Acoustic Performance of Composite Materials Made from Textile Waste

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Abstract: - Research presented in this paper are focused on determining the acoustic performance of some composite materials made from textile waste as raw materials and polyurethane foam as binder. Negative effects of pollution intensified research on acoustic materials based on renewable resources, which can lead to viable alternatives to conventional materials for current and future applications. The produced materials were characterized in terms of acoustic performance, by determining the acoustic absorption coefficient and acoustic impedance using the impedance tube and was analyzed the influence of structure and thickness of these materials on the sound absorbing properties.

Keywords: - acoustic impedance, sound absorption coefficient, textiles waste, composite materials

1. INTRODUCTION

A variety of methods exist for treating waste and end-of-life textiles. It is of interest to investigate the solutions to avoid landfilling or incineration in favor of recycling and reusing textile and fiber waste.

A trend of great interest and great actuality is the research orientation towards using alternative raw materials (especially waste) and finding new solution to reduce noise in the context of environmental related problems.

Textile waste is a source of raw materials with various recovery possibilities due to their diversity. These types of products have a long history, but in the past they were used only to obtain paper and not to obtain new textile products. Textile waste recovery has positive effects on the environment, on employment and also on revenue of those involved.

Utilization of textile fabric in composite materials as reinforcement is well recognized for high-performance fabric, just like it is with natural fabric.

Research confirms the possibility to use different types of fibers, natural or synthetic, in making composite materials with acoustic properties. Thus, researchers have used different waste with fibrous characteristics to obtain sound absorbing materials: cellulose fibers [1, 2], cotton [3], bamboo fibers [4], hemp fibers [5], jute fibers [6], banana fibers, nonwoven short polypropylene fibers [7], coconut fibers [8], textile fibers [9] and agricultural waste [10].

Recently, search for new high performance materials at affordable costs has been expanded, as a result of the increasing environmental awareness. The search was also focused on developing, creating and innovating eco-friendly materials [11].

Fibers and fiber containing products have followed the same trend towards sustainability. Because fiber production and textile processing are sophisticated processes and demand large amounts of energy, the reuse and recycling are highly recommended, not only for ecological reasons but also for economic reasons.

2. MATERIALS AND METHOD

2.1. Materials

The binder used for making composite materials makes the bond with the reinforcing material, and influences the physical, mechanical and acoustic properties and establishes the final structure of the material.

For the production of composite materials from textile wastes with sound absorbing properties, two systems of bi-component polyurethane foam were used as binder, one for obtaining a material with a flexible structure and open pores, and the other for a material with a rigid structure and closed pores.

The polyol component of the foam mixture includes polyol, catalyst and other additives. The isocyanate component includes a diphenyl methane diisocyanate mixture [12].

Textile waste (Figure 1) used as raw materials for making sound absorbing composite materials, come from the production of knitted clothing (knitting on straight section machines). The textile waste is made of synthetic fibers, with the following composition: 15% polyamide, 40% polyacryl and 45% modal.

Figure 1. Textiles waste

To study the acoustic performance of composite materials obtained from textile waste and polyurethane foam, six samples were analyzed. The materials mix is presented in table 1.

Table 1. The samples mix

Samples	Type of binder	Binder [%]	Textiles waste [%]	Thickness [mm]
M1	Rigid Polyurethane Foam	90	10	40
M2		90	10	50
M3		40	60	40
M5		100	0	
M4	Flexible Polyurethane Foam	40	60	
M6		100	0	

2.2. Density test

Density of a material is often considered to be an important factor governing the acoustic absorption of a material. Meanwhile, the cost of an acoustic material is directly related to its density. In a study conducted by Koizumi et al [4], it was proved that with the increase of material density, sound absorption at medium and high frequencies also increases.

Density of obtained materials was determined in accordance with SR EN 323:96. Samples were weighed and measured according to the standard, and density was calculated using the formula [13]:

$$\rho = \frac{m}{l \cdot L \cdot d} \quad [\mathrm{g/cm^3}] \tag{1}$$

Where:

m – mass of the sample, [g].

L, l, d – length, width and thickness of the sample [mm].

