EVALUATION OF ACOUSTIC PROPERTIES OF COMPOSITE MATERIALS WITH POTENTIAL APPLICATION IN THE SOUND BARRIERS STRUCTURES

Mariana Domnica Stanciu, Janos Timar, Ioan Curtu, Calin Rosca

Transilvania University of Brasov, Department of High Tech Product for Automotive, Romania

KEYWORDS – composite, noise, barriers, acoustic, properties

ABSTRACT – The European strategy requires harmonization of various methods to reduce noise with actions on the noise sources, on the receptor and on the sound propagation medium. Regarding the reduction of noise level using insulating structures, one of the issues of research is based on study of acoustical properties of materials and optimum geometry of sound barriers. The paper aims to present one of the modern and non-destructive method to determine the natural frequencies and damping coefficient of plates made from different materials: plywood, composite (epoxy /glass fibre mixed with various form of reinforcement pattern). Based on Rayleigh-Ritz method and the vibration tests of the freely supported composite plates, natural frequencies were predicted.

INTRODUCTION

In the framework of European policy regarding the noise reduction as European normative 2002/49/CE and 2003/613/CE, is suggested to develop global strategies with actions on the noise sources, on the receptor and on the sound propagation medium (11). The sources of noise are numerous and complex: from industrial areas where noise is produced by various type of machinery (fan, stem pressure, drilling machine, stamping, road breaking), characterized by high or low frequencies; from transportation noise in terms of road traffic noise with remark that the main sources are the engine and the frictional contact between tires and road bed or contact between vehicle and air; from rail traffic where the most important sources of noise are generated on shunting operations or in station; from air traffic noise produced by turbo fan engine on get off and landing; from sonic booms which are developed in air due to the supersonic flight of aircraft and another type of noise sources is from construction, public works (such as garbage disposal, street cleaning) and military noise (from heavy vehicle and from small or large fire arms). Other unpleasant sounds are generated inside or outside the buildings by ventilation and air conditioning plants, heat pumps, elevators, domestic noise, or noise from leisure activities (motor-racing, motorboats and water skiing, discotheques and rock concerts) (2). All these have a significant impact on human health, especially in the urban area. The European strategy requires harmonization of various methods to reduce noise such as: traffic redirection to achieve a uniform distribution in terms of noise, setting the unidirectional streets, speed restrictions, the interdiction of certain categories of vehicles on certain streets, construction of subways and overground passage, emplacement of sound barriers and/or green areas.

