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SOUND ABSORPTION OF RECYCLED PLASTIC MATERIAL

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Abstract - *In this paper an empirical model to predict the acoustic properties of materials, recycled plastics and polyurethane resins as a binder is developed. The parameters of model were determined on the basis of samples of thicknesses from 10 mm to 50 mm. Measurement of the sound absorption coefficient was performed in an impedance tube – Transfer function method (SRPS EN ISO 10534-2:2008). In order to form an empirical model, on the same samples was carried out measuring the resistance of the air flow according to the method SRPS ISO 9053:1994.*

Keywords: *recycled plastic, absorption coefficient, passive noise protection*

1. INTRODUCTION

Research by various authors has shown that materials from the recycled plastic can be made with the desired acoustic properties.

Energy consumption in the construction sector can reach up to 40% of the total energy demand of an industrial country. Sustainable materials can play an important role, as less energy is usually needed for their production than is required for conventional materials. In the past few years, many new noise control materials have been studied and developed as alternatives to traditional (glass or stone wool); these materials are natural (cotton, cellulose, hemp, wool, clay, etc.) or made of recycled materials (rubber, plastics, carpets, cork etc.). [1]

In recent years, many new noise control materials have been studied and developed as alternatives to traditional (glass and stone wool); these are natural materials (cotton, cellulose, hemp, wool, clay, etc.) or recycled (rubber, plastic, carpet, cork, etc.) [2]

In the paper [3], the possibilities of attenuation of noise by means of absorption materials are shown, among which are plastic materials, which can be used for the production of sound barriers.

Murugan in his work [4] presents the ways of using recycled plastic waste for sound absorption.

Wood-plastic composites are a new group of materials that can be used because of their acoustical properties in the range of 25 Hz to 2000 Hz. A wide range of polymers such as polypropylene, polyethylene, polyvinyl chloride and so on are used in the production of wooden plastic composites. [5].

To address noise pollution, materials such as rock wool, glass wool and asbestos in the past used as sound absorbers for decades. These materials are harmful to both producers and consumers and could endanger human health [6,7].

The effect of density on the dissipation of sound energy will require further study of the microstructure. Compared to conventional noise reduction materials, wood-plastic composites have excellent absorption characteristics at medium and low frequencies, and in addition require less space for installation. The results showed that the wood-plastic composites have a wide potential applications, particularly in view of their ability to further recycling. [8]

The sound absorption of various fibrous materials, including a series of plastic, was experimentally tested. The results show the relationship between sound absorption and air resistance. Higher airflow resistance always gives better sound absorption, but for air resistance greater than 1000, sound absorption has less value, because in that case there are difficulties in moving sound waves through the material. [9]

Polyester fibrous materials made from recycled plastic bottles (PET) have also been studied. [10]

In recent years, researchers such as [11-13] have been working on composites with a combination of plastic and rubber granular material. Embedding granular materials such as rubber crumb, increases the density of filling and the resistance of composite materials. [14]

Composite materials are increasingly used for sound insulation. Particularly are important composites that can be characterized as "green" that include different recycled materials such as, recycled rubber, recycled plastics, and waste materials from industrial processes. Zainulabidin [15] and others have studied the acoustic properties of two kinds of materials: rubber sponges and fibers of glass wool.

Soleimani [16] and others examined the acoustics mixture of wood fibers and recycled plastics. Samples are dried and cast in molds for a certain amount of time. The research show that the addition of nano-clays to the composite, the water absorption decreased and that the plastic has a negligible water absorption.

The acoustic properties of rubber were the subject of many studies [17-21] in order to examine the possibility of using rubber barriers and panels for noise reduction.

In works by Radičević, Ristanović, Kolarević [22-25], experimental research on the acoustic and non-acoustic properties of recycled rubber and recycled plastics material have been demonstrated, on the basis of which an empirical model for the prediction of the acoustic properties of these materials have been formed.

The assumption is that the empirical models that exist for the recycled rubber can also be useful for recycled plastics, bearing in mind that it is also a granular material that is bound with a polyurethane resin.

2. MATERIAL

The basic raw materials used for the preparation of the samples is obtained by grinding a recycled plastic. Grain size in the granulate ranges from 1mm to 3mm. The average density of the samples for testing was 759.5 kg / m3. The percentage of the binding agent (polyurethane resin) was 10%.

Test samples were made from recycled plastics granules from insulation from automotive cables (granule dimensions 3 to 5mm) and polyurethane resin binding agent. Samples were 10mm, 20mm, 30mm, 40mm and 50mm thick and were cast in molds of 100mm diameter without pressing to ensure porosity of the samples (Figure 1.). Recycled plastics belongs to a group of PVC materials .