2.3. Sound absorption coefficients and acoustic impedance

Acoustic performance of sound absorbing materials is defined by a set of constants determined experimentally or analytically, namely: absorption coefficient, reflection coefficient, acoustic impedance, propagation constant and transmission losses. There are different methods to determine these acoustic parameters, but all these methods mainly involve material exposure to known sound fields and measuring their effect.

The impedance tube was used to determine the sound absorption coefficient and acoustic impedance of sound absorbing materials analyzed.

Material measurements were based on a two-microphone transfer-function method according to ISO 10534-2 [14].

In this study, a medium tube kit from Brüel&Kjaer Type 4206 A was used to measure different acoustic parameters for the frequency range of 100 ÷ 3200 Hz.

The acoustic system for material testing consists of: Brüel&Kjaer Type 4206 A medium impedance tube, two 4187 Brüel&Kjaer microphones, Analyzer PULSE 3560-B-030 acoustic signal generator, 2716 Brüel&Kjaer signal amplifier and a PC for recording and processing results with the Brüel & Kjaer PULSE interface [15].

The medium impedance tube kit consisted of a 63.5 mm diameter tube and therefore materials were cutting on circular samples with a diameter of 63.5 mm (Figure 2).

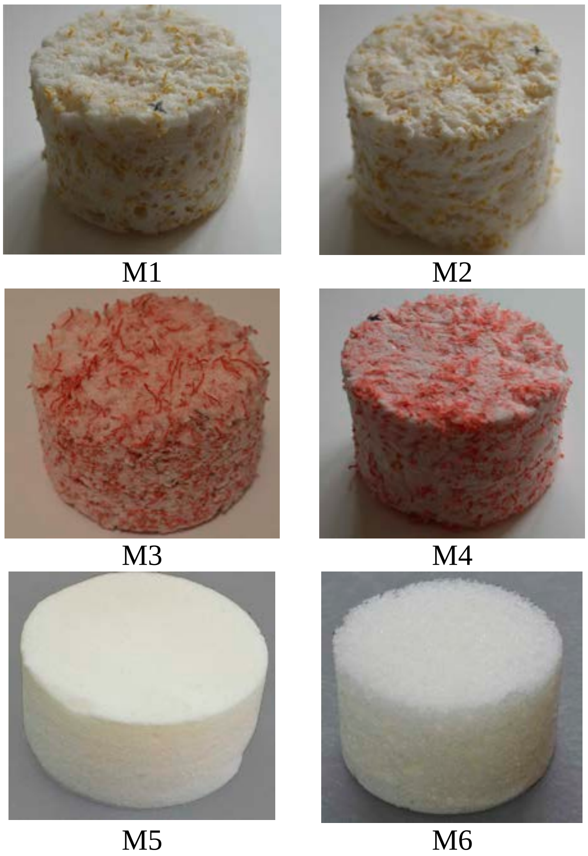

Figure 2. Materials used for determining the sound absorption coefficient

3. RESULTS AND DISCUSSION

3.1. Density

Density variation plot of sound absorbing composite materials made in this research, depending on the type of binder and percentage of added waste, is represented in Figure 3. It can be observed that density of materials obtained from rigid polyurethane foam with closed pores (M1, M3 and M5) is higher than density of materials made from flexible polyurethane foam with open pores (M4 and M6).

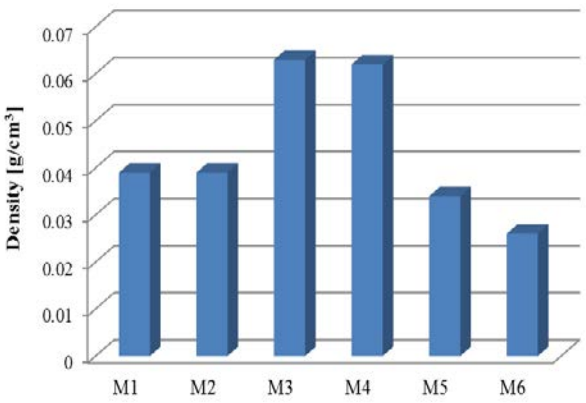

Figure 3. Density of composite materials

Also, as seen in Figure 3 we can conclude that with the increase of textile waste percentage used for obtaining sound absorbing composite materials, material density also increases (M1, M3 and M5).

3.2. Effect of material thickness on the sound absorption coefficient

Studies that have dealt with the absorption of sound in porous materials concluded that: at low frequencies, the sound absorption coefficient is influenced by material thickness [16-18].

