

Comparative analysis of thermal and acoustic performance of composites made from wood fibres, recycled rubber and ABS

S V Georgescu¹ and C Cosoreanu^{1*}

¹ Department of Wood Engineering and Wood Products Design, Faculty of Wood Engineering, Transilvania University of Brasov, B-dul Eroilor 29, Brasov, Romania

* E-mail: cboieriu@unitbv.ro

Abstract. The paper investigates the thermal and acoustic properties of composites made from wood fibres (WF) and recycled rubber (R) crumbs and acrylonitrile butadiene styrene (ABS) shavings resulted in the particleboards' edge banding. Panels with a target density of 300 kg/m³ were manufactured for testing the thermal conductivity coefficient and sound absorption coefficient. Mixed panels WF:ABS, R:ABS with participation rates (in %) of 10:90, 20:80, 30:70; 40:60; 50:50 and WF:R:ABS with participation rates (in %) of 5:5:90, 10:10:80, 15:15:70; 20:20:60; 25:25:50 were investigated in this paper. The experiment simulated the indoor and outdoor temperature conditions for the winter and summer seasons, namely 20 °C for indoor and -10 °C to 35 °C for the outdoor temperatures. The results show that, with the increase of ABS share, the thermal performance of the panel increases. The presence of WF in the composition has a good influence on the thermal performance of the panels, whilst the presence of rubber brings a better acoustic performance of the composites. The analysis of the results show that the thermal conductivity coefficient (λ) experimentally determined depends on the outdoor temperature and recorded the best value for the composite WF-ABS (0.0434 Wm⁻¹K⁻¹) followed by WF-R-ABS (0.0460 Wm⁻¹K⁻¹) and R-ABS (0.0477 Wm⁻¹K⁻¹). Maximum values were recorded for R-ABS structure at a temperature of 35 °C (0.0573 Wm⁻¹K⁻¹), but this structure recorded the best sound absorption coefficient (0.87).

1. Introduction

Today's high consumption is one of the major causes of waste accumulation. Some materials, such as rubber and plastics decompose naturally over decades and centuries respectively, study estimates. A feasible way to reduce the inventory of such waste materials is to recycle them and design new added value products.

Acrylonitrile-Butadiene-Styrene copolymer (ABS) is a thermoplastic widely used in appliance housings, automotive interior parts, electrical devices, toys, medical equipment and furniture, because of its toughness, dimensional stability, heat and scratch resistance and excellent colour and aesthetic functions. Nowadays, the researchers investigate the possibility of recycling the used and aged ABS, by end-of-life treating and reprocessing it into new products [1, 2], or by using natural fillers such as agro-wastes [3, 4] or wood flour [5, 6] incorporated into ABS-matrix and obtaining composites with low density, improved strength and water resistance and good thermal performance. An unused resource of ABS results in the edge banding process of melamine faced particleboard in the furniture industry. Generally, the edge of melamine faced particleboard is preferably banded with ABS, which is 1.5 mm wider than the thickness of particleboard and it is finally removed by a levelling operation.



Even though ABS polymers are used largely for mechanical purposes, they also have good thermal insulation properties and the present research intends to use this waste resource to obtain composites with high thermal and acoustic performance.

Waste tires are significant raw materials for use in composites, because of rubber characteristics, such as good elasticity, sound insulating and light weight. The short life time of rubber and improvement of the living standards have as result a major demand for recycling the waste tires. Considering the thermal and acoustic properties as outputs, fine or coarse recycled tire rubber crumbs are used by researchers as fillers or matrix in manufacturing and testing composites with application in construction [7, 8, 9]. By adding wood flour, novel composites with tailored mechanical properties and optimized water resistance were obtained and tested by researchers in composites field [10, 11, 12]. Other recycled plastics such as high-density polyethylene (HDPE) or low-density polyethylene (LDPE) blended with rubber and wood dust resulted in strengthened and water resistant composites [13, 14].

