New Multilayered Composite for Sound Absorbing Applications

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Abstract: - Lightweight structures made of composite materials are increasingly used in many industrial fields for high-technology applications due to their versatile property profile. Waste wood cause both health and environmental problems and this has forced governments to develop laws for recycling. Using fir sawdust in the domain of soundproofing materials is of major importance from technical, economic and ecological point of view. In this paper we determined the sound absorbing ability of each obtained multilayered composite plates by measuring the sound absorption coefficient depending on frequency, using the impedance tubes. Multilayered composite plates were made from layers of composite materials in combination with layers of other materials on the market (cork or felt). The composite materials were made from fir sawdust and a polyurethane foam.

Keywords: - acoustic-materials, sound absorption coefficient, fir sawdust, polyurethane foam.

1. INTRODUCTION

Sound absorption constitutes one of the major requirements for human comfort today. Sound insulation requirements in automobiles, manufacturing environments, and equipment, generating higher sound pressure drive the need to develop more efficient and economical ways of producing sound absorption materials [1, 2]. Industrial applications of sound absorption generally include the use of materials such as mineral fibers, glass wool, polyurethane foams and their composites [3]. A solution for reducing sound pollution is to develop new materials with high sound absorption efficiency [1-5].

Structural design is another method to improve the sound insulation property of polymer composites [6, 7]. The bilayer or multilayer plate insulation structure was used to attenuate acoustic energy as more as possible. It had been proved that the multiple reflections of acoustic waves and multiform deformation of interlayer during the waves' propagation in a multilayered material can dissipate acoustic energy effectively [8].

Flexible polyurethane foams (FPFs) are used in thermal insulation and acoustic absorption [9, 10]. Sound absorption properties of FPFs can be improved by mixing it with sawdust resulting new composite porous materials with open pores. These materials can absorb sound with high efficiency and can increase value of fir sawdust [11].

A composite structure with a combination of perforated panel, rubber particle, porous material, polyurethane (PU) foam and glass wool, were found to demonstrate significant sound attenuation [12].

Multi layer of nonwoven composite structures has been employed focusing to improve acoustic properties. In the multilayer polyester structures, the closely-packed high number of layers improves sound absorption properties of the composite [13].

Coconut coir fiber compressed into bales and mattress sheet was found to demonstrate improved good sound absorption coefficient. When compared to a single layer, multilayer coconut coir fibers with airspace layers increase the absorption coefficient of the material at lower frequencies [14].

Sandwich structures consisting of polylactide / hemp / polylactide and polypropylene / glass fiber / polypropylene improved sound absorption rates in the mid to high frequency ranges [15].

By analyzing national and international research, studies have been identified about the possibility of using various types of waste in composite materials with various properties [16-20]. In this paper we studied the possibility of obtaining new multilayered composite for sound absorbing applications. The composite materials analyzed in this study were made of fir sawdust and flexible polyurethane foam with open pores. Multilayered composite plates were made from layers of composite materials in combination with layers of other materials on the market (cork or felt).

2. MATERIALS AND METHODS

Multilayer sound-absorbing materials can improve sound absorption at medium and high frequencies [21, 22]. Starting from a new composite material based on sawdust and polyurethane as binder in combination with two existing sound absorbing materials, namely cork and felt, 7 multilayer materials and 2 unilayer materials of different thicknesses were made.

The cork (Figure 1a) used to make multilayer sound absorbing materials was purchased in the form of plates (910×610×3 mm). Cork slabs are designed for insulation and are used under floors, linoleum, parquet, wood flooring to provide thermal and sound insulation [23].

The soundproofing felt (made from textile waste), see Figure 1b), used to make multilayer materials in this study, is commonly used for sound soundproofing of machines, furniture upholstery, etc. The sheet used has a thickness of 3 mm.

a) Cork b) Felt

Figure 1. Materials used for layers

Composite materials were prepared by mixing fir sawdust with polyurethane foam (mix of isocyanate and polyol). The polyurethane foam was prepared by mixing the polyol and isocyanate at a 1:0.7 ratio at 22÷24°C room temperature. A 30% weight percentage sawdust was used. Polyol and isocyanate were mixed with sawdust at determined weight ratios. To obtain a homogeneous composition, the mixture was poured into the mold and mixed at 2000 rpm with a mixer.

