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Article

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Development of materials obtained from recycled cars and their subsequent use in noise reduction

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Abstract

In terms of design and material composition, cars are the large set of diverse materials and raw materials. The relative proportion of materials varies along with the development and innovation of new types of cars. The most represented material is metal. On average, outdated cars feature about 8% of plastic and approximately 4% of rubber products. The problem is the further use of these recycled materials. The research has found new areas for the use of tires, waste foam and interior materials—noise reduction. The authors have designed and tested several variations of acoustic absorption materials. Of the tested materials, the best parameters were shown by "ecofoam"—almost across the entire frequency range (100–5000 Hz).

Keywords

Recycling, sound absorption coefficient, sound absorption material

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Introduction

Extremely high and still rising annual rates for disposal of solid waste caused a big problem for environmental protection all around the world.

As the authors point out in article,[1] there is an urgency to improve pollution caused by a large number of "retired" vehicles.

Unlike the first "environmental" revolution in 1970 that focused on cleaning up hazardous waste from contaminated sites and natural resources, the second revolution addressed the issue of reducing waste at its source. Addressing these issues cannot rely only on legislation itself, it must be supported by other effective methods. This objective can be achieved by proposing and designing products that support dismantling, reuse, and recycling of their components.[2] Recycling is commonplace in many industries.[3,4] Extended product liability is prompting manufacturers to maintain accountability for their products throughout their life cycle. As a result, manufacturers are under constant pressure to dispose of their products in an environmentally responsible manner. The automotive industry has been involved in these processes in particular. The directive of the European Union has set a minimum rate of reuse of individual parts of a car after they cease to fulfill their purpose. This framework provides an incentive to construct products suitable for recycling.[5] Widespread use of recycled plastics has been very limited due to the low levels of knowledge about the behavior of these recycled materials.[6] The second most commonly used components for recycling are tires. However, tire recycling rate is currently only about 22% of all discarded tires.[7] Tire recycling is also a social problem.[8,9] Tire separation technology and tire reuse are still very difficult. As some of the tires are environmentally hazardous, procedures need to be developed to eliminate this risk.[10] This article outlines the types and forms of fireproof sound-absorbing materials made out of recycled tires and rubber.

The authors examined composite materials made from cement paste and particulate rubber and aimed at characterizing their airborne insulating potential. The research team of the authors focused on the use of various waste materials from the disposal of used cars in the field of acoustic insulation. Waste material from tires and car interiors is an ideal raw material for products used in the field of noise reduction or interior acoustic conditioning.[11]

Materials in vehicle recycling, used till date, have been used only in simple applications to reduce noise, for example, barriers. Article authors[12] indicate that there is the use of polyurethane foam, which also has certain acoustic properties, but they are displayed only at high frequencies. Research will allow more efficient use of materials from recycled cars. It rests in designing a suitable material with precisely defined spectral attenuation properties for particular applications. Basically, it is to adapt the composition of the sandwich panel to the particular frequency spectrum to be absorbed.

Methodology

Research was carried out in a specialized accredited laboratory under objective environmental conditions. We measured sound insulation using impedance Kundt's tube which is a suitable solution for obtaining measurement results across a wide frequency spectrum. The test material in the measuring device partially absorbs and partially reflects the normal incidence of sound waves.[13] The measurements made use of four-microphone method in places where it was necessary to carry out preliminary tests, followed by corrections during the same test to minimize the amplitude and phase difference between microphones. With regard to the measurement process itself, it was necessary to ensure that the sample corresponds to the equipment used, while at the same time, the sample could not be pressed beyond the point of deformation.[14,15] Results were calculated using specialized software. During the

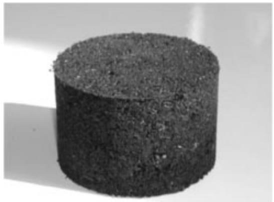

Figure 1. Mono-structural material.

measurement of sound absorption coefficient, we used samples with a diameter of 30 mm and thickness of 70 mm (according to the tested frequency) made of different layers (sandwich). A sandwich structure is very suitable due to its gradual transformation of the energy of sound waves into thermal energy. As an effect of the sound absorbing material, acoustic energy is partly reflected and partly absorbed into the structure of the porous material, where it is converted into thermal energy. If the sound-absorbing material has a sandwich structure, the effect of the conversion of acoustic energy into thermal energy taking place on the interlayer of the material increases. Sound waves that pass the upper layer and are partly reflected from the subsequent lower layer tend to partially return from the borderline back to the lower layer. Then, these sound waves get partially absorbed in the upper layer when passing through it yet again—thus converting into thermal energy. The design of the sandwich material can significantly affect the resulting efficiency and level of sound absorption.

