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Acoustic properties of biodegradable materials in the low and medium frequency range

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Abstract Materials commonly used in various public spaces are characterized by sound-absorbing or insulating properties. Natural fiber composites are an eco-friendly promising alternative to conventional synthetic fiber composites. For specialized rooms, it is essential to provide good insulation and properly selected sound-absorbing materials. This article presents the results of tests on the acoustic properties of selected natural, biodegradable materials. The aim of the research was to find biodegradable composites that would have good insulating and absorption properties in the low- and medium-frequency ranges. Firstly we tested several configurations of composites made of various wood-based materials in terms of sound pressure vs. frequency. Then, the sound absorption coefficients of the best natural fiber composites used were measured by the technique of two microphone transfer functions in the impedance tube. It was concluded that multi-functional composite materials can be made by natural fibers so that both the good acoustic insulation together with appropriately high sound absorption coefficients in the low and medium frequency range can be achieved.

Keywords: acoustic properties, sound absorption coefficient, sound absorbers.

1. Introduction

Today, in public and enclosed spaces, increasing attention is paid to improving the quality of individual functioning. At the design stage, depending on the user's needs, suitable materials are used to perform specific functions. Natural fibre composites (NFCs) are a promising eco-friendly alternative to conventional synthetic fibre composites due to their inherent biodegradability and low environmental impact properties [1]. Room acoustic properties can be improved by installing the appropriate sound-absorbing and insulating materials. Although synthetic materials, such as glass fibres and plastics, have superior mechanical qualities to natural fibre, they are an environmentally harmful and non-biodegradable material [2]. In addition, most of them have the significant drawback of being not very useful as materials in acoustic adaptations in low and medium frequency ranges [3-5].

Research in this area is conducted mainly on composites created from materials developed from artificial or natural fibre reinforced polymer composites. It is common to use artificial materials, such as mineral or glass foams or synthetic fibres (eg, polystyrene, polypropylene, polyvinyl chloride, polyethylene, etc.), which usually have a high absorption coefficient at higher frequencies [6]. At this point, studies of rubber granules as one of the main acoustic components of composite samples show promising sound absorption and vibration properties, depending on the percentage of granules [7].

On the other hand, currently we observe a general tendency to search for 'green' solutions to increase the applicability of recyclable or biodegradable natural materials in engineering [8]. Many attempts have been made to study the properties of plant-based fibres which have become the most popular and have a raises market value [2]. Sound pollution is a major problem in urban areas and can cause health problems. Therefore, there is a great demand for NFCs that are characterised by good acoustic insulation properties with appropriately selected sound absorption parameters. It is worth noting that natural fibres can be found in nature and there are renewable resources.

Natural plant-based fibers can be classified as follows: seeds (kapok and cotton), leaves (banana, pineapple, sisal), fruit (oil palm, betel nut, coir, palmyra palm), grasses (bamboo, sugarcane bagasse), straws (rice husk, wheat, corn), bast fibers (jute, kenaf, hemp, flax) and wood fibers, including softwood and hardwood. This last category, wood fibers and cork, has been taken into account in this paper.

Research in this area is being carried out on composites made from materials of natural origin or its derivatives. Some publications demonstrate good acoustical properties of jute fiber and felt [9]. The results indicate that reduced-density jute shows better sound absorption properties. The sound absorption behavior of sisal and palm fiber reinforced hybrid composites was investigated in [10]. The composite with 20% sisal fiber and 15% palm showed a high sound absorption coefficient at frequency levels of 1600 Hz 2000 Hz, 2500 Hz, 3150 Hz, and 4000 Hz.

Following this path, the acoustic properties of kenaf and jucca waste were examined. On the basis of the tests, it was found that the flow resistance decreased with the kenaf content in the samples. Promising performance in the low- and medium-frequency bands was also recorded for a sample made of 100% kenaf fibers [5]. In addition to raw materials occurring naturally in nature, research is carried out on waste materials. The evaluation of acoustic properties consisted of determining the sound absorption coefficient for fibers originating from hollow fibers from palm fruit. Fiber tests show that, depending on the density and thickness of the sample, the value of the absorption coefficient can reach high values in the high frequency range [4]. Other promising performances on the acoustic properties of wood fibers have been reported. On the basis of subsequent tests, it was shown that properly profiled wood-based materials have high sound-absorbing properties for frequencies from 125 to 500 Hz [11].

