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ACOUSTIC PROPERTIES OF RECYCLED PLASTIC

Milan Kolarević [1*], *Branko Radičević* [1], *Vladan Grković* [1], *Ivana Ristanović* [2], *Marina Ivanović* [1]
[1] University of Kragujevac, Faculty of Mechanical and Civil Engineering, Kraljevo, Serbia, kolarevic.m@mfkv.rs
[2] Visoka škola tehničkih strukovnih studija, Čačak, Srbija

Abstract - *This paper presents the results of testing acoustic properties of samples formed of recycled plastics granules and a binding agent made of polyurethane resins. The testing was performed in an impendance tube with the diameter of 100 mm by using the transfer function method between two microphones defined by the standard SRPS EN ISO 10534-2. The samples with the thickness between 10mm and 50mm were tested. The results show that recycled plastics has excellent absorption properties and that the increase in thickness of the material leads to the increase in the values of the sound absorption coefficient at lower frequencies..*

Keywords – *recycled plastics, absorption coefficient, passive noise protection*

1. INTRODUCTION

The acoustic properties of polyurethane foams, fibrous and granular materials were examined within the project TR 37020 “Development of Methodologies and Means for Noise Protection in Urban Enviroments” financed by the Ministry of Education, Science and Technological Development of Republic of Serbia [1]. Special attention was given to recycled materials such as recycled rubber and recycled plastics and their possible application for noise protection.

Acoustic properties of rubber and the possibility of using rubber for passive noise protection have been the subject of a lot of research [2÷6]. It has been shown that the preliminary results of the absorption coefficient of these tyre samples, under normal incidence conditions, are rather high.

In addition to rubber, a large part of industrial waste is also taken up by plastic waste. This paper presents the initial results of the research organised for the purpose of finding possibilities for mastering new products on the basis of recycled plastics granules obtained by removing the worn electric cables.

1.1. Research plan

The research plan involves testing of acoustic properties of recycled rubber granules in the frequency range 125Hz-1600Hz as well as the dependence of the sound absorption coefficient on the material thickness. The factors tested and the intervals of their change are presented in Table 1.

1.2. Material and preparation of samples

The testing samples were made of recycled plastics granules (granule dimensions from 3 to 5mm) and a binding agent made of polyurethane resins. The samples were 10 mm, 20 mm, 30 mm, 40 mm and 50 mm thick and they were cast in moulds whose diameter was 100mm without pressing in order to provide the porosity of samples (Figure 1).

Table 1 *Factors for response surface study*

Factor	Name	Mark	Units	Low Level (-1)	High Level (+1)
A	frequency	*f*	Hz	125	1600
B	thickness	*d*	m	0.01	0.05

Enlarged view of the structure of the granulate from recycled plastic is shown in Figure 2.

The physical properties of recycled plastic materials have not been tested and will be subject to future research.

1.3 Method and equipment

The absorption coefficient was measured in an impedance tube at the Laboratory for Acoustics at the Faculty of Electrical Engineering in Belgrade. Transfer function method between two microphones, described in the SRPS EN ISO 10534-2 standard was used [7].

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. This method results in obtaining the values of the absorption coefficient at normal incidence, in the frequency range defined by the physical dimensions of the tube and the distance between the microphones. By using this method, it is possible to obtain fast measurements for normal incidence, using small samples.

$$\alpha = 1 - |R|^2 \qquad (1)$$

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

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

where:

- *H* - the corrected transfer function,
- *s* - the distance between microphones ,
- *I* - the distance between the closer microphone and the sample, and
- *k* - the wave number.