In Figure 4 we can observe that with the increase of material thickness the value of the absorption coefficient increases, resulting in improved sound absorbing properties, at frequencies lower that 700 Hz and higher than 2000 Hz.

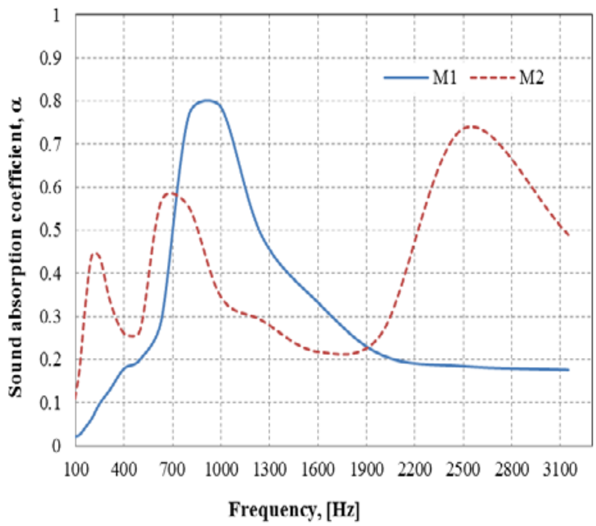

Figure 4. Sound absorption coefficient variation depending on thickness of materials

3.3. Effect of material structure on the sound absorption coefficient

The influence of textile waste percentage used in obtaining composite materials based on rigid polyurethane foam on the sound absorption coefficient is presented in Figure 5.

In the graphical representation we can observe that composite materials have sound absorbing properties superior to material M5 (100% rigid polyurethane foam) on the whole frequency range that was analyzed. Material M2 (40% textile waste and 60% binder) has the best sound absorbing properties in the frequency ranges of 100÷900 Hz and 1300÷3100 Hz.

The maximum value of the acoustic absorption coefficient of 0.83 is achieved by material M3 at a frequency of 800 Hz, and respectively by material M5 at a frequency of 1000 Hz.

$$Z = Zr + jZi \qquad (2)$$

Where: Zr – resistive component;
Zi – reactive component.

The two components of acoustic impedance are very important because they also concern energetic phenomena related to the propagation of sound waves. The resistive part of impedance sums up energy losses through thermal phenomena, vibrations of various encountered objects, viscosity phenomena and interaction with the boundary layer. On the other hand, the reactive component sums up elastic effects of gas of propagation environment.

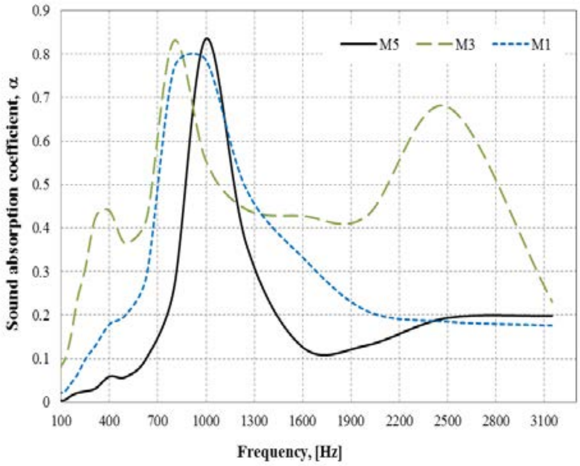

Figure 5. Sound absorption coefficient variation depending on percentage of waste textiles

Due to the fact that rigid polyurethane foam (M5) has a cellular structure with closed pores, we can observe in Figure 6 that it has sound absorbing properties lower than flexible polyurethane foam (M6 with cellular structure and open pores) on the whole frequency range analyzed.

Also in Figure 6 we can observe that material M6 (100% flexible polyurethane foam) has the best sound absorbing properties, excepting the frequency range of 600÷900 Hz, where M3 (40% textile waste and 60% rigid polyurethane foam) has the best sound absorbing properties and the frequency range of 1200÷1400 Hz, where M4 (40% textile waste and 60% flexible polyurethane foam) has the best sound absorbing properties.