On the other hand, there are great demands for the acoustic properties of the material to control the noise. However, comparatively, very few studies have reported on the vibration damping behavior of environmentally friendly green materials, which are recyclable and biodegradable. Singh and Mukhopadhyay [12] present an analysis of the acoustic properties of the hybrid composite in the context of the material's transmission loss. The researchers noticed the highest transmission loss for the 25% fiber content of the coir and banana fiber at 2000 and 4000 Hz.

However, the materials described above have poor sound absorbing and sound-insulating properties in the low- and medium-frequency range. The appropriate selection of materials that have good acoustic properties can reduce levels of noise and reverberation in meetings, workplaces, or residential spaces. The main objective of the research was to develop a composite made of biodegradable materials, mainly wood-based materials, that would have good sound insulation and sound-absorbing properties.

The research process describes composites made of various biodegradable materials with different acoustic properties and sound absorption coefficients. In the first step, several configurations of composites made of various wood-based materials (i.e. oak, pine, fir, cork, and beech) in terms of sound pressure vs. frequency have been tested. The results were compared with those of a synthetic material with good insulating properties, namely, mineral wool. Then, the sound absorption coefficients of the best natural fiber composites used were measured using the technique of two microphone transfer functions in the impedance tube. Finally, we obtain the multifunctional composite materials created from natural wood-based fibers for which good acoustic insulation and appropriately high sound absorption coefficients in the low and medium frequency range were achieved.

2. Characteristics of selected biodegradable materials

During the design of the samples, special attention was paid to the well-known recyclable natural biodegradable materials. In the first stage, using catalogue notes, a group of materials was selected that were expected to have good damping properties. Several wood-based materials with different structures and binders were selected for the investigation. The main emphasis on the structure of the composites was placed on various species of wood fibres (oak, fir) of various fractions connected with a binder. In addition, for several materials, new layers were added in the form of compressed wood fibre and soundproof mats.

From the selected materials, samples were prepared using, among other methods, the compression moulding method. The machining process involved giving the sample the same shape as the selected material. Subsequent layers of material were selected using an experimental method, taking into account the porosity of the internal structure and the thickness of the sample. During the creation process, the thicknesses of the materials and the arrangement of successive layers were manipulated. The prepared layers of material were formed in a cylinder shape (Figure 1).

Currently, special processing methods are used to produce all kinds of damping and soundproofing materials. In many cases, it is a mixture of suitable artificial raw materials and plastic fibres. In addition, such a material must be thermally treated, generating a carbon footprint. In turn, the composition of the prepared materials consists mainly of common biodegradable materials, including various types of wood fibres. The design of the samples is based on a layered combination of different materials. In the next section, each sample was characterised in detail, and Figure 1 shows the appearance of each sample.

Sample No. 1 is mainly leftover material from wood processing, sometimes used as a structural material for filling or insulation. A two-component polyurethane system was used to create a solid wood bran structure. On the outer sides, the material was protected with compressed wood fibre and a silencing car mat.

Sample No. 2 is also a residual material from wood processing, but only of one species of wood, the so-called oak chips. Compared to the previous one, sample No. 2 was supplemented with additional insulation in the form of mineral wool and compressed wood fibres.

Sample No. 3 consists mainly of crushed granules, combined with a binder and additives. A combination of granular cork and fire extinguishing powder was used to produce it. As in previous cases, a two-component polyurethane system was used to bond the material.

Sample No. 4, on the other hand, is a material left over from wood processing, called fir shavings. A two-component polyurethane system with different parameters was used to join the materials. In the final finish, the sample was protected similarly to sample No. 1.

Table 1 summarises detailed information on the base materials of the composites.