In this study recycled ABS-rubber-wood fibres based composites were obtained, where ABS acts as a matrix, wood fibres and rubber as fillers. The obtained composites could be used as potential heat and sound insulating materials. The thermal and acoustic properties of the composites were characterized by performing tests for thermal conductivity and sound absorption.

2. Experimental

2.1. Materials

The materials used in designing and developing composites are presented in figure 1, and they are wood fibres (WF), recycled tire rubber crumbs (R) as fillers and acrylonitrile-butadiene-styrene waste particles (ABS) as matrix.

2.1.1. ABS waste. ABS used in the present research was obtained from the production facility of the Wood Engineering Faculty in Brasov, Romania, where ABS waste particles were collected in special bags attached to the edge banding machine. ABS waste consists of thin shavings of various colours (figure 1), having thicknesses between 0.2 mm and 0.5 mm, lengths in the range 2 mm - 16 mm and widths in the range 1 mm - 2.5 mm.



Figure 1. Sample of ABS shavings resulted in the furniture manufacturing process of edge banding melamine faced particleboard and used in the present research as matrix for new composites.

2.1.2. Recycled tire rubber crumbs. One size of crumb rubber was used to prepare the composites, namely coarse crumb rubber with particle size ranging from 2 mm to 4 mm. The rubber was provided by a local supplier and it was used in the present research as filler (figure 2).



Figure 2. Sample of crumb rubber with sizes between 2 mm and 4 mm used in the present research as filler for the new composites.

2.1.3. Wood fibres. The wood fibres were supplied by Kastamonu Romania, located in Reghin and they constitute the raw material used by the company to produce medium density fibreboard. The fibres are a mixture of 80% resinous wood and 20% beech wood (figure 3).



Figure 3. Wood fibres composed of 80% resinous wood and 20% beech wood, used in the present research as filler for the new composites.

2.2. Composites manufacturing

The composites were prepared using different ABS, R and WF shares, as shown in table 1. The target density of the panels was 300 kg/m³. The components were mixed mechanically for 5 minutes and the mixture was then poured into suitable wood frames with the interior dimensions of 420 mm x 420 mm x 16 mm. It should be mentioned that it was difficult to prepare homogenous composites with more than 50% rubber content. The mat thus formed had an initial thickness of 50 mm and resulted with the final thickness of 16 mm after hot pressing. A thermo-resistant foil was used to cover the faces and edges of the mat in order to prevent sticking of the sample with the hot press. The mixture thus formed was then introduced in the hydraulic hot press machine at a temperature of 160 °C and hot pressed between the plates for 20 minutes without applying a pressure from the plates. After conditioning the panels for 48 hours, they were sized to 410 mm x 410 mm x 16 mm and then cut into specimens and subjected to different thermal and acoustic tests according to European standards. The number and sizes of specimens used for the tests are according to DIN EN 12667: 2001 standard and SR EN ISO 10534-1: 2002.

Table 1. Composites prepared for thermal and acoustic investigations and concentrations of ABS, R and WF.

	ABS (%)	R (%)	WF (%)
WF-ABS 1	90	0	10
WF-ABS 2	80	0	20
WF-ABS 3	70	0	30
WF-ABS 4	60	0	40
WF-ABS 5	50	0	50
WF-R-ABS 1	90	5	5
WF-R-ABS 2	80	10	10
WF-R-ABS 3	70	15	15
WF-R-ABS 4	60	20	20
WF-R-ABS 5	50	25	25
R-ABS 1	90	10	0
R-ABS 2	80	20	0
R-ABS 3	70	30	0
R-ABS 4	60	40	0
R-ABS 5	50	50	0