Fig. 1 *Samples made of recycled plastics*

Fig. 2 *Enlarged view of the structure of the granulate from recycled plastic*

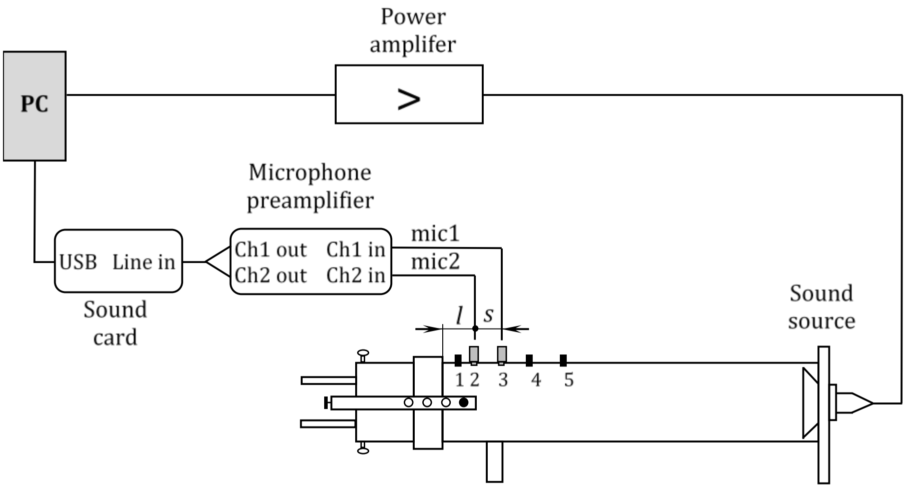

Fig. 3 *System for measuring absorption according to the standard SRPS EN ISO 10534-2 [7]*

The method of the impedance of thet tube has numerous advantages, which are described in the literature [7], the most important of them being:

- the measuring device is of small dimensios, so that is very practical for use ,
- the samples themselves have small dimensions, which facilitates their preparation for measurement,
- small costs of the experiment.

The disadvantages of this method:

- only normal incidence of waves are measured, although it is possible to apply correction to obtain a value of the absorption coefficient with random incidence,
- different diameters of tubes and samples are necessary in order to cover a wider frequency range.

2. RESULTS AND DISCUSSION

2.1. Experimental results

Experimental values of the absorption coefficient per 1/3 octave bands for different material thicknesses obtained by measuring in the impedance tube are shown in Table 2.

From Table 2. and Figure 4. the following can be noted:

- At low frequencies up to 400Hz, recycled plastic does not have pronounced absorption properties.

- The absorption coefficient ranges in the interval from 0,05 for the thickness of 10mm to 0,21 for the material thickness of 50mm.
- The absorption coefficient increases with the increase in the material thickness.
- For the material thicknesses from 10mm to 30mm the maximum value of the absorption coefficient is at the frequency of 1600Hz as follows: for d=10mm it is α=0,13, for d=20mm it is α=0,72 and for d=30mm it is α=0,91.
- For the plastics thickness of d=40mm, the maximum value of the absorption coefficient is α=0,93 for the frequency f=1250Hz while this value decreases at higher and lower frequencies.
- For the plastics thickness of d=50mm the maximum value of the absorption coefficient is α=0,97 for the frequency f=1000Hz while this value decreases at higher and lower frequencies.

It can be concluded that the absorption coefficient of recycled plastic increases with the increase in the material thickness, but at the same time its maximum moves toward relatively lower frequencies up to 1000Hz. In comparison with recycled rubber [8], recycled plastic has slightly more advantageous absorption properties.

Table 2 *Values of the absorption coefficient for recycled plastic*

***f* (Hz)**	***d* (cm)**				
	1	**2**	**3**	**4**	**5**
125	0.07045	0.08159	0.06360	0.06229	0.11737
160	0.04500	0.06167	0.06059	0.06724	0.10029
200	0.04998	0.06342	0.07518	0.07554	0.12036
250	0.03962	0.05359	0.07307	0.08124	0.13322
315	0.04424	0.06393	0.08620	0.09630	0.15780
400	0.05110	0.07538	0.10281	0.12230	0.21353
500	0.05196	0.09267	0.13902	0.16619	0.30182
630	0.05469	0.11156	0.19746	0.23917	0.46519
800	0.05815	0.14845	0.31262	0.39413	0.76533
1000	0.07396	0.22894	0.54481	0.66599	0.97240
1250	0.10531	0.40526	0.89514	0.93225	0.79133
1600	0.13402	0.71772	0.91522	0.82113	0.54213