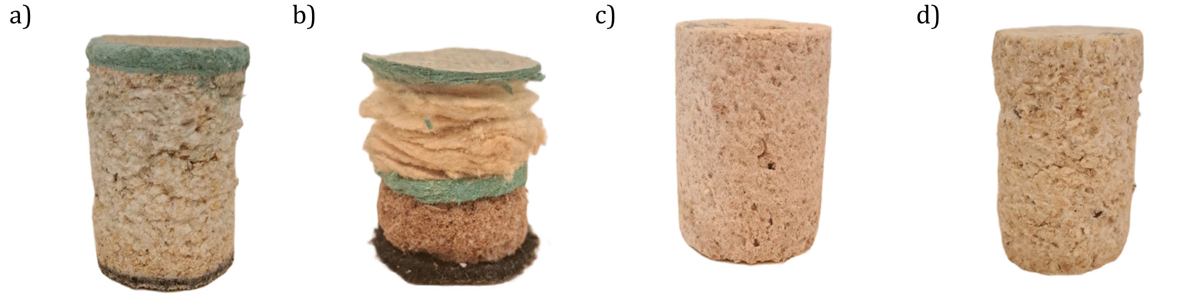

Figure 1. View of the distribution of materials in composite:
a) sample 1, b) sample 2, c) sample 3, d) sample 4.

Table 1. Material characteristics of the prepared samples.

Material No. (sample)	Filling	Thickness all (mm)
1	- 5 mm compressed EKOPOR wood fibre sawdust - cork granulate - larger (500 ml) + PU mix - ECO PRODUR PM 4032 (80 + 80 ml) 300 - 2mm mat. Car	52.5
2	- 5 mm compressed EKOPOR wood fibre - 50mm compressed PROMATA ISOVER up to 20mm - 5 mm compressed EKOPOR wood fibre - 25 mm ECO PRODUR/100/ (40 + 40 ml) + oak chips 400 ml /mix/ - 2mm mat. Car	57
3	- granules 1-3 crushed cork (500 ml) - mix + PU ECO PRODUR PM 4032 (90 + 90 ml) 100 - 100 ml of extinguishing powder.	50.03
4	- +5mm compressed EKOPOR wood fibre - 600 ml of sawdust (No. 1) fir PU IZY FOAM 30 (50 ml + 50 ml) - Mix - sample thickness 50 mm - +2mm car soundproofing	54.4

3. Measurements of the acoustic properties of materials

3.1. Designing materials with favourable absorption and insulation properties

The appropriate selection of materials with good absorption and insulating properties would significantly improve the acoustics of the room. To access the acoustic properties of the biodegradable materials considered, transmissions of the acoustic pressure and the sound absorption coefficient were applied. The search for sound-absorbing and insulating materials began with measuring the sound pressure transition as a function of frequency.

Various configurations of layered materials were prepared, for which acoustic pressure transmissions through the composites were performed first. Based on the passage of sound pressure through the sample, we can evaluate the ability of the material to protect the room against the noise. As a result of the tests, four samples with the best insulation properties were selected for further research. Figure 2 shows the sound pressure transition values as a function of frequency for the selected composites.