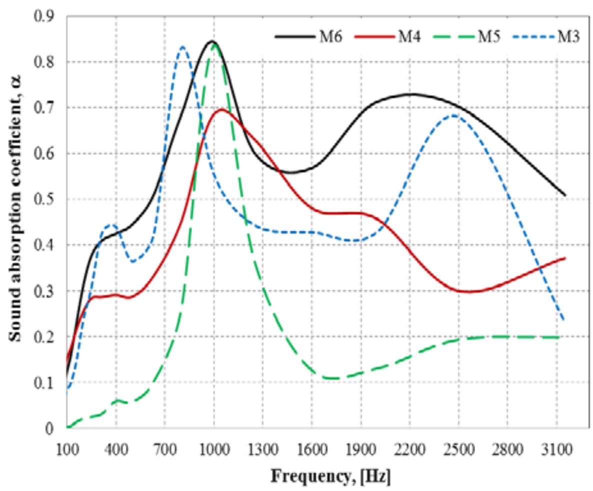

Figure 6. Sound absorption coefficient variation depending on type of binder

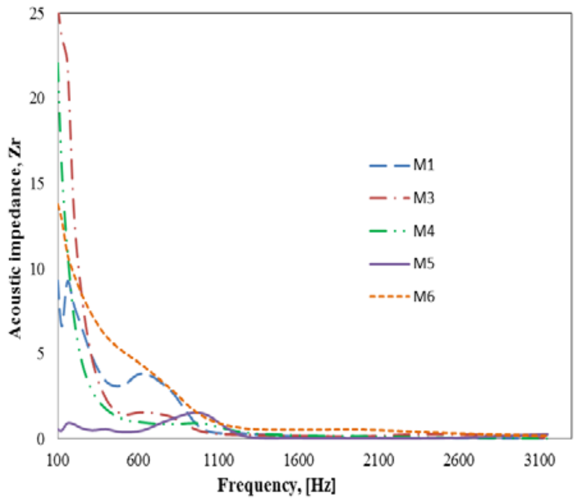

Figure 7. Real part of acoustic impedance for samples used

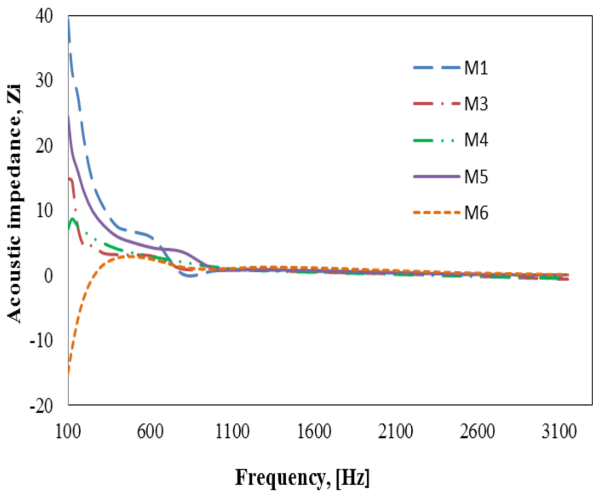

Figure 8. Imaginary part of acoustic impedance for samples used

3.4. Acoustic impedance

Impedance is a complex number and is used to take into account the relationship between phase of the wave and acoustic speed [19].

Figures 7 and 8 show, respectively, the real and the imaginary part of acoustic impedance obtained from different samples. The real part is the resistance associated with energy losses and the imaginary part is the reactance associated with phase changes.

4. CONCLUSIONS

By developing new sound absorbing materials, we try to eliminate the classic waste recovery methods, which can be an advantage in the reduction of waste quantity and at the same time of sound pollution.

Sound absorbing material performance depends mainly on the material structure and thickness.

The obtained materials could be used in making sound absorbing panels for use in industry, road, rail or air transportation.

The application of composite materials reinforced with textile fiber forms is basically limited to low and medium load bearing applications. Thus, research should be continued to improve the fiber reinforced composite materials to suit the purpose of application.

Textile recycling impacts many entities and contributes significantly to the social responsibility of today's society.

ACKNOWLEDGMENTS

This paper was supported by the Post-Doctoral Programme POSDRU/159/1.5/S/137516, project co-funded from European Social Fund through the Human Resources Sectorial Operational Program 2007-2013.