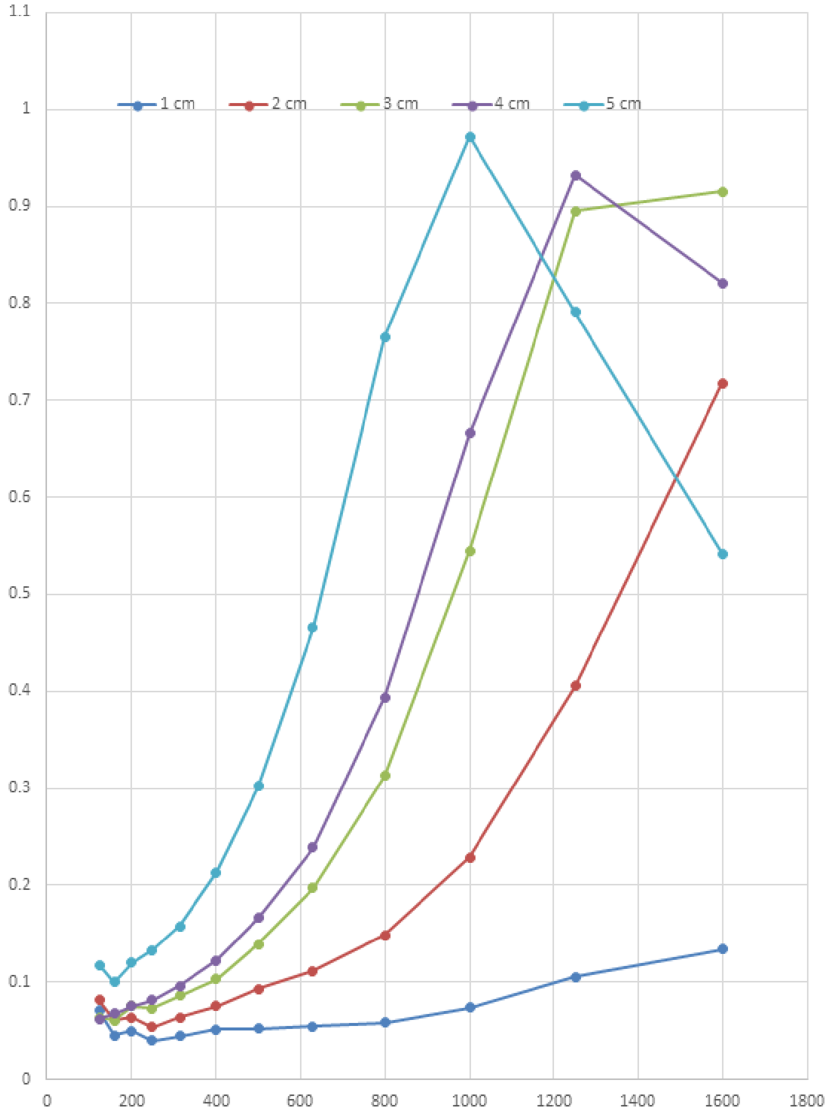

Fig. 4 *Values of the absorption coefficient for recycled plastic*

2.2. Procession and analysis of the experimental results

The data procession was performed in the software package Design Expert v.9.0.6.2. [9-11]. Out of the available mathematical models, the models proposed have the form of third and fourth degree polynomials (Table 3).

Table 3 *Summary statistics of possible mathematical models*

Source	Std. Dev.	R-Squared	Adjusted R-Squared	Predicted R-Squared	PRESS	
Linear	0.39	0.8466	0.8412	0.8212	10.02	
2FI	0.37	0.8652	0.8580	0.8076	10.78	
Quadratic	0.34	0.8900	0.8798	0.8277	9.65	
Cubic	0.11	0.9890	0.9870	0.9821	1.00	Suggested
Quartic	0.10	0.9917	0.9891	0.9725	1.54	Suggested
Fifth	0.095	0.9935	0.9905	0.9616	2.15	Aliased

The cubic model was adopted. In order to improve the results of the analysis, it was necessary to perform the transformation of the response function by means of the natural logarithm (Natural Log, k=0, λ=0). After reduction of nonsignificant members from the proposed model, the analysis of variance (ANOVA) for the transformed cubic model was performed.

Table 4 *ANOVA report for recycled plastic*

ANOVA for Response Surface Cubic model						
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	55.39	9	6.15	497.56	< 0.0001	significant
A-f	9.02	1	9.02	729.60	< 0.0001	
B-d	1.85	1	1.85	149.85	< 0.0001	
AB	0.35	1	0.35	28.64	< 0.0001	
A^2	1.00	1	1.00	80.59	< 0.0001	
B^2	2.05	1	2.05	165.43	< 0.0001	
A^2B	2.18	1	2.18	175.93	< 0.0001	
AB^2	2.34	1	2.34	189.49	< 0.0001	
A^3	0.58	1	0.58	47.20	< 0.0001	
B^3	0.44	1	0.44	35.44	< 0.0001	
Residual	0.62	50	0.012			
Cor Total	56.01	59				

The high F value of the model (F=497,56) and the low value of probability (p<0,0001) indicate that the model is significant. The coefficient of determination (R-Squared) and other statistic (Table 5.) have good values, which justifies the selection of the adopted mathematical model.