LITERATURE REVIEW

The problem of traffic noise reduction has many approaches. The traffic noise emission has been study in almost European country on real cases from urban area due to the legislation on this filed. The noise maps lead to improve solution regarding the traffic operation at roundabouts and their capacity, reduction of speed and traffic flow, location the acoustics panels. Regarding the reduction of noise level using insulating structures, one of the issues of research is based on study of acoustical properties of materials and optimum geometry of sound barriers. Numerous studies approach the efficiency of different configuration, materials and shapes of noise barrier. Some aspects about dimensions and geometry of sound barriers are standardized in EN 1793-3. Ishizuka & Fugiwara studied the performance of noise barrier with various edge shapes (T shape, branched barriers, double cylindrical barrier and barrier with side panels), shown that absorbing and soft edges improve significantly the efficiency of the panels comparison with configuration modifications (distance between the barrier and source lane and position of receiver, height and distance from the barrier, the topography and acoustic properties of the ground, the presence of other obstacles, the atmospheric conditions) (13). Peyrard investigated the combination between type of asphalt (porous or dense) and sound barriers with 2m high and he noticed that the maximum benefit were obtained in case of porous asphalt and barrier – the maximum sound pressure level L_{Amax} (dB)A decreased with 12.4 dB (A) (16). The acoustical properties of materials have been studied by many researchers, but each approach differs by the objectives of analyses, the method, types of tested structures or the features of materials. In Acoustic of Wood, Bucur focused on progress and current acknowledge in wood acoustic based on literature review from the last 25-30 years, in terms of velocity of wave propagation in wood, elastic parameters determined with ultrasonic methods, logarithmic decrement of different wood species. Speed of sound transmission, attenuation of induced stress wave techniques and other parameters measured leads to characterization of wood (3). Rossing and Fletcher develop the theoretical aspects of the fundamental principles of vibrations and sound waves for different materials and structures as beam, plate, membrane, musical instruments, microphone and cavities (17). Asdrubali & all studied the absorbing properties of materials made from recycled tyre granules, using the impedance tube (1). They noticed that sound absorption coefficient has values up to 0.75, over the frequency range 100-5000 Hz, which recommend to develop the prototype of sound barrier made from recycled tyre granules. Lee & Kam estimated the mechanical properties of several elastically restrained laminated composite plates through experimental investigation using the impulse vibration test. Based on experimental natural frequencies, Lee and Kam identify the elastic constants of laminated composite plates with free boundary conditions (14). Deobald and Gibson analyzed a thin orthotropic plate with different boundary conditions and discovered that a plate with all boundaries free can obtain better results than that with one or more fixed edges (9). McIntyre and Woodhouse estimated both elastic and damping constants of thin orthotropic plates measuring the low modes of vibrations (15). Cugnoni & all evaluating the constitutive properties of composite laminates through a mixed numerical– experimental identification procedure based on both the extracted mode shapes and the corresponding natural frequencies of the structures (6). Hatami & all analyze vibration of multi-span travelling cross-ply laminates and a semi-analytical finite strip method with arbitrary boundary conditions (12). Tran Ich Thinh and Tran Huu Quoc studied the free vibration and bending failure of laminated stiffened glass fiber/polyester composite plates with laminated open section (rectangular or T-shaped) and closed section (hat shaped) of stiffeners by finite element method and experiment investigation (19). Stanciu M. D., Curtu I., (2010) applied the impact hammer test to determine the natural frequency and damping ratio of lignocelluloses plates (18). The previous studies of authors are focused on finite element analyses and experimental research of plates from guitar body, bodies as individual structures and in conjunction with neck in terms of dynamical behavior (fundamental frequency, natural frequency, logarithmic decrement, resonance frequency and modal shape (8). Cerbu and Curtu studied the influence of aggressive environmental factors on elastic properties of composite materials (4).

EXPERIMENTAL SETUP

The composite plates made from different materials as plywood (spruce, lime, hornbeam), E-fiber glass mixed with wood flour and epoxy/fiber glass layers were supported by elastic pads around the peripheries (corners) of rectangular plates. The method of impulse vibration tested consists of exciting the composite plate (structure) on central points with an *impact hammer* for light structures as it can be seen in Figure 1.

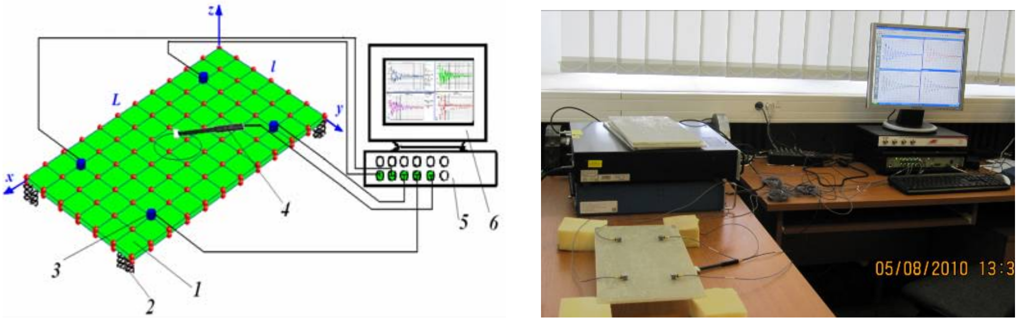

Figure. 1 *Experimental set-up of vibration testing (1- studied sample, 2 – flexible pads, 3 - accelerometer (s), 4 - impact hammer, 5 - Pulse hardware, 6- Pulse software)*