2.3. Test methods

2.3.1. Thermal conductivity. The tests were performed on HFM 436 Lambda equipment (Netzsch, Selb, Germany), according to ISO 8301: 1991 [16] and DIN EN 12667: 2001 [15]. This testing method is based on the determination of the quantity of heat that is passed from a hot plate to a cold plate through the sample. After recording the temperature difference between the cold plate and the hot plate, the thermal conductivity coefficient (λ) is automatically calculated based on Fourier's Law. The equipment is first calibrated depending on the temperature differences (ΔT) and mean temperatures (T_m) set for the experiment. Table 2 presents the values configured for temperature in order to simulate outdoor and indoor temperatures. In this respect, the indoor constant temperature was considered to be 20 °C. The dimensions of the specimens were of 300 mm x 300 mm x 16 mm. The average of three measurements was reported as result.

Table 2. Temperatures set on HFM 436 Lambda equipment for the determination of thermal conductivity coefficient (λ).

	Temperature T1 (°C)	Temperature T2 (°C)	$\Delta T = T2 - T1$ (°C)	$T_m = (T1 + T2) / 2$ (°C)
1	-10	20	30	5
2	-5	20	25	7.5
3	0	20	20	10
4	5	20	15	12.5
5	10	20	10	15
6	15	20	5	17.5
7	20	20	0	20
8	25	20	-5	22.5
9	30	20	-10	25
10	35	20	-15	27.5

2.3.2. Textural examination of composites. The examination of the composites was carried out using a HP Scanjet 7650 scanner. The samples with sizes of 50 mm x 20 mm x 20 mm were scanned with the highest resolution of 4800 dpi in order to achieve maximum magnification of textural and morphological characteristics of the composite edge. The scanned images were afterwards cropped and magnified so as to obtain a clear textural representation of the composite.

2.3.3. Sound absorption. The samples were tested using a SCS80FA impedance Kundt tube with the following characteristics: diameter of the tube of 100 mm and frequency range between 70 Hz and 1800 Hz. The standard Kundt's tube measurement method for the determination of the sound absorption coefficient under normal sound incidence was applied according to the SR EN ISO 10534-1: 2002 standard [17]. The circular specimens prepared for the experiment had a diameter of 100 mm and a thickness of 16 mm. The result reported in the research is the average value of three measurements.

3. Results and Discussion

3.1. Thermal conductivity measurements

The prepared composites with varying filler (WF and/or R) content ranging from 0 to 50% of the total mass were tested to determine their thermal conductivity coefficient (λ). The results, as seen in figure 4, show that the incorporation of fillers (R and/or WF) in the ABS matrix increases the value of the thermal conductivity coefficient. Thus, R-ABS composite has a higher λ as compared to both WF-R-ABS and WF-ABS composites, but all of them are good thermal insulators with thermal conductivity reaching values between 0.0434 Wm⁻¹K⁻¹ (for WF-ABS) and 0.0573 Wm⁻¹K⁻¹ for R-ABS (figure 5).

The same trend was noticed for WF-ABS sample, for which, with the increasing of the WF content, the thermal conductivity coefficient also increased. The higher values of the thermal conductivity coefficient both for R-ABS and WF-R-ABS samples are related to the big size of crumb rubber which occupies voids in the ABS matrix of composites and diminishes the air gaps of the structure and the porosity, affecting thus the thermal performances.