The final equation of the mathematical model which adequately describes the dependence of the sound absorption coefficient of recycled plastic on the frequency and the material thickness is:

$$Ln(\alpha) = -2.77031 - 5.63955E{-}003\cdot f + 54.58375\cdot d + 0.29244\cdot f\cdot d + 5.00031E{-}006\cdot f^2 - 3554.33097\cdot d^2 - 7.15031E{-}005\cdot f^2\cdot d - 2.61071\cdot f\cdot d^2 - 1.37120E{-}009\cdot f^3 + 50369.01689\cdot d^3 \quad (1)$$

Table 5 *Calculation values of the statistics for the evaluation of the mathematical model*

Std. Dev.	0.11
Mean	-1.92
C.V. %	5.80
PRESS	1.00
R-Squared	0.9890
Adj R-Squared	0.9870
Pred R-Squared	0.9821
Adeq Precision	68.485

The value of regression coefficients of the mathematical model, the standard error, 95% confidence intervals and the Variance inflation factor (VIF) of regression coefficients are presented in Table 6.

Table 6 *Values of coefficients of the mathematical model and confidence intervals*

Factor	Coefficient Estimate	df	Standard Error	95% CI		VIF
				Low	High	
Intercept	-1.05	1	0.032	-1.12	-0.99	
A-f	1.95	1	0.072	1.81	2.10	9.55
B-d	0.83	1	0.067	0.69	0.96	11.02
AB	0.18	1	0.034	0.11	0.25	1.43
A^2	-0.38	1	0.042	-0.46	-0.29	1.10
B^2	-0.51	1	0.040	-0.59	-0.43	1.33
A^2B	-0.78	1	0.059	-0.90	-0.66	3.17
AB^2	-0.77	1	0.056	-0.88	-0.66	2.76
A^3	-0.55	1	0.080	-0.71	-0.39	8.30
B^3	0.40	1	0.068	0.27	0.54	9.03

The diagnostics of statistical characteristics of the model (diagram of normal distribution of residuals, BoxCox diagram, etc.) show that residuals are normally distributed and that the model has satisfactory statistical characteristics.

The graphical presentation of the mathematical model described by Eq. (1) is shown in Figures 5. and 6.