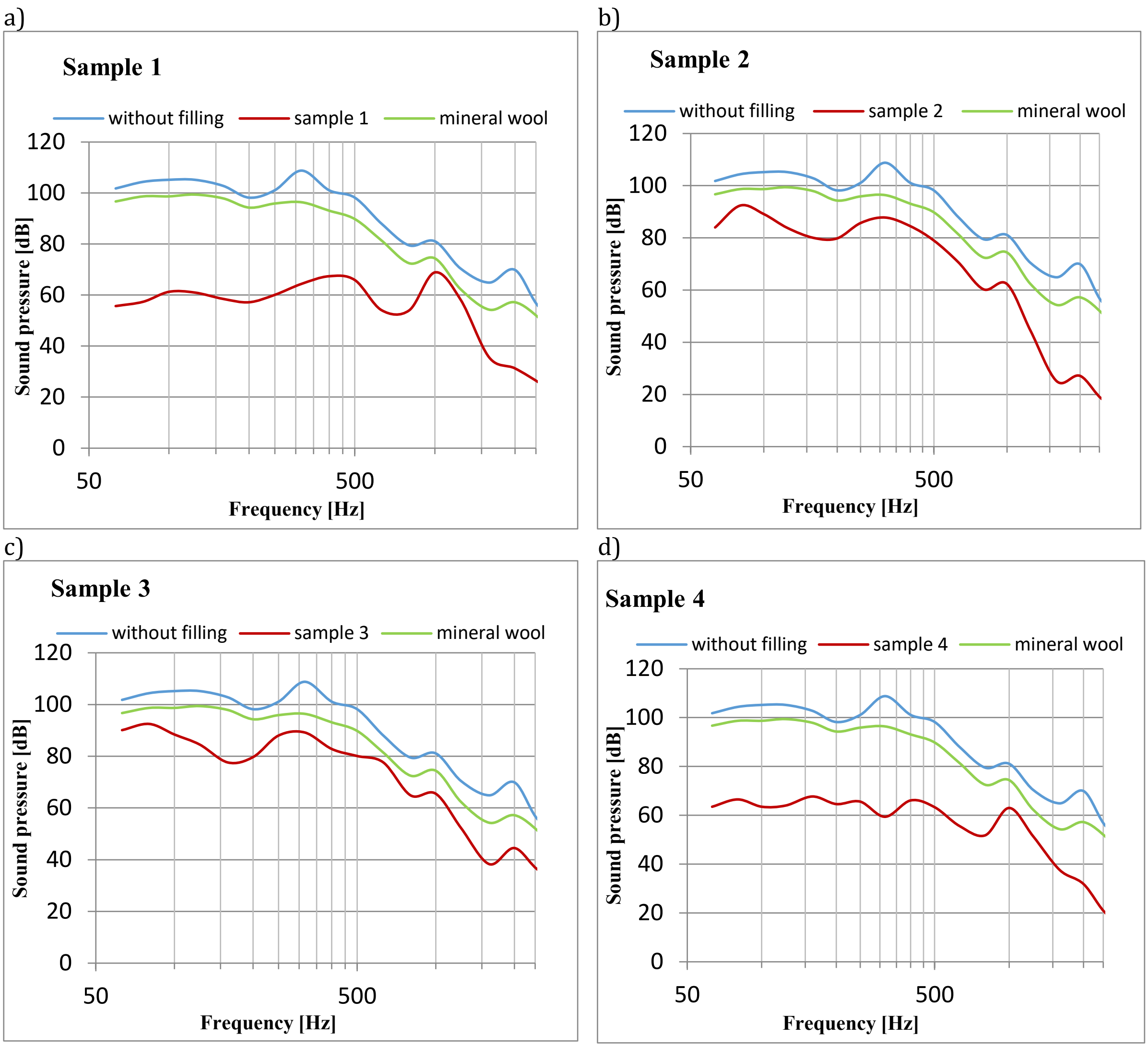

Figure 2. Comparison of the sound pressure transition values versus frequency for the considered materials; a) sample 1, b) sample 2, c) sample 3, d) sample 4.

In Figure 2 we can compare the test results obtained for different samples. The measurement was carried out for three cases: without filling, with mineral wool filling, and a sample. Among many commercial materials, it was decided to choose mineral wool with good insulating properties for the measurements. Mineral wool fulfils its purpose, but it also has a serious impact on health and the environment related to its production or use. With this in mind, to assess the insulating properties, it was decided to compare the test results for the designed samples with commonly used mineral wool. For all materials, it can be concluded that the developed samples achieved insulation values that were better than those of mineral wool, especially in the low and medium frequency ranges.

3.2. Absorption coefficient measurements

The measurements were carried out on a test stand using a Siemens impedance tube type Mecanum Inc. S/N: 2444-408. Our study used the impedance tube method according to PN-EN ISO 10534-2:2003. This method requires small round test samples with a diameter of only 34.25 mm. Other advantages include faster and generally repeatable measurements. Since in this method the sound wave falls perpendicularly on the sample, the measured sound absorption coefficient is called the normal sound absorption coefficient. The system performs measurements according to the defined standard: PN-EN ISO 10534-2:2003 and ASTM E-1050, ASTM E-2611 (TL) [13-15].

The test set shown in Figure 3 consists of a measurement device, i.e. an impedance tube (1) with sections (rigid tube (3) and absorbing tube (2) with an inner diameter of about 34 mm), a set of ¼ inch microphones (4), a signal amplifier (5), SCADAS measurement equipment with built-in source (6) and a computer with Simcenter Testlab software. Based on the configuration of the equipment and the arrangement of the microphones, the coefficient determined was measured in the frequency range of 50 Hz to 2.4 kHz.