The response of structure to vibrations has been captured by means of four accelerometers (measuring on z direction) located in symmetrically points of the plate (18). The captured signal was displayed with Pulse soft and the primary data were processed with ME' Scope VES 4.0 software. The experimental stand was built as it can be seen in Figure 1. Each plate (1) was freely supported on a foam device (2) and hit with impact hammer type B & K 8204 (4) in central point of plate. The vibrations of plate were captured with four accelerometers type B&K 4320 (3) and transmitted to Pulse hardware and displayed with Pulse soft. A work program in Pulse soft was developed to capture and processing the experimental data. The connections of experimental set-up has been configured, the types of measurements and implicit functions (Time, Fast Fourier Transform, Fourier Spectrum, Complex Time) were established. The results of measurement were displayed in a different task of soft and saved as files for processing with ME' Scope program.

RESULTS AND DISCUSSIONS

First results obtained with Pulse system refer to time capture and frequency response spectrum which are similarly with Figures 2 and 3.

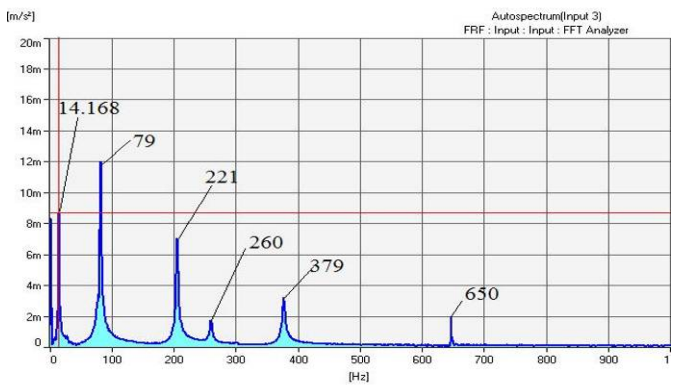

Figure 2. *Frequency response spectrum of the Sample 5 E-Glass/ softwood flour*

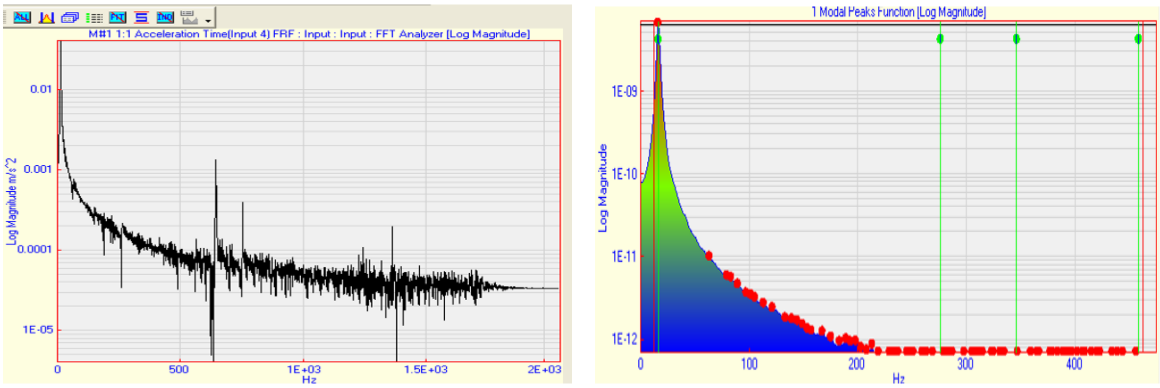

Figure 3. *Signal Processing with ME' Scope soft*

The dynamical behaviour of composite plates is governed by the damped harmonic motion. Applying Fast Fourier Transform (FFT) to the time signal exported from Pulse to ME' Scope soft, the values of natural frequencies and damping coefficient were obtained as it. It is found that the analyzed composite plates present multiple natural frequencies. In the next part of paper the fundamental frequencies and damping ratio will be discussed.

Processing the data with ME'Scope soft, it were determine the fundamental frequency and damping ration ζ which are summarized in Table 1.

