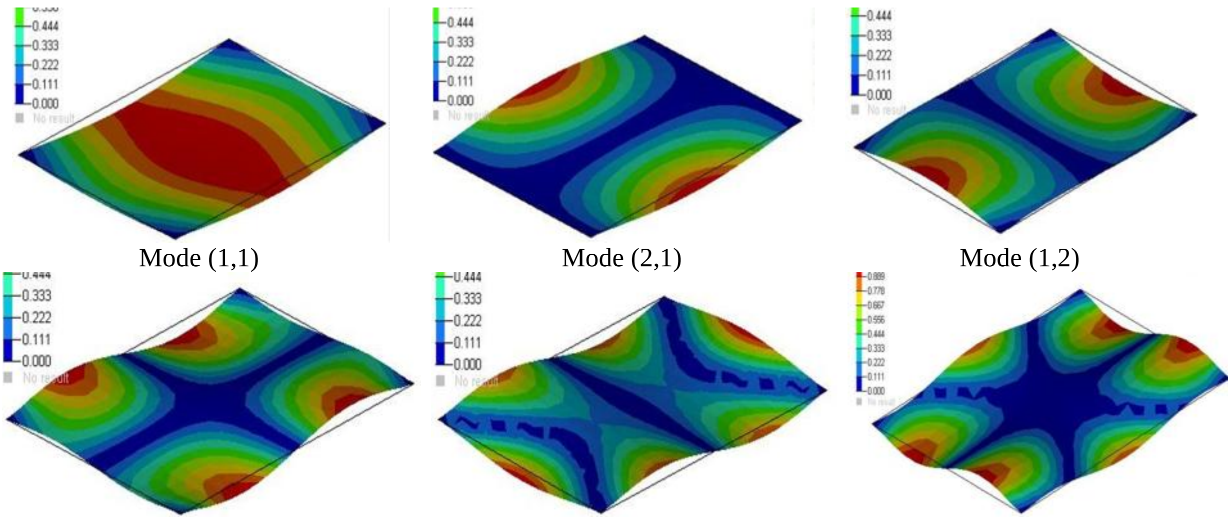


Figure 3. Example of the response signal (left- exponential decay function, right – Fast Fourier Transform function)



Mode (1,1) | Mode (2,1) | Mode (1,2)

Mode (2,2) | Mode (1, 3) | Mode (2, 3)

Figure 4. The structural modes of simply supported lignocelluloses plate

In Table 2 are summarized the results of numerical simulation and experimental investigation. Comparing the experimental results with numerical ones, it can be noticed that there are small differences between them due to the hypotheses used in numerical simulation. This can be sized from the plotting in Fig. 5.

Table 2. Measured and calculated values of fundamental frequency and damping ratio

Materials of plates	FEM Fundamental Frequency f_{FEM} [Hz]	Natural Frequency F_{EXP} [Hz]	Experimental Damping Ratio ζ	Mass m [Kg]
Sample 1 Spruce	8.2556	9.67937	0.0187	0,281
Sample 2 Spruce	8.2278	8.93062	0.0171	0,282
Sample 3 Spruce	8.3489	9.80125	0.0179	0,284
Sample 4 Spruce	8.2278	8.91125	0.0174	0,276
Sample 5 Hornbeam	8.7866	9.28187	0.0157	0,350
Sample 6 Lime	10.4650	9.92312	0.0177	0,312