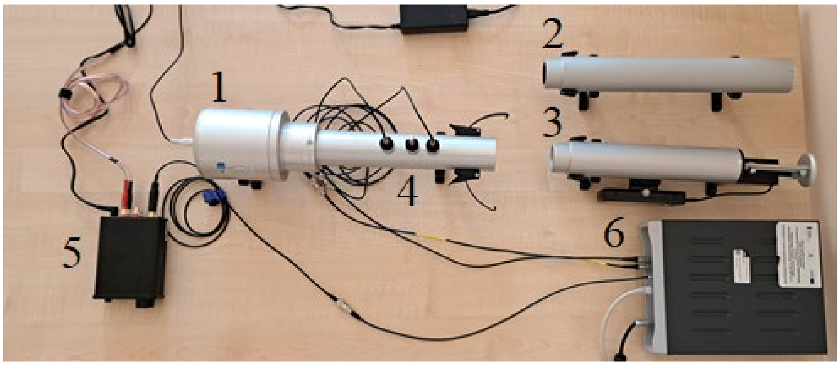

Figure 3. Test stand for acoustic properties.

The composites were made with a diameter of 34.25 mm to match the dimensions of the unit. Then, they were placed in the tube measuring unit and subjected to a sequence of measurements, averaging the result. The absorption coefficients were determined using the transfer function between two microphones using Simcenter software. Measurements were made in accordance with the recommendations of the above-mentioned standards.

Figure 4 shows the sound absorption coefficient for the selected composites.

4. Analysis and comparison of results

Initial tests of the sound absorption coefficient (SAC) were performed for samples presented of layered materials. The results were presented in the form of graphs and comparisons.

Figure 4 shows the sound absorption characteristics as a function of frequency for the samples considered No. 1-4. The best result was obtained for sample No. 1, Figure 4a. This figure shows the two results of the SAC obtained for two different configurations. The blue graph shows the measurements when the acoustic signal starts from the top of the sample (configuration A), and the purple curve presents the results for the sample rotated about 180 °(configuration B). It can be stated that both curves demonstrated a quite high value of the acoustic absorption coefficient in the low frequency range, namely between 200 and 400 Hz. The best value of SAC= 0.55 was achieved for 350 Hz, configuration A.

Sample No. 2, Figure 4b was tested in a similar way (configurations A and B). It can be seen that for configuration B, the SAC rises from 200 Hz to 1200 Hz. In the case of configuration A, we can observe that SAC rises from 200 to 450 Hz where a 0.55 value of SAC was achieved and then it worsens to 0.4 values for 1000 Hz. It can be stated that the sequence of layers has a great influence on SAC. This is because the applied layers have different porosity.

Figure 4c shows the value of the absorption coefficient for sample No. 3. Measurements showed that the material does not have enough absorption values in a wide frequency range. In this case, the structure of the material had a very low porosity. The SAC values of the last sample are presented in Figure 4d. The high values of the absorption coefficient can be observed for frequencies between 400 and 600 Hz, and the highest value of SAC =0.6 was recorded for approximately 500 Hz.