Fir sawdust with 10.4% humidity, 0.088 g/cm3 density and particle size greater than 2 mm was used for making sound absorbing composite materials. The binder used was a two-component flexible polyurethane foam with open pores (Neukadur PU 131, manufactured by Altropol Kunststoff GmbH, Stockelsdorf).

Samples 1 and 2 were made of a mixture of fir sawdust and 30% polyurethane as binder with a thickness of 15 mm for sample 1 and 36 mm for sample 2.

Multilayer materials were made by direct casting of the sample 1 recipe into the mold over which cork / felt layers was placed. In some samples, depending on the number of layers, above the cork / felt layer, a new sample 1 mixture was poured. The binder used to make the bond between fir sawdust also constituted the bond between the layer 1 and the layers of cork or felt. No additional binder has been used which could have reduced the sound absorbing properties and increased the price of multilayer materials.

The thickness of the multilayer materials from this study varies with the number of layers, as shown in Table 1.

Table 1. Thickness of multilayer materials according to the number of layers

Samples	Number of layers	Thickness (mm)
1	1	15
2	1	36
3 and 4	2	18
5 and 6	3	33
7, 8 and 9	4	36

Compared to sample 1, sample 3 has in addition a layer of cork with a thickness of 3 mm, and sample 4 a layer of felt with a thickness of 3 mm.

Samples 5 and 6 were made from three layers: a first layer was a mixture of fir sawdust and 30% polyurethane as binder, a second layer was made with cork for sample 5 and felt for sample 6 and the third layer was made with a mixture of fir sawdust and 30% polyurethane as binder.

Samples 7 and 8 were made with four layers: the first layer was a mixture of fir sawdust and 30% polyurethane as binder, the second layer was made with cork for sample 7 and with felt for sample 8, the third layer was made with a mixture of fir sawdust and 30% polyurethane as binder and the fourth layer was made of cork.

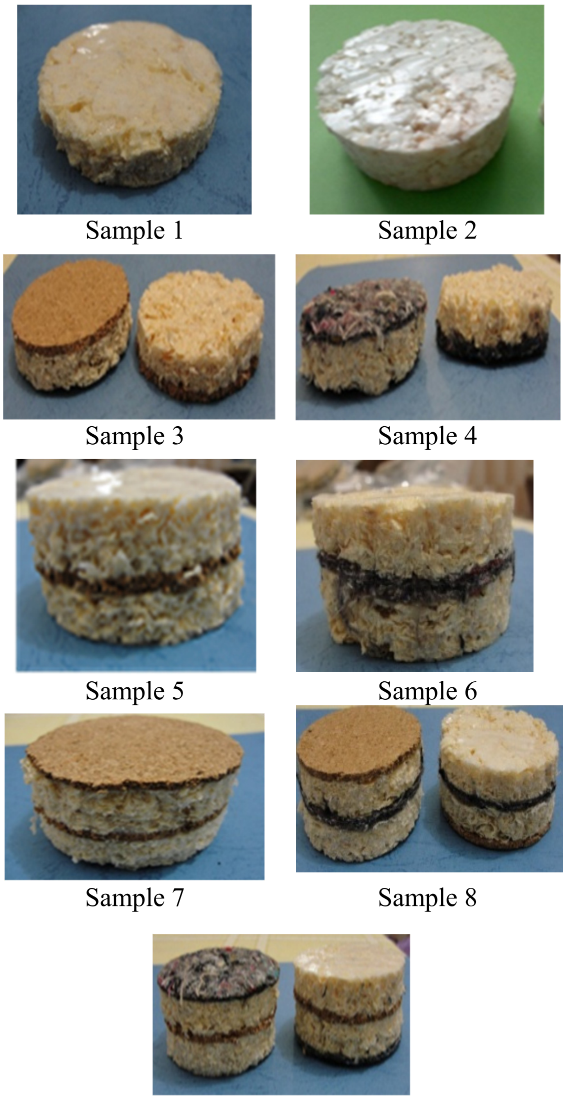
Sample 1
Sample 2
Sample 3
Sample 4
Sample 5
Sample 6
Sample 7
Sample 8
Sample 9

Figure 2. Materials used for determining the sound absorption coefficient

Sample 9 had four layers: a layer of a mixture of fir sawdust and 30% polyurethane as binder, the second layer was made with cork, the third layer was made with a mixture of fir sawdust and 30% polyurethane as binder and the fourth layer was made of felt.