The aim of the research was to see how the sandwich structure influences the sound absorption rate of researched recycled materials found in car wrecks based on their different combinations.

Test samples of sandwich structures

A piece of plastic or rubber from the recycled cars gives materials suitable for making sound-absorbing materials. The main sources of these materials are used tires, car seats, and seat covers. The production of sound-absorbing materials uses mainly different sized pieces of crumb rubber and textile cables from polyester. The sandwich made of sound-absorbing material usually uses crumb rubber of minimum two different grain sizes.

The most suitable materials for the production of sound-absorbing materials is crumb rubber of different grain sizes, textile cables, and rubber “tablecloth” from retread tires. Basically, it is possible to produce several variants of sound-absorbing materials:

a. Mono-structural material made of one size piece of crumb rubber (Figure 1).
b. Sandwich structure made of two to three layers of different-sized grains of rubber crumb.
c. Sandwich structure made of—one to two layers of crumb rubber and one layer of a textile cable (Figure 2).
d. Sandwich structure made of one to two layers of crumb rubber and a layer of crushed car seats and seat covers (Figure 3).

None of these products is self-supporting and must be used in combination with a supporting structure. For our research of acoustic properties, we have proposed various materials, some of them are shown in Figures 1 to 3.

The authors have focused their research on various combinations of materials, thicknesses, and abiders. In the report, the materials are selected from a variety of tested materials. The purpose is

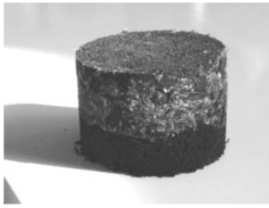

Figure 2. Two layers—crumb rubber and textile cables.

Figure 3. Two layers—crumb rubber and crushed car seats.

not to define the precise composition of the product but to show the differences in the attenuation characteristics of the material used in different combinations of feedstocks.

In the course of the research, we came with the following proposals for sandwich structures:

- Sample 1—usually made out of a piece of rubber (grain size: 4–6 mm). Its front wall may have smooth or relief surface. Reliefs allow for an increased surface of the product which in turn has a positive effect on the level of sound absorption. Sound absorption values, however, are closely related to the bulk density of the product and its hardness and strength. Tires are included without any specification. When recycled, they are stripped of textile cords and metal reinforcements.
- Sample 2—bottom layer has a decisive sound absorption function. The bottom layer, that is, the carrier is made up of the same material as sample 1. A second layer is added to it, made of textile cords from tires and car interiors. The sample is 50 mm high. The supporting rubber layer is 20 mm thick, and the other layer has a thickness of 30 mm.
- Sample 3 is similar to the previous sample. Its bottom layer is made out of pressed textile cables. When compared to rubber, textile cords provide better sound absorption. However, they are more difficult to press and do not form as solid and coherent layer as the sandwich made out of rubber. The proportion of the layers is 10:40 mm.
- Sample 4 has three-layered sound-absorbing sandwich structure. The layer of textile cables is replaced by a layer of crushed and pressed car seats and car seat covers. The composition of this sandwich was chosen based on the analysis of sound absorption of the compacted waste from car seats and the car seat covers. Moreover, this material can provide stronger and more compact components. The layers of individual materials are 10, 30 and 10 mm.
- Sample 5—Ecofoam is an example of effective solution for single-layer samples. It consists of foam used in car seats and interiors as well as all interior fabrics and thin plastics. Its disadvantage is variable material composition which can vary depending on the recycled car parts.

Table 1. The description of two-layer sandwich materials and their combinations.