Table 1. *Measured and calculated values of fundamental frequency and damping ratio*

Sample	*Mass m [Kg]*	*Calculated Fundamental Frequency f [Hz]*	*Experimental Fundamental Frequency f [Hz]*	*Experimental Damping Ratio ζ*
Sample 1 Plywood Spruce	0.281	8.2556	9.331	0.018
Sample 2 Plywood Hornbeam	0.350	8.7866	9.612	0.024
Sample 3 Plywood Lime	0.312	10.4650	9.923	0.017
Sample 4 E-Glass/ hardwood flour	0.839	13.8208	13.894	0.043
Sample 5 E-Glass/ softwood flour	0.752	14.23396	14.619	0.040
Sample 6 Epoxi/glass	1.084	12.1067	12.775	0.039
Sample 7 Epoxi/glass	1.265	11.7514	11.975	0.042
Sample 8 Epoxi/Glass	1.094	10.3952	10.544	0.045

It was noticed that average values of fundamental frequency and damping ratio depending on the particular characteristics of composite materials of plate. In Figure 4 is displayed the comparison between calculated and measurement fundamental frequency.

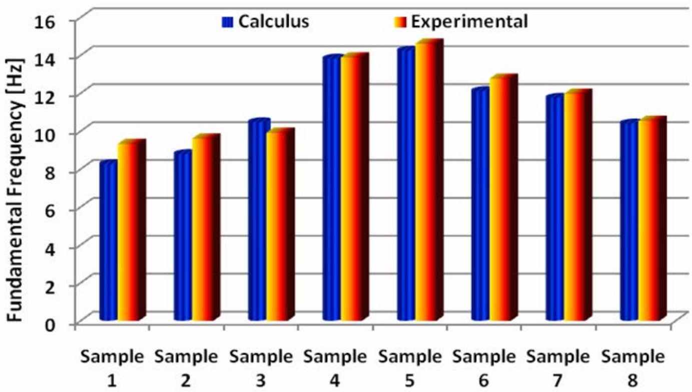

Figure 4. *Comparison between calculated and measurement fundamental frequency*

Wood and all lignocelluloses materials are versatile materials being used for acoustic insulating when the damping ratio and implicit the acoustic loss have big values (more than 0,02), or for resonance values in musical instruments construction. The highest values of natural frequencies were obtained in case of plates made from wood flour mixed with epoxy resin and fibre glass. With increasing the stiffness of plates, the eigenvalue increased too.

Comparing the experimental results with literature as is shown in Table 2, it can be remarks that we obtained similarly values, in terms of approximate experimental methods and composite.

Table 2. *Comparison of results to the literature ones*

References Experimental	Stanciu Spruce plywood	Bucur (2006) Sitka spruce Solid wood	Stanciu Sample 6 Epoxi/glass	Lee & Kam (2006)	Masoud (1999)
Natural Frequency f [Hz]	9.476	9.531	12,775	13,95	13,94
Damping Ratio ζ	0.017632	0,013000	0,039	-	-

It can be noticed that were obtained small differences due to the hypothesis used in mathematical chalculus. The calculus is based on Eq (1), where: h is thickness of plate [mm], L – witdh of plate [mm], E – Young's Modulus [MPa], ρ – Density [kg/m^3] and n – the number of mode (17).

$$f_n=(0.113*h/L^2)*sqrt\ (E/\rho)\ *\ [3.0112^2,\ 5^2,\ ....(2n+1)^2 \qquad (1)$$

CONCLUSSION

The present method the presented method is an advanced variant of scientific research to study the dynamic characteristics of materials in a modern and relatively easy way. Impact hammer method involves the proper equipment, an adequate software and rigor in determination. This method of scientific investigation can be used for any type of structure and material. In our research the acoustical characteristics of lignocelluloses composite plates were presented. Each species presents own macro and microstructure, for which appreciation acoustic characteristics requires a very rigorous statistical study, which is not subject to present research. Even within the same species, there were differences due non-homogeneity sensitive material timber and method of cutting. The further investigation will continue with other types of lignocelluloses composite plates: medium density fiber (MDF), chipboard (PAL), lamella panels, corrugate and others. After the fundamental frequency and damping ratio determination, the sound absorption coefficient, reflection coefficient, acoustic impedance, transmission loss coefficient will be studied for each wood based materials using advanced equipment of High Tech Product for Automotive Department and all results will be correlated with noise barrier design.