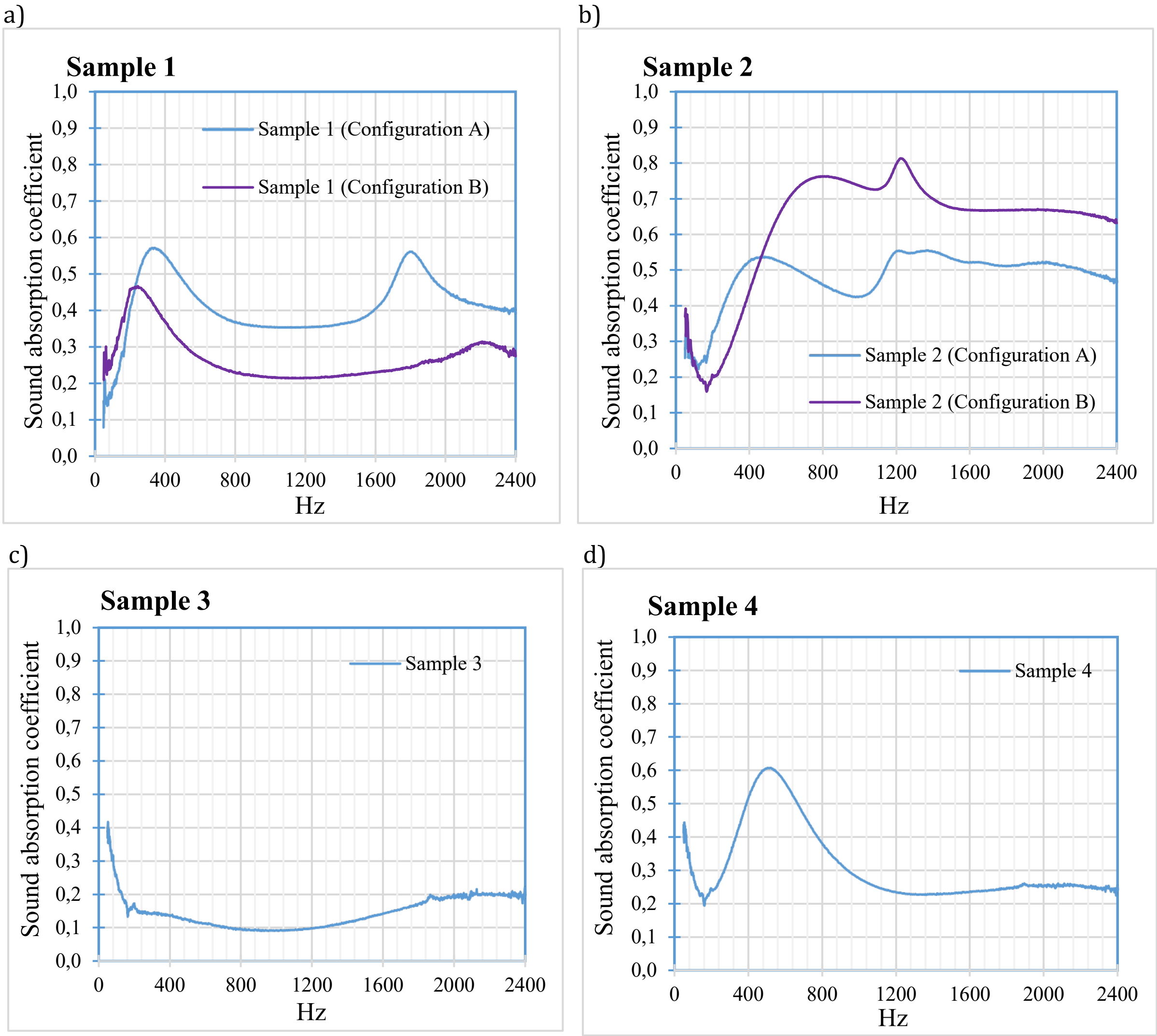

Figure 4. Sound absorption characteristics for a) sample No. 1, b) sample No. 2, c) sample No. 3, d) sample No. 4.

5. Conclusions

Natural fibers have superior advantages over synthetic fibers in terms of eco-friendliness, renewability, recyclability, and satisfactory mechanical properties.

This paper investigates experimentally the effect of different layers of biodegradable materials on selected acoustic properties. The aim of the research was to find biodegradable composites that would have good insulating and absorption properties in the low- and medium-frequency ranges. Several configurations of composites made of various wood-based materials (i.e. oak, pine, fir, cork, and beech) have been tested in terms of sound pressure vs. frequency. The results were compared with mineral wool, a synthetic material with good insulating properties. The best configurations were then used for sound absorption coefficient measurements.

The measurements of the sound absorption coefficient were conducted using the impedance tube method. Based on the research conducted, it was found that biodegradable wood-based composites are suitable for the design of materials with favorable insulating and absorbing properties. The best result in the low- and mid-frequency ranges was achieved for sample No. 2, especially for its configuration B. The mentioned sample consists of processed wood fibers and oak chips, connected to a binder. Based on the measurements, it can be stated that the SAC parameter SAC achieved high values, increasing from 0.5 to 0.75 for frequencies in the 400 to 800 Hz range. As a result, we obtained the multifunctional composite material created from natural wood fibers for which good acoustic insulation and appropriately high sound absorption coefficients were achieved in the low and medium-frequency ranges were achieved.

It should be emphasized that the use of alternative biodegradable resources, in the form of wood-based materials, allows sustainable waste management. This natural material has high sound absorption capabilities because of the different porosities and resistivity. Additionally, considering their natural availability, low production cost, and biodegradability, they constitute an important alternative to traditional synthetic materials.

Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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