Description		Frequency (Hz)	Sound-absorption coefficient α
Two-layer sandwich			
Total thickness of the sandwich (mm)	65	100	0.13
		200	0.41
Thickness of the rubber layer (mm)	15	315	0.71
		400	0.89
Thickness of the cable layer (mm)	50	500	0.87
		800	0.77
Bulk density (kg/m^3)	506	1000	0.79
		2000	0.76
Sound absorption DL_α (dB)	6.2	5000	0.53
Two-layer sandwich with increased bulk density			
Total thickness of the sandwich (mm)	65	100	0.08
		200	0.34
Thickness of the rubber layer (mm)	15	315	0.71
		400	0.81
Thickness of the cable layer (mm)	50	500	0.93
		800	0.90
Bulk density (kg/m^3)	563	1000	0.87
		2000	0.82
Sound absorption DL_α (dB)	6.9	5000	0.67
Two-layer sandwich made out of foam			
Total thickness of the sandwich (mm)	65	100	0.12
		200	0.40
Thickness of the rubber layer (mm)	15	315	0.69
		400	0.90
Thickness of the cable layer (mm)	50	500	0.96
		800	0.85
Bulk density (kg/m^3)	—	1000	0.83
		2000	0.82
Sound absorption DL_α (dB)	7	5000	0.74

Source: Own elaboration.

Verification results of acoustic properties of absorbers made out of recycled tires

When developing absorbers made out of recycled tires, we have tested several sandwich composition and thickness variations (Tables 1 to 3). The main area of their use is noise barriers constructed beside roads or used for industrial noise reduction.

The results regarding two-layer sandwich materials are presented in Table 1, and the results regarding three-layer sandwich materials are presented in Table 2. The samples differed in thickness of the individual layers and their apparent density.

For materials featuring plastic frames we have developed and tested a sandwich made by pressing. Its upper layer is made out of recycled rubber and the lower layer (sound absorbing) of textile cables. This type of sandwich is suitable only for low-frequency absorption panels. However, it has good properties at high frequencies as well. By increasing the bulk density to 563 kg/m^3, DL_α increased to 6.9 dB, but the absorption at lower frequencies decreased. To

Table 2. The description of three-layer sandwich materials and their combinations.

Description		Frequency (Hz)	Sound absorption coefficient α
Three-layer sandwich made out of car seat covers			
Total thickness of the sandwich (mm)	65	100	0.45
		200	0.81
Thickness of the rubber layer (mm)	15	315	0.99
		400	0.94
Thickness of the cable layer (mm)	50	500	0.84
		800	0.79
Bulk density (kg/m^3)	—	1000	0.93
		2000	0.85
Sound absorption DL$_\alpha$ (dB)	8.7	5000	0.78
Three-layer sandwich made out of textile cables			
Total thickness of the sandwich (mm)	65	100	0.38
		200	0.90
Thickness of the rubber layer (mm)	15	315	1.00
		400	0.98
Thickness of the cable layer (mm)	50	500	0.88
		800	0.88
Bulk density (kg/m^3)	—	1000	0.96
		2000	0.85
Sound absorption DL$_\alpha$ (dB)	9.5	5000	0.77
Three-layer sandwich made out rubber—textile cables—rubber			
Total thickness of the sandwich (mm)	65	100	0.39
		200	0.91
Thickness of the rubber layer (mm)	15	315	0.97
		400	1.00
Thickness of the cable layer (mm)	50	500	0.91
		800	0.84
Bulk density (kg/m^3)	—	1000	0.97
		2000	0.85
Sound absorption DL$_\alpha$ (dB)	9.3	5000	0.76

Source: Own elaboration.

utilize waste from vehicles and automobile production more effectively, a sandwich with a layer of crushed car seat covers (prevalence of PUR) instead of pressed recycled cables has been developed. It turned out that in terms of sound absorption, textile cables and crushed seat covers are basically equal in their features.

In order to track sound absorption changes depending on the thickness of the absorber and its composition, we have proposed the following combinations of two-layer sandwich materials of different types. Materials provide relatively high level of sound absorption at low frequencies (500 Hz).

Developments in the field of sound absorption materials focused on products made out of recycled car seats or a mixture of car seats and car seat covers—Ecofoam. This product has a high level of sound absorption. With thickness of 100 mm, it greatly exceeds the value of the highest sound absorption coefficient. Ecofoam achieves this coefficient even in combination with a

Table 3. Ecofoam description.

Description		Frequency (Hz)	Sound absorption coefficient α
Ecofoam			
Total thickness of the sandwich (mm)	100	100	0.57
		200	0.74
Thickness of the rubber layer (mm)	—	315	0.93
		400	0.87
Thickness of the cable layer (mm)	—	500	0.96
		800	1.00
Bulk density (kg/m^3)	—	1000	0.96
		2000	0.95
Sound absorption DL_α (dB)	12	5000	0.87

Source: Own elaboration.