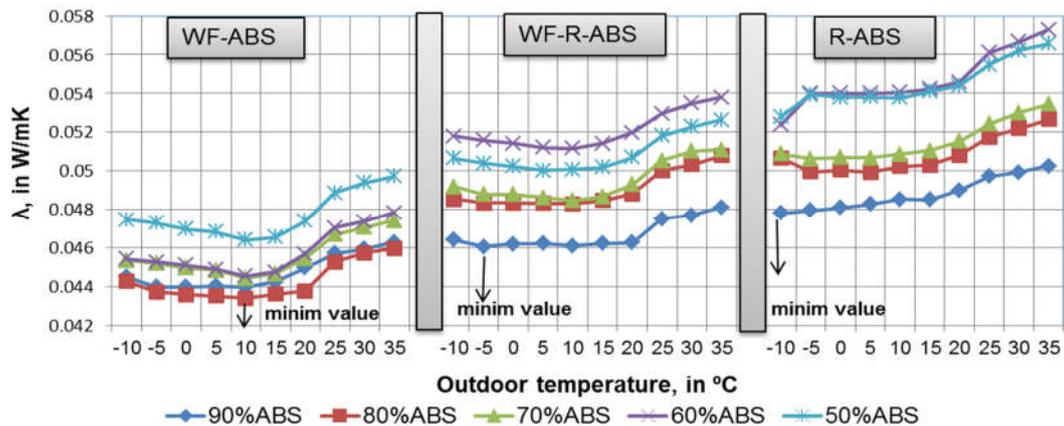


Figure 4. Thermal conductivity coefficient as function of temperature and structure.

The experimental results of all samples show that the thermal conductivity of the prepared composites depends on the temperature, as illustrated in figures 4 and 5. The thermal efficiency of the samples is different, depending on their components and structure. For example, the minimum thermal conductivity value obtained for the WF-ABS structure ($0.0434 \text{ Wm}^{-1}\text{K}^{-1}$) was reached at an outdoor temperature of $10 \text{ }^\circ\text{C}$ and $\Delta T = 10 \text{ }^\circ\text{C}$ respectively and an ABS content of 80% of the total mass. For the WF-R-ABS structure, the minimum value of λ was reached at an outdoor temperature of $5 \text{ }^\circ\text{C}$ (equivalent to $\Delta T = 15 \text{ }^\circ\text{C}$) and ABS content of 90% of the total mass, whilst for the R-ABS structure, the maximum efficiency was reached at a temperature of $-10 \text{ }^\circ\text{C}$ (equivalent to $\Delta T = 30 \text{ }^\circ\text{C}$ and a cold climate) and ABS content of 90% of the total mass. In general, the thermal conductivity of the prepared composites is promising and supports their utilization in constructive applications, their values being comparable with the thermal conductivity of commercial heat insulators such as EPS or XPS, for which the manufacturers provide technical sheets with values between $0.031 \text{ Wm}^{-1}\text{K}^{-1}$ and $0.045 \text{ Wm}^{-1}\text{K}^{-1}$. The maximum values of λ were recorded for an ABS content of 60% of the total mass in case of both R-ABS and WF-R-ABS structures, and 50% in case of the WF-ABS structure, for an outdoor temperature of $35 \text{ }^\circ\text{C}$ (equivalent to $\Delta T = -15 \text{ }^\circ\text{C}$ and a hot climate).

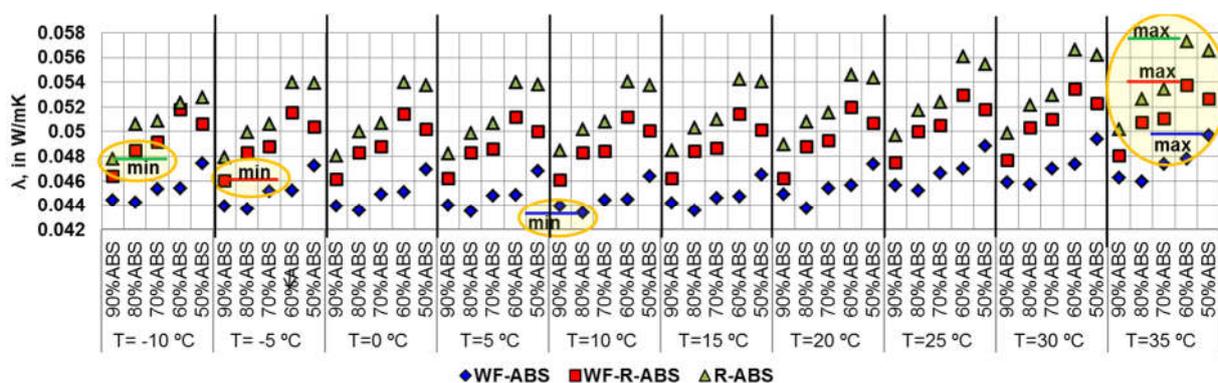


Figure 5. The dependence of thermal conductivity on ABS content and outdoor temperature.