The sound absorption coefficients for multilayered composites were determined by the impedance tube method. The material measurements were based on a two-microphone transfer-function method according to ISO 10534-2 [24].

The method of measuring the acoustic absorption coefficient by means of the impedance tube (or method of transfer function) is based on the fact that the reflection coefficient at normal incidence (r) can be calculated from the measured H12 transfer function between two positions of the microphone at different distances from the tested material. The transfer function of the incident (HI) and reflecting waves (H_R) between the microphone positions are defined as [24]:

$$H_I = \frac{p_{2I}}{p_{1I}} = e^{-jk\cdot(x_1 - x_2)} = e^{-jk\cdot s} \tag{1}$$

$$H_R = \frac{p_{2R}}{p_{1R}} = e^{-jk\cdot(x_1 - x_2)} = e^{-jk\cdot s} \tag{2}$$

where: $s = x_1 - x_2$ is the distance between the two microphone positions; x_1 and x_2 is the distance from the reference point to microphone position 1 and 2 respectively; p_I and p_R are the sound pressure propagating in the incident and reflected direction, k is a complex-valued wavenumber.

Transfer function H_{12} for the total sound field can be calculated with the formula [24]:

$$H_{12} = \frac{p_2}{p_1} = \frac{e^{jk\cdot x_2} + re^{-jk\cdot x_2}}{e^{jk\cdot x_1} + re^{-jk\cdot x_1}} \tag{3}$$

The reflection coefficient at the sample surface, x=0, can therefore be derived is [24]:

$$r = \frac{H_{12} - H_I}{H_R - H_{12}} e^{2jk\cdot x_1} \tag{4}$$

Sound absorption coefficient at normal incidence is calculated with the formula [24]:

$$\alpha = 1 - |r|^2 \tag{5}$$

In this study a medium tube kit of Brüel&Kjaer Type 4206 A, was used to measure various acoustic parameters. The medium impedance tube kit consisted in a 63.5 mm diameter tube and therefore materials were cut in circular samples with a diameter of 63.5 mm (Figure 2).

Acoustic signal generated by the PULSE Analyzer 3560-B-030 was amplified by the Power amplifier 2716 B&K and then results were recorded and processed on a PC [25].

Samples 3, 4, 8 and 9 were measured on both the composite material side and the cork / felt side. Thus, the acoustic absorption coefficient was determined by placing samples with both faces towards the source of sound wave generator.

3. RESULTS AND DISCUSSION

Sound absorption coefficient of new multilayered composite analyzed was determined using cylinder samples. Measurements were made in the frequency range of 100÷3200 Hz. Measurements data were processed and sound absorption coefficient variation with frequency plots were drawn (using 1/3 octave spectrum). Figures 3÷10 represents normal sound absorption coefficient variation with frequency.

3.1. Influence of multilayered composite surface on acoustic absorption coefficient

Figures 3÷6 show the influence of the multilayered composite material surface on the acoustic absorption properties. For samples 3 and 4 made of two layers – a layer of a mixture of sawdust and polyurethane as binder and a layer of cork and felt respectively, the acoustic absorption coefficient was measured on both sides of the samples. For samples 8 and 9, made of four layers, the acoustic absorption properties were measured on the surface of the sawdust and polyurethane as binder mixture and on the cork or felt surfaces.