ACKNOWLEDGMENTS

This paper is supported by the Sectoral Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and by the Romanian Government under the contract number POSDRU POSTDOC-DD, ID59323.

REFERENCES

Asdrubali Fr., Baldinelli, G., D'Alessandro Fr., Evaluation of the acoustic properties of materials made from recycled tyre granules, in Proceedings of 36th International Congress and Exhibition on Noise Control Engineering, August 28-31, Istanbul, 2007.

Berglund Birgitta, Lindvall Th., (1995) Community Noise, Archives of the Center for Sensory Research, 1995, 2(1), 1-195, ISBN 91-887-8402-9, 1995.

Bucur, V. "Acoustic of wood" Springer-Verlag Berlin Heidelberg New York, 2006.

Cerbu, C., Curtu, I., Ciofoaia, V., Rosca I. C., Hanganu, L. C., "Effects of the Wood Species on the Mechanical Characteristics in Case of Some E-Glass Fibres/Wood Flour/Polyester Composite Materials", in Rev. Materiale Plastice, MPLAAM 47 (1) 2010, Vol. 47, nr. 1 – martie 2010, Bucuresti Romania, ISSN 0025/5289 – ISI (CNCSIS A), pp.109-114, 2010.

Ciafrini, C., Corcione, M., Fontana, L. (2007) Experimental verificatiom of the acoustic performance of diffusive roadside noise barriers, Applied Acoustics 68, 1357-1372, 2007.

Cugnoni, J., Gmur, Th., Schorderet, A., Inverse method based on modal analysis for characterizing the constitutive properties of thick composite plates, Computers and Structures 85, 1310–1320, 2007.

Curtu, I., Ghelmeziu, N. Mechanics of Wood and Wood Based Materials (in Romanian language), Ed. Tehnică, Bucureşti, România 1984.

Curtu I, Stanciu M, Cretu N & Rosca I, "Modal Analysis of Different Types of Classical Guitar Bodies", Proceedings of the 10th WSEAS International Conference on Acoustics & Music: Theory & Applications – AMTA09, 23-25 March 2009, Prague, Czech Republic, pp. 30-34, 2009.

Deobald LR, Gibson RF. Determination of elastic constants of orthotropic plates by a modal analysis/Rayleigh–Ritz technique. Journal of Sound Vibration 124:269–83, 1988.

Duhring, M., Jensen J., Sigmund O., Acoustic design by topology optimization, Journal of Sound and Vibration 317 (2008) 557-575, 2008.

Environment Noise Directive 2002/49/CE, Guidelines on Strategic Noise Mapping and Action Planning, 2002.

Hatami, S., Azhari, M., Saadatpour, M.M., Free vibration of moving laminated composite plates, Composite Structures 80 (2007) 609–620, 2007.

Ishizuka, T., Fujiwara, K., Performance of noise barriers with various edge shapes and acoustical combination, Applied Acoustics 65 (2004), 125-141;

Lee, C.R., Kam, T.Y., Identification of mechanical properties of elastically restrained laminated composite plates using vibration data, Journal of Sound and Vibration 295, 999–1016, 2006.

McIntyre ME, Woodhouse J. On measuring the elastic and damping constants of orthotropic sheet materials. Acta Metallurg 36, p. 1397–416, 1988.

Peyrard D., Utilisation combine des revetements de chaussee et des ecran antibruit, Jurnees d'Etude Bruite du Traffic Routier, Comite Francais, Nantes, 2001.

Rossing, T., Fletcher, N., „Principle of Vibration and Sound" – second edition. Springer Science, New York, 2004.

Stanciu M. D., Curtu I., "Using Advanced Method To Determine The Acoustical Parameter Of Lignocellulose Composite Materials", in Proceedings of the 12th International Conference AFASES 2010, organizata de Academia Fortelor Aeriene Henri Coanda din Brasov, 27-29 mai 2010.

Tran Ich Thinh, Tran Huu Quoc, Finite element modeling and experimental study on bending and vibration of laminated stiffened glass fiber/polyester composite plates, Computational Materials Science, 2010.