Fig. 1 *The appearance of the test sample*

Fig. 2 *Structure of the sample from recycled plastic*

When sound is spread in interconnected pores of a porous material, it loses its sound energy. This energy loss is due to the complex heterogeneous microstructure and the viscous effects of the boundary layer, so that the sound energy is dissipated through friction with the pore walls. As with viscous effects, there are losses due to thermal conductivity from the air to the porous material, which are expressed in low frequencies [22].

Due to the accelerated global depletion of raw materials, especially oil, it is expected that waste plastic in the future will have the character of a valuable resource.

3. METHODS

The measurement of absorption was done in the impedance tube by using the transfer function method between two microphones, defined in the EN ISO 10534-2 [26]. This method is based on the decomposition of the standing wave which is formed in the tube by recording signals from two microphones and calculating their transfer function. The reflection coefficient is calculated from the transfer function, and then the absorption coefficient is calculated under conditions of normal incidencea.

$$\alpha = 1 - |R|^2 \tag{1}$$

where R is the reflection coefficient calculated according to the expression:

$$R = \frac{H - e^{-jks}}{e^{jks} - H} e^{j2k(l+s)} \tag{2}$$

where: H – the corrected transfer function, s – the distance between the microphones, l – the distance between the closer microphone and the sample, k – the wave number.

In order to form an empirical model for determining the acoustic impedance and material coefficient, measurement of the resistance to air flow was also performed.

Air resistance is one of the main non-acoustic parameters that shows the behavior of porous materials used in sound absorption systems. The standard SRPS ISO 9053 specifies two methods for measuring airflow resistance: a steady state airflow method and an alternating airflow method. The paper presents the results of measurements using the method of constant air flow.

The vacuum pump ZAMBELLI, type ZB1, is used as the device for creation of airflow. The pump is of a membrane type and can realize the maximum free flow of 30 l/min. The underpressure produced by the pump is higher тхан 0.773 bar (580 mmHg)). The pump has two airflow metres, which operates on тhe principle of the ball rotametre. Smaller airflows in the range of 0.2÷6 l/min are measured by means of the smaller rotametre, and higher flows in the range of 5÷30 l/min are measured by means of the bigger rotametre. The maximum flow measurement error is ± 2%. The pump allows the fine control of flow and the stability of flow in the part of the measuring cell which is behind the sample. By its characteristics, the pump provides a sufficiently small air velocity so that the measured airflow resistance could not depend on air velocity. The pump enables airflow velocity of $0{,}4\cdot10^{-3}$ m/s in the measuring cell, which completely corresponds to the recommendations by the standard SRPS ISO 9053 ($0{,}5\cdot10^{-3}$ m/s).

In the measuring cell, the atmospheric pressure is on one side of the sample, and the underpressure produced by the vacuum pump is on the other side of the sample. In order to provide the conditions for maintaining underpressure, the measuring cell must be well sealed on one side. The differential pressure gauge TESTO 512 is used for measuring the difference in pressures on both sides of the sample. This gauge has a measuring range of 0 to 200 Pa with the resolution of 0.1 Pa. The equipment used allows measurement of differential pressure up to the accuracy ±5% of the specified value.

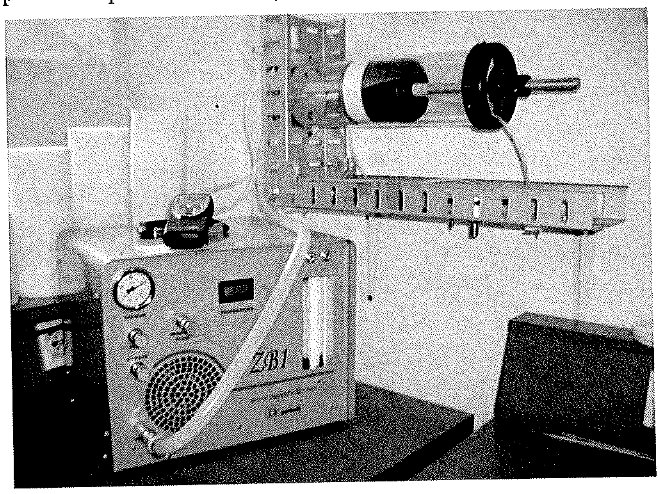

Fig. 3 *The appearance of a measuring system for determining the air flow resistance*