3.2. Structure and morphology

Figure 6 presents the scanned structure and morphology of the prepared samples, showing differences between their cores and exterior faces. The structure is more compact on the faces, and the fillers are well incorporated in the ABS matrix, which practically melted at the contact with press hot plates and created a resistant surface of the composite. Instead, the core looks more porous, with a lot of voids created between the curled ABS shavings and filled from place to place by WF and R fillers.

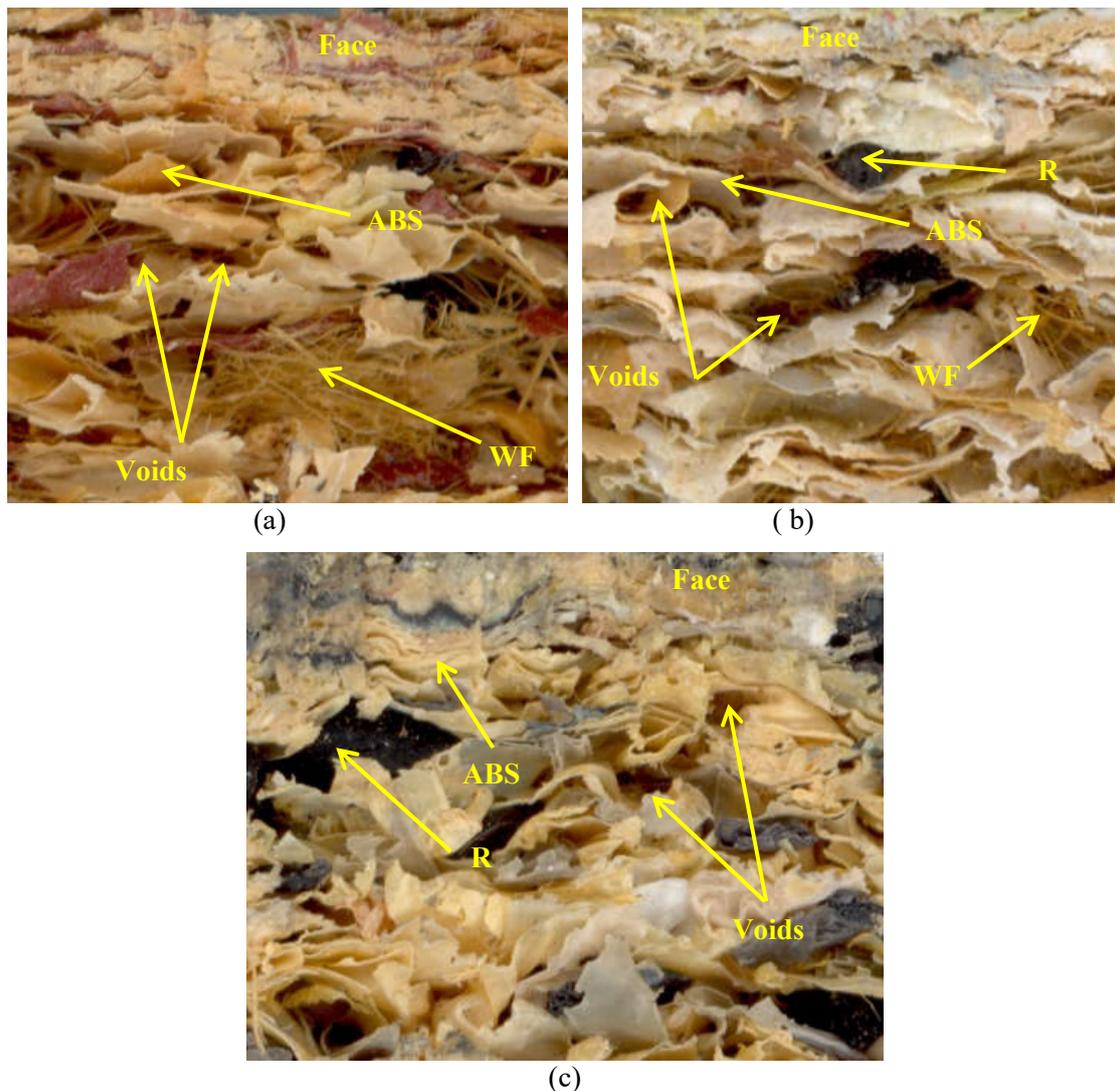


Figure 6. Scanned structures of composites with 50% ABS (a) WF-ABS, (b) WF-R-ABS, (c) R-ABS.