REFERENCES

[1] E. Gliścińska, M. Michalak, I. Krucińska, J. Kazimierczak, A. Bloda, D. Ciechańska, Sound Absorbing Composites from Nonwoven and Cellulose Submicrofibres, *Journal of Chemistry and Chemical Engineering*, Vol.7, 2013, pp. 942-948.

[2] I. Krucińska, E. Gliścińska, M. Michalak, D. Ciechańska, J. Kazimierczak, A. Bloda, Sound-absorbing green composites based on cellulose ultra-short/ultra-fine fibers, *Textile Research Journal*, Vol. 85, Issue 6, 2015, pp. 646-657.

[3] M. Akaydin, K. Yilmaz, N.D. Yilmaz, Effect of finishing on performance characteristics of wovwn and warp-knitter terry fabrics, *Indian Journal of Fibre &Textile Research*, Vol.40, 2015, pp. 301-307.

[4] T. Koizumi, N. Tsujiuchi, A. Adachi, *The Development of Sound Absorbing Materials Using Natural Bamboo Fibers*, High Performance, WIT Press, 2002.

[5] P. Glé, E. Gourdon, L.Arnaud, Acoustical properties of materials made of vegetable particles with several scales of porosity, *Applied Acoustics*, Vol.72, 2011, pp. 249 – 259.

[6] S. Fatima, A.R. Mohanty, Acoustical and fire-retardant properties of jute composite materials, *Applied Acoustics*, Vol.72, 2011, pp. 108 – 114.

[7] G. Thilagavathi, E. Pradeep, T. Kannaian, L. Sasikala, Development of Natural Fiber Nonwovens for Application as Car Interiors for Noise Control, *Journal of Industrial Textiles*, Vol.39, 2010, pp.267 – 278.

[8] M. Fouladi, et al. Analysis of coir fiber acoustical characteristics, *Applied Acoustics*, Vol. 72, 2011, pp. 35 – 42.

[9] I. Curtu, M.D. Stanciu, C. Cosereanu, O.Vasile, Assessment of Acoustic Properties of Biodegradable Composite Materials with Textile Inserts, *Revista de Materiale Plastice*, Vol. 49, 2012.

[10] E. Jayamani, S. Hamdan, S. K. Heng, M. R. Rahman, Sound Absorption Property of Agricultural Lignocellulsic Residue Fiber Reinforced Polymer Matrix Composites, *Applied Mechanics and Materials*, Vol. 663, 2014, pp. 464-468.

[11] T. Alomayri, F.U.A. Shaikh, I.M. Low, Characterisation of cotton fibre-reinforced geopolymer composites, *Composites Part B: Engineering*, Vol.50, 2013, pp. 1–6.

[12] N.N. Mat Hassan, Anika Zafiah M. Rus, Acoustic performance of green polymer foam from renewable resources after uv exposure, *International Journal of Automotive & Mechanical Engineering*, Vol.9, 2014, pp. 1639.

[13] Standardul SR EN 323:96 Plăci pe bază de lemn. Determinarea masei volumice.

[14] Standard SR EN ISO 10534-2, Determination of sound absorption coefficient and acoustic impedance with the interferometer. Part 2. Transfer function method, 2002.

[15] A. Borlea (Tiuc), T. Rusu, S. Ionescu, Research on obtaining soundproof materials from wastes, *Acta Technica Napocensis, Series: Environmental Engineering and Sustainable Development Entrepreneurship*, Vol. 1, No. 3, 2012, pp. 13-20.

[16] M. Coates, M. Kierzkowski, *Acoustic Textiles - Lighter, Thinner And More Absorbent*, Technical - Textiles -International, 2002.

[17] A.J. Kannan, *Acoustical Absorptive Properties of Nonwovens*, A thesis submitted to The Graduate Faculty of North Carolina State University in partial fulfillment of the requirements for the Degree of Master of Science, Textile management and technology, Raleigh, 2005

[18] O. Buzzi, S. Fityus, Y. Sasaki, S. Sloan, Structure and properties of expanding polyurethane foam in the context of foundation remediation in expansive soil, *Mechanics of Materials*, Vol. 40, 2008, pp. 1012–1021.

[19] S.W. Rienstra, A. Hirschberg, *An Introduction to Acoustics*, Eindhoven University of Technology, Ed. of IWDE 92-06, 2015.