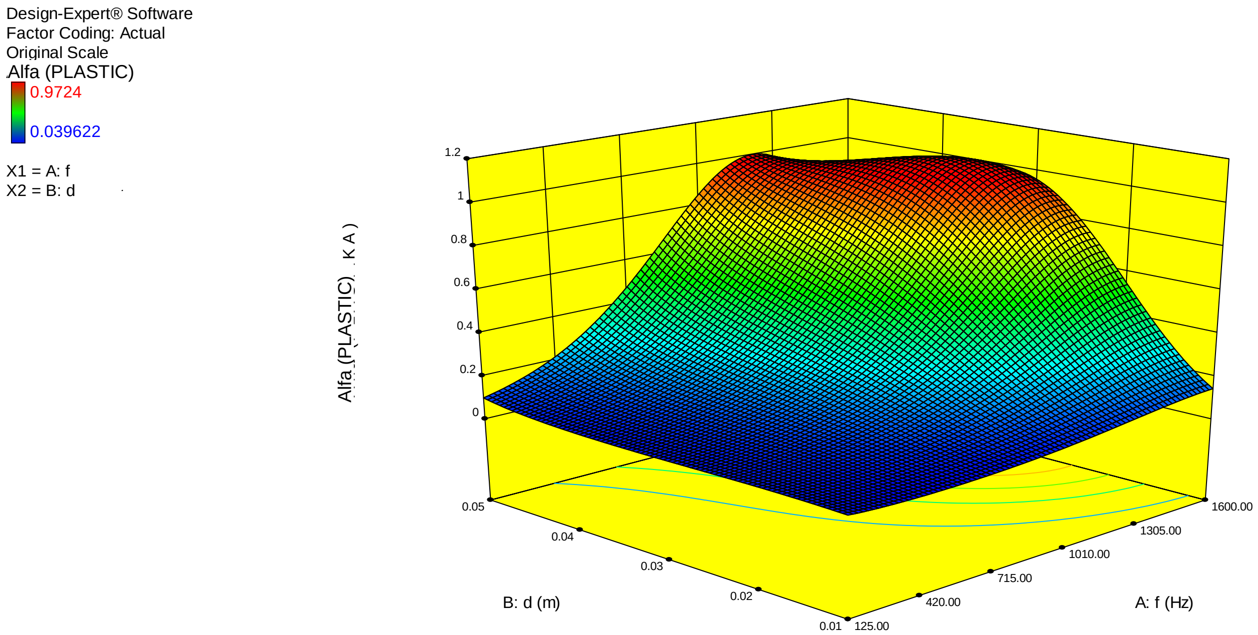

Fig. 5 *3D graphical presentation of the dependence of the absorption coefficient on the material thickness in the examined frequency range*

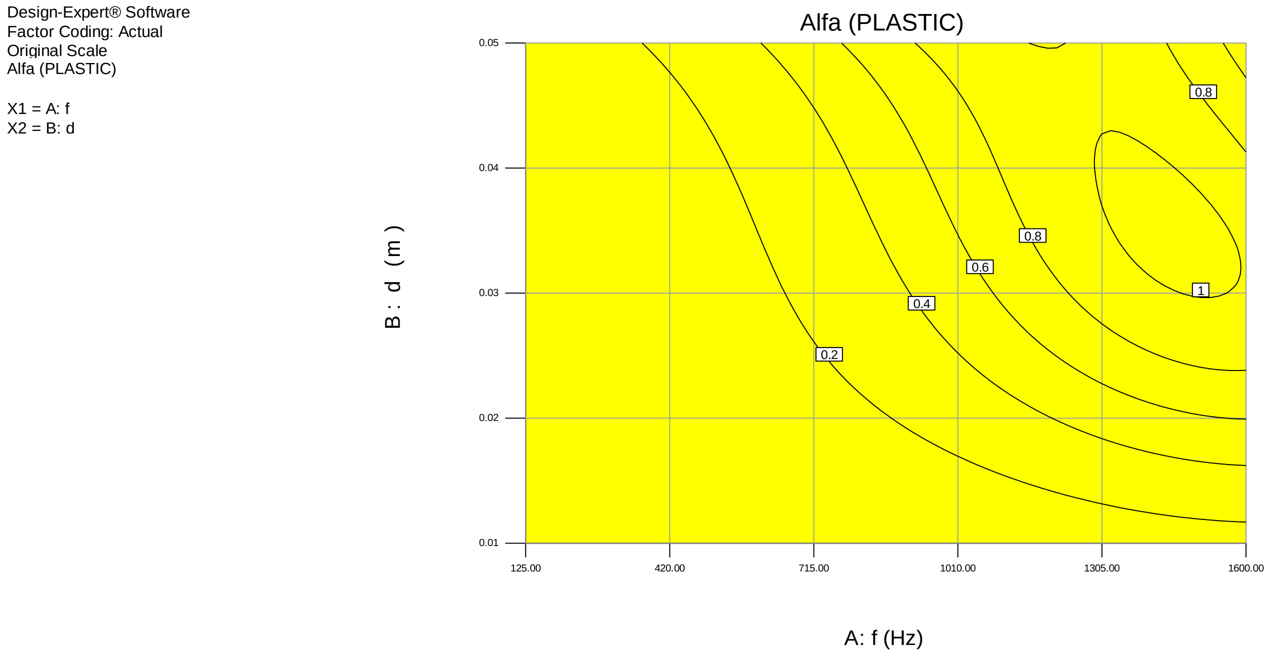

Fig. 6 *Contour 2D presentation of the mathematical model for recycled plastic*

3. CONCLUSION

Experimental results show that the absorption coefficient of recycled plastic increases with the increase in frequency up to the value of 1250Hz and after that it decreases. The best values of absorption coefficient are obtained in the interval of 800Hz do 1600Hz.

At higher frequencies above 1250Hz the thickness of the material has a significant effect on increasing the absorption coefficient to a thickness of 30mm and after that has a negative effect which causes a slight decrease of the absorption coefficient.

It can be concluded that these materials manifest a high level of sound absorption in the medium frequency range, which is not characteristically in most absorption materials, and as such can have a wide range of applications in the field of noise protection.

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