3.3. Sound absorption measurement

One sample of each composite panel was measured for sound absorption coefficient on the impedance tube. The results are shown in the diagrams in figures 7, 8 and 9. Contrary to the results of thermal conductivity, the rubber incorporation in the ABS matrix has a favourable influence on the acoustic performance of the composites. The best sound absorption coefficient was recorded for R-ABS sample with 50% R (0.87) followed by WF-R-ABS sample with 50% R (0.73) for frequencies around 1500 Hz.

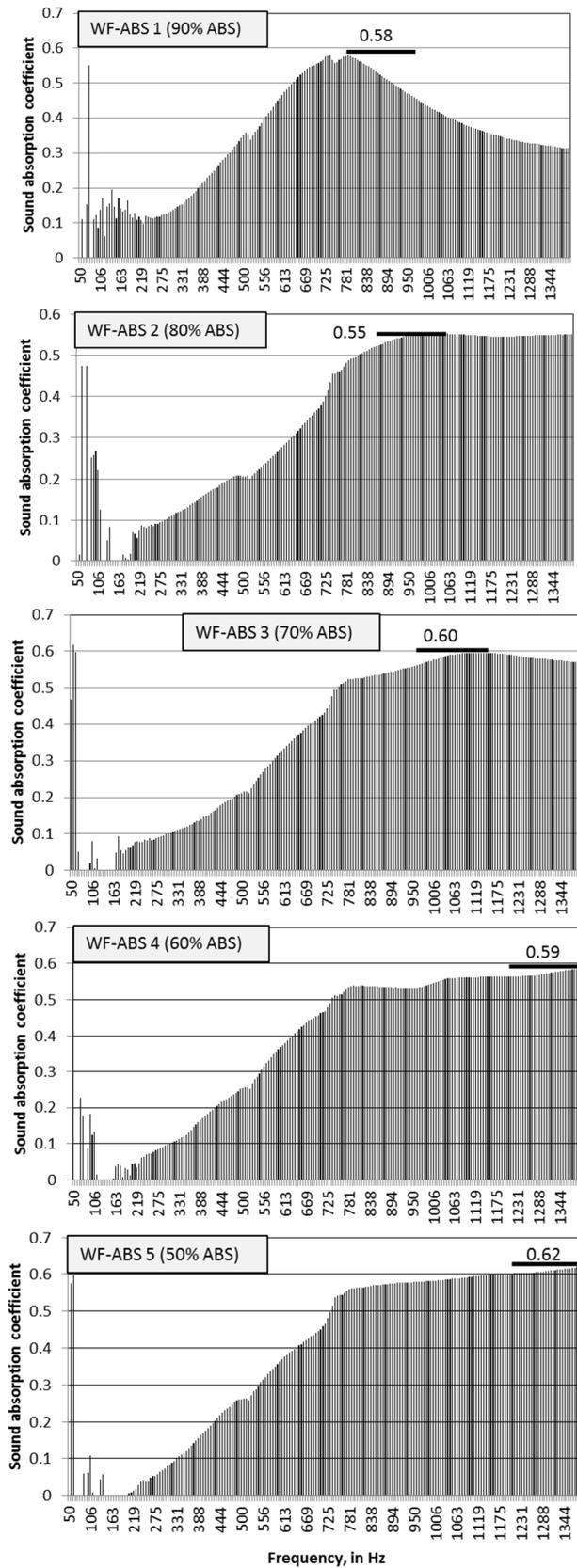


Figure 7. Sound absorption coefficient for WF-ABS structures.