The measuring cell has the form of a circular cylinder, and it is made of plexiglass so that placing of the sample could be visually monitored. The inner diameter of the measuring cell is 100 mm, which satisfies the requirement of the standard SRPS ISO 9053 that the inner diameter must be longer than 95 mm. [27]

4 PROPOSAL FOR A NEW EMPIRICAL MODEL FOR DETERMINING THE ACOUSTIC PROPERTIES OF COMPOSITES OF GRANULAR MATERIALS

Theoretical models require five input parameters, which can not often be easily and reliably determined. This is the basic lack of the so-called phenomenological or micro models for determining the acoustic properties of porous materials. Therefore, in this paper, an experimental macro model for predicting acoustic properties of recycled rubber and plastic materials has been developed. The basic advantage of such models is that they have one input parameter - longitudinal resistance to air flow.

The propagation of sound in an isotropic homogeneous material can be represented by the characteristic impedance (Zc) and the sound propagation constant in the absorption material.

$$Z_c = R + jX \tag{3}$$

$$\gamma = \alpha + j\beta \tag{4}$$

Starting from the well-known Delany & Bazley relations:

$$R = \rho_0 c_0 \left[1 + C_1 \left(\frac{\rho_0 f}{r} \right)^{-C_2} \right] \tag{5}$$

$$X = -\rho_0 c_0 \left[C_3 \left(\frac{\rho_0 f}{r} \right)^{-C_4} \right] \tag{6}$$

$$\alpha = \left(\frac{2\pi f}{c_0} \right) \left[C_5 \left(\frac{\rho_0 f}{r} \right)^{-C_6} \right] \tag{7}$$

$$\beta = \left(\frac{2\pi f}{c_0} \right) \left[1 + C_7 \left(\frac{\rho_0 f}{r} \right)^{-C_8} \right] \tag{8}$$

where R and X are real and imaginary parts of characteristic acoustic impedances Zc, and α i β real and imaginary parts of propagation constant (γ) of the sound in absorption material, ρ_0 – air density, f - frequency and r - longitudinal resistance to air flow.

Starting from equations (9) to (13) and the recommendations of European norm EN 12354-6: 2003, the diffuse coefficient of sound absorption of porous materials can be calculated. For a diffuse acoustic field, the absorption coefficient α_s can be determined as:

$$\alpha_s = \int_0^{\pi/2} \alpha_\varphi \sin 2\varphi d\varphi \tag{9}$$

$$\alpha_\varphi = 1 - |r_\varphi|^2 \tag{10}$$

$$r_\varphi = \frac{Z' cos\varphi - 1}{Z' cos\varphi - 1} \tag{11}$$

$$Z_c' = \frac{Z_c}{\rho_0 c_0} \tag{12}$$

$$Z' = Z_c' \coth \gamma d \tag{13}$$

where:

- φ - angle of incidence, in radians,
- α_φ - the absorption coefficient for a plane sound wave, bound to the angle φ,
- r_φ - reflection coefficient for plane sound wave, bound to the angle φ,
- Z' - normalized surface impedance layer
- Z_c' - normalized characteristic impedance of absorbent material,
- d - layer thickness m.

An empirical macroscopic model for the determination of the acoustic properties of recycled plastic materials can not be found in the available scientific literature. A new model for the prediction of the acoustic properties of composites of recycled rubber and plastics was developed using the method of the smallest squares. By calculating the coefficients C1, ..., C8, the deviation of the absorption coefficient is minimal in relation to the values obtained by measuring in the impedance tube.

Table 1 *Basic parameters of the new empirical model*

Material	Recycled plastic
Longitudinal resistance to air flow, r [Pas/m^2]	5045
Characteristic impedance, Z_c	$Z_c = \rho_0 c_0 \left[\left(1 + 0.570 \cdot C^{1.221}\right) - i\left(1.74E-07 \cdot C^{1.649}\right) \right]$ (14)
Coefficient of expansion, γ	$\gamma = \frac{2\pi f}{c_0} \left[\left(0.174 \cdot C^{0.843}\right) + i\left(1 + 0.680 \cdot C^{0.0594}\right) \right]$ (15)
Coefficient of absorption EN 12354-6:2003	$\alpha_s = \int_0^{\pi/2} \alpha_\varphi \sin 2\varphi d\varphi$ (16)
Medium absolute error, $\Delta\bar{\alpha}$	0.0384
Medium relative error, $\bar{\varepsilon}$ [%]	28.0