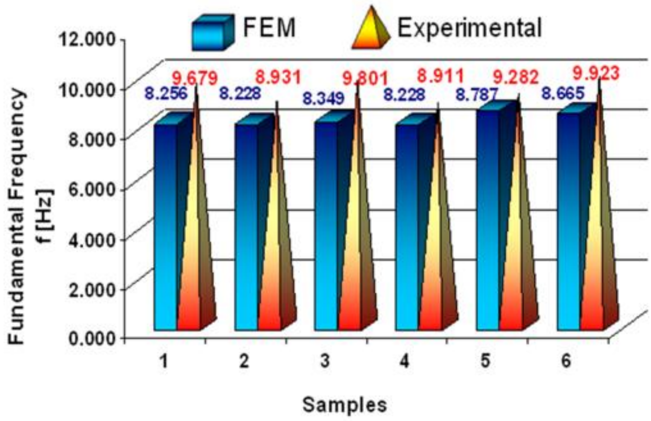


Figure 5. Comparison between FEM and experimental fundamental frequencies

The lignocelluloses composites are biomaterials and for this reason each plate even is made from the same species, have its own dynamical behaviour. This can be noticed from the different values obtain in case of plates made from spruce veneers as can be seen in Fig. 6. The smaller value of damping ratio is obtained in case of hornbeam plate. In case of spruce, the damping ratio varied due to the influence of physical, mechanical and chemical composition of wooden species.

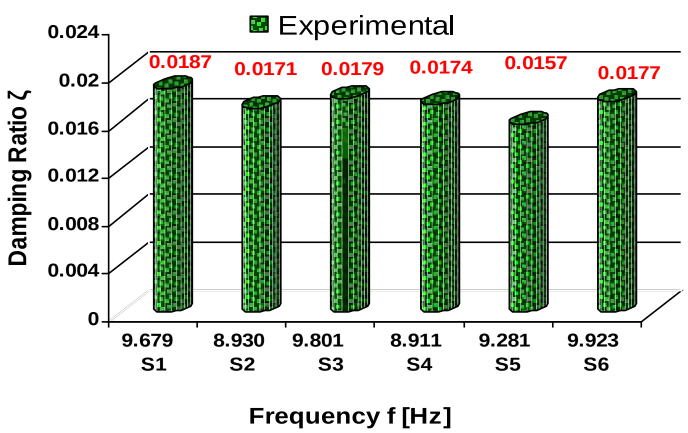


Figure 6. Variation of damping ratio with experimental fundamental frequency

The physical and mechanical properties of plates made from the wood species considered, in terms of their eigenvalues, are listed in Table 3. The plate made from resonance spruce (sample 3) presents numerous harmonics. With growth of vibration modes, the values of frequency tend to be almost identical.

Table 3. The natural frequencies of lignocelluloses plates

f_n	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
f_1	9.68	8.93	9.80	8.91	9.28	9.92
f_2	19.90	20.58	20.34	19.04	20.93	20.57
f_3	41.42	41.65	41.54	39.20	38.10	31.65
f_4	-	-	458.64	-	450.00	-
f_5	644.00	-	644.00	643.75	644.33	643.81
f_6	-	752.50	751.24	751.60	751.81	751.50

Comparing the experimental results with literature as is shown in Table 4, it can be remarks that we obtained similarly values, using different experimental method.

Table 4. Comparison of experimental results with the literature ones

Measurements in Longitudinal – Radial plane of wood	*Experimental Fundamental Frequency f [Hz]*	*Experimental Damping Ratio ζ*
Stanciu [12] - Spruce plywood (h= 2 mm)	9.476	0.017632
Bucur [2] /Sitka spruce	9.531	0,013000

4. CONCLUSIONS

It is noted that the present method can predict natural frequencies of lignocelluloses plates. This experimental method represents a non-destructive way used to identification of mechanical properties using hybrid method. The theoretical and experimental investigations of modal analysis of lignocelluloses plates were performed. The results in terms of natural frequencies and damping ratio extracted from both applied methods were compared. Experimental fundamental frequencies have values similarly with calculated frequency by analytical method.

The mechanical properties (Young's Modulus, density) influence the dynamical response of plates in case of quantitative increasing of the plate's thickness. The panels made from lignocelluloses materials can be design with the purpose to be used in different applications such as automotive industry, soundproofing panels for highway, in concert halls architecture, sound insulation of buildings.

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