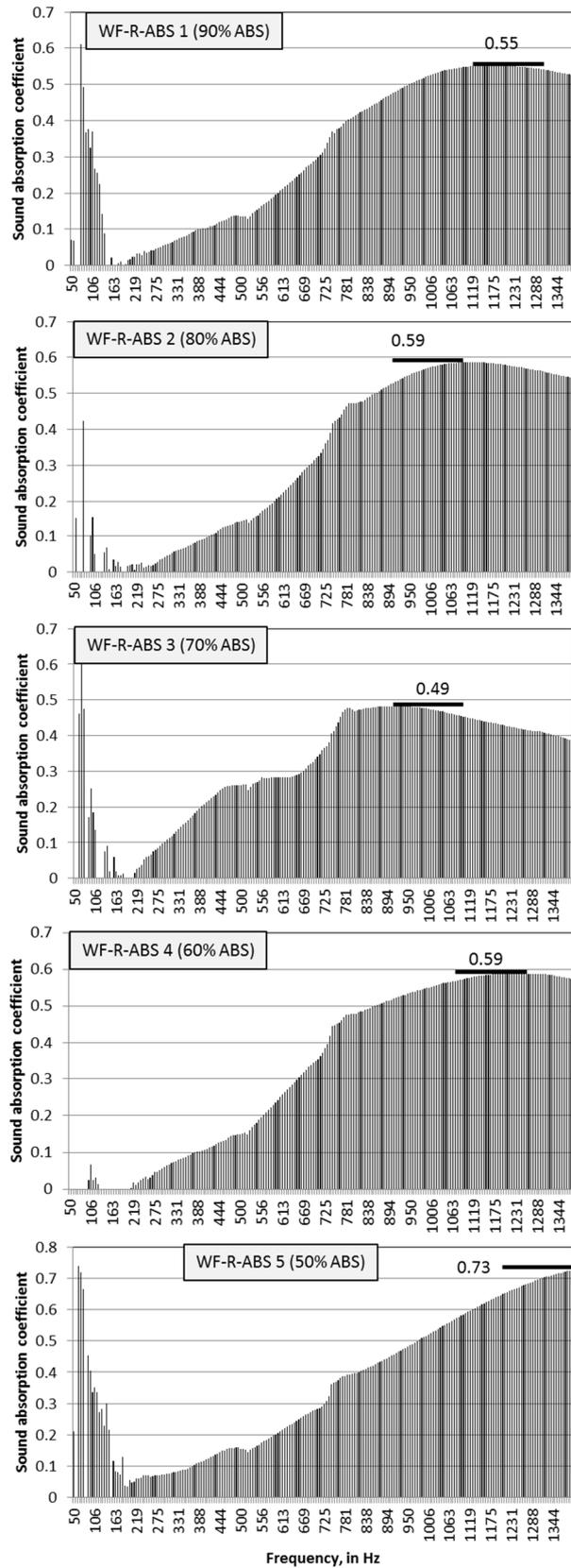


Figure 8. Sound absorption coefficient for WF-R-ABS structures.