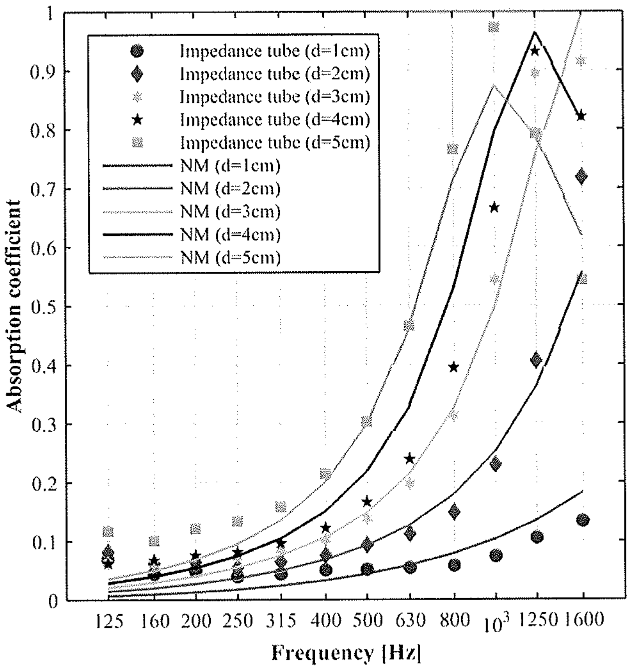

Fig. 4 *The absorption coefficient of the recycled plastic material according to the prediction of the new model in relation to the measured values in the impedance tube*

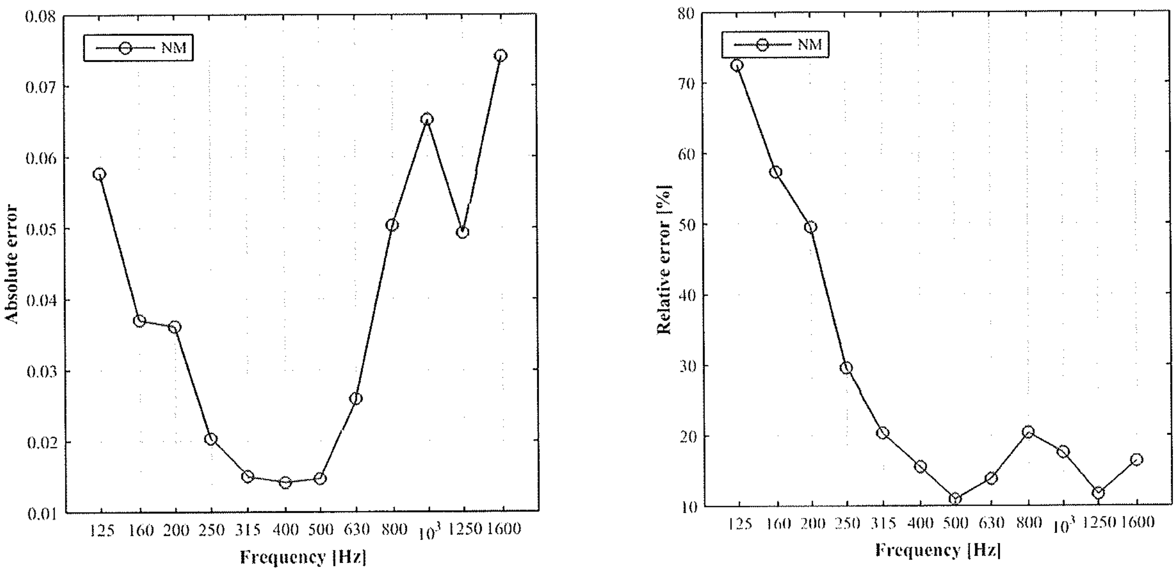

Fig. 5 *Absolute and relative error of model*

The deviation of the absorption coefficient obtained using the new proposed model in relation to the impedance tube measurement is 3.84%, [28] which is very good compared to the most frequently used limit value of 10% from the available scientific literature.

5 CONCLUSION

The paper presents the methodology for the formation of the empirical macroscopic model for predicting the acoustic properties of composites from recycled plastic. As the input parameter in the model, the measured longitudinal resistance to air flow was used for five different sample thicknesses.

The new model has confirmed the good absorption properties of composites of recycled plastics. The average absolute error of the new model is 3.84% in relation to the measured values of the sound absorption coefficient in the impedance tube. On this basis, the new model can be considered as adequate for assessing acoustic properties of recycled plastics, where polyurethane resin is used as a binding agent.

With the increase in the number of materials to which a new model can be applied, it can also be expected to improve it in terms of prediction of acoustic properties of porous materials. Considering that the grain structure material has been analyzed, it is realistic to expect that this model can be applied to predict acoustic properties and other porous materials with a grain structure.

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