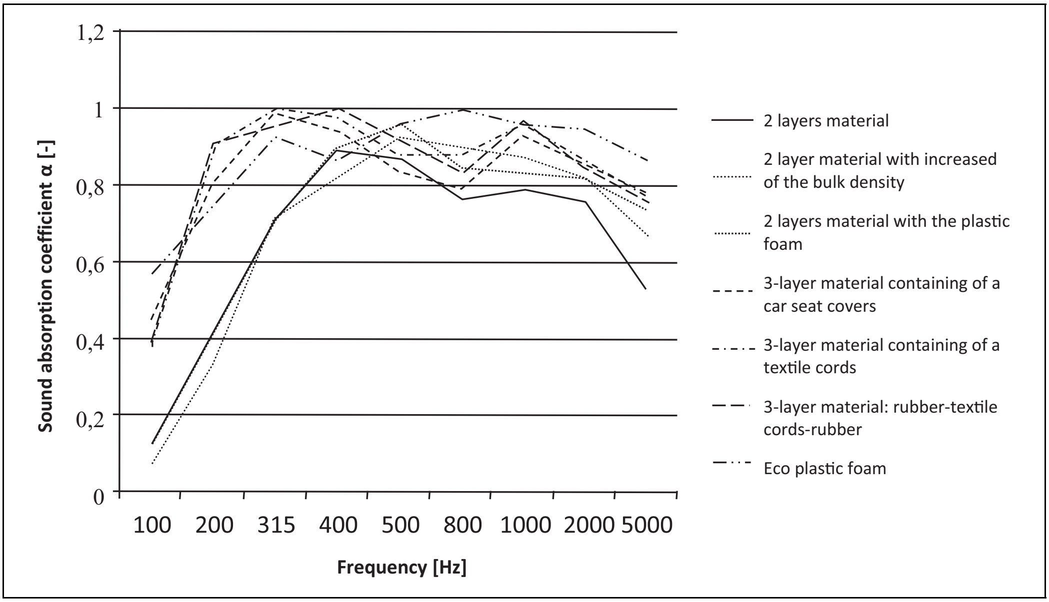

Figure 4. The overall evaluation of sound absorption coefficients of absorbers made out of recycled tires.
Source: Own elaboration.

firm protective perforated plastic film. $DL_\alpha = 12$ dB and sound absorption coefficient values are presented in Table 3.

This type of absorber has properties similar to the three-layer sandwich made of rubber, and in some cases even better. From all types of absorption material, this one stands out at low frequencies, which makes it suitable for industrial use.

Figure 4 shows sound-absorption coefficients of the abovementioned materials. It is clear that the most balanced results are provided by Ecofoam across almost the entire frequency range from 100 Hz to 5000 Hz.

Figure 4 summarizes the results of sound-absorption coefficients for each of the proposed sandwich materials. It follows that the materials can be used for frequencies as low as 100–150 Hz, a value justifiable in practice. Obviously, the two-layer sandwiches show significantly worse properties at frequencies 100–350 Hz, the zone which is the most critical for industrial use. At higher frequencies, different materials are much more dispersed. Nevertheless, their properties are still sufficient. Although Ecofoam is not a sandwich material, it showed very good properties at low frequencies and outstanding properties at mid and high frequencies.

Conclusion

Products made out of recycled materials are a good source for producing acoustic panels. However, such process is still under development. Nevertheless, it deserves attention because the use of recycled materials for the production of acoustic panels has a synergistic environmental effect—it addresses the reduction and recovery of waste while also addresses environmental problem of excessive noise. The authors have researched these materials and their use in acoustic insulation. On the basis of laboratory measurements and practical measurements, the authors recommend absorbers suitable for a specific solution. The research focused mainly on the sandwich absorbers and Ecofoam. These materials have been verified, are suitable for practical use, and reduce industrial noise. They can be used in engineering, metallurgy, printing, food industry, and transport. In addition, Ecofoam will be useful in reducing noise in plants with a risk of high level of noise. Since Ecofoam is a product of recycling, it can be recycled again, thus helping to minimize waste.

Declaration of conflicting interests

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