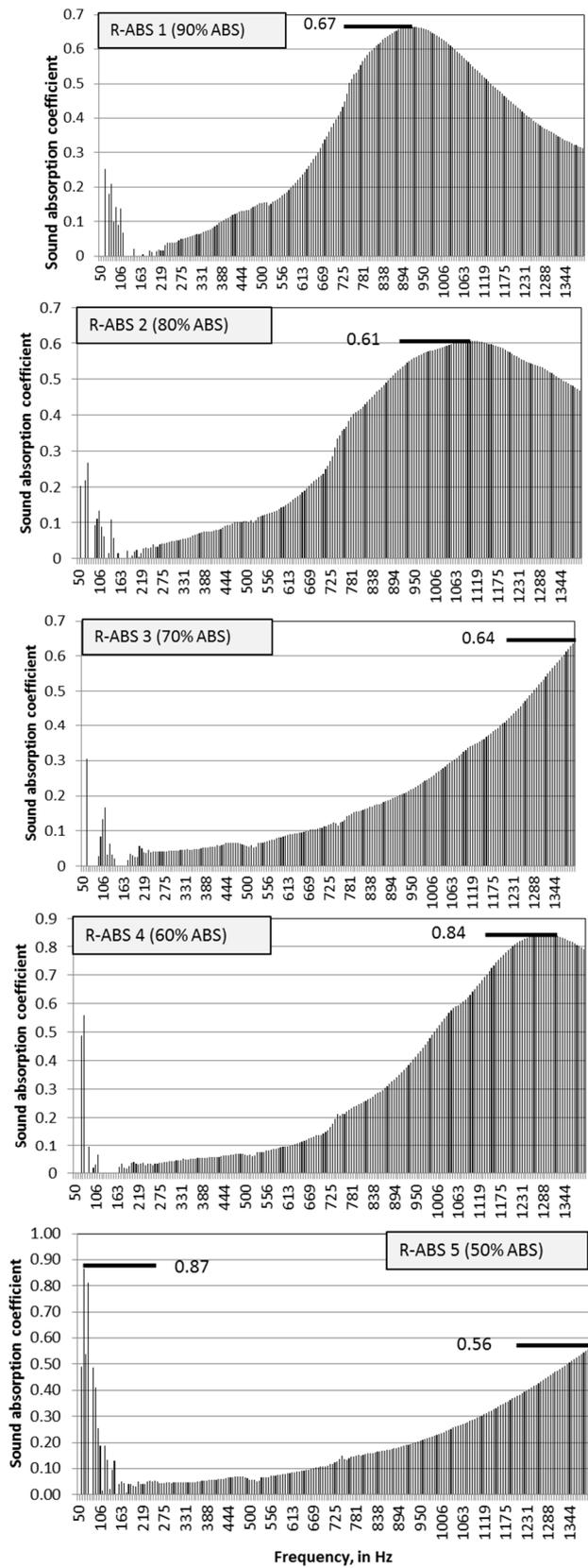


Figure 9. Sound absorption coefficient for R-ABS structures.

4. Conclusions

The aim of the present research was to create and test composites with good thermal and acoustic performances using wood fibres and recycled materials, such as rubber crumbs and ABS, where ABS acts as a matrix of the composite. The results show that the higher participation rate of recycled tire rubber crumbs and wood fibres as fillers reduce the thermal performance of the composites. Instead, incorporation of rubber in the ABS matrix increases the acoustic performance of the composite. The higher content of rubber, the better sound insulation coefficient was registered (0.87) for a rubber content of 50% of the total mass and for composite R-ABS. The best thermal performance was registered by the WF-ABS sample ($0.0434 \text{ Wm}^{-1}\text{K}^{-1}$), followed by the WF-R-ABS sample ($0.0460 \text{ Wm}^{-1}\text{K}^{-1}$) and the R-ABS sample ($0.0477 \text{ Wm}^{-1}\text{K}^{-1}$). The analysis of the results shows that the thermal efficiency of the composites depends on the outdoor temperature. The potential of using recycled materials such as rubber and ABS to manufacture composites for thermal and acoustic insulation of buildings is promising. The testing of water permeability and water absorption of the composites presented in this paper is in progress.

5. Acknowledgement

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