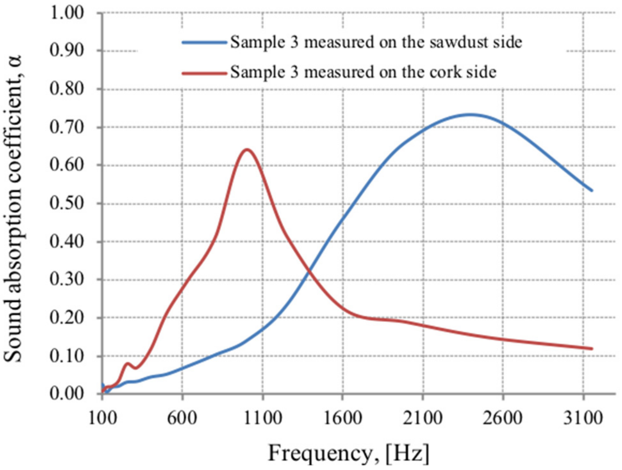

Figure 3. Sound absorption coefficient of Sample 3

As seen in figure 3, if sample 3 was placed with the cork layer to the direction where the sound wave comes, the acoustic absorption coefficient has better values in the frequency range of 100÷1400 Hz, while at frequencies above 1400 Hz, the absorption coefficient has better values if the sample is placed with the layer of sawdust to the direction of the noise source.

Analyzing Figure 4, in the case of the four-layer material, the type of the surface facing the noise source has a lower influence for frequencies lower than 600 Hz. For frequencies above 600 Hz, however, when the sample was placed with the cork layer facing the noise generating source, the absorption coefficient has much lower values than if the sample would be placed with the mixture of sawdust and polyurethane as binder layer facing the source.

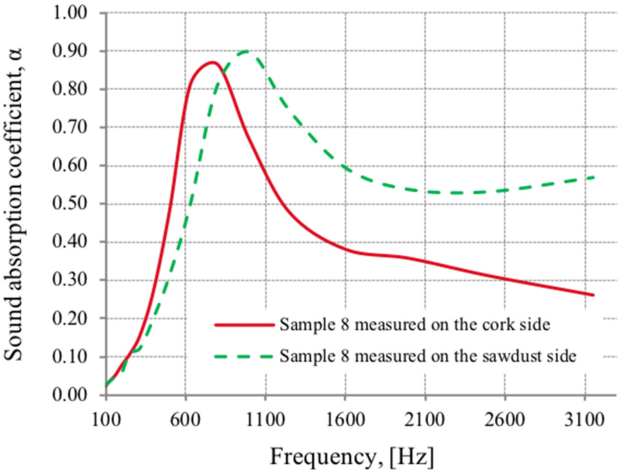

Figure 4. Sound absorption coefficient of Sample 8

As seen in Figures 3 and 4, the cork layer as the final layer of the sound absorbing material gives better absorption properties at frequencies lower than 1000 Hz. This is mainly due to the higher density of cork when compared to the sawdust and flexible open-pore polyurethane foam material [26]. But also because of the closed structure of the cork in comparison with the open structure of the sawdust-polyurethane binder [27].

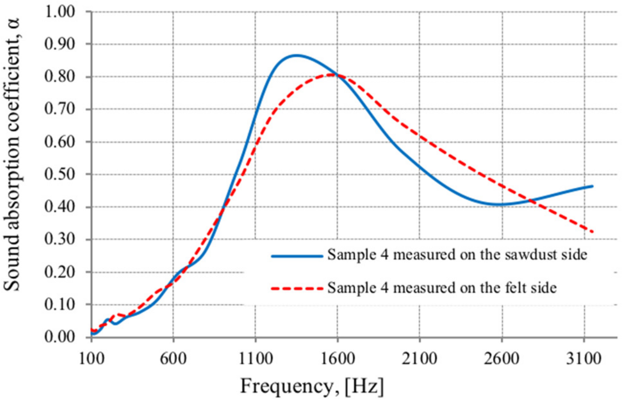

Figure 5. Sound absorption coefficient of Sample 4

When a cork layer was used instead a felt layer (pressed textile waste material), there was a rather small influence on the acoustic absorption coefficient, irrespective the type of the surface facing the noise source in case the two-layer material (Sample 4), see Figure 5. These aspects are valid at frequencies lower than 600 Hz and in the case of the four-layer Sample 9 material. However, at frequencies above 600 Hz, it was observed that facing the Sample 9 with the felt layer toward the noise source, resulted in a slight decrease of acoustic absorption coefficient, see Figure 6.

It must be highlighted that first layer of such a double layer material is playing the most important role in acoustic performance [13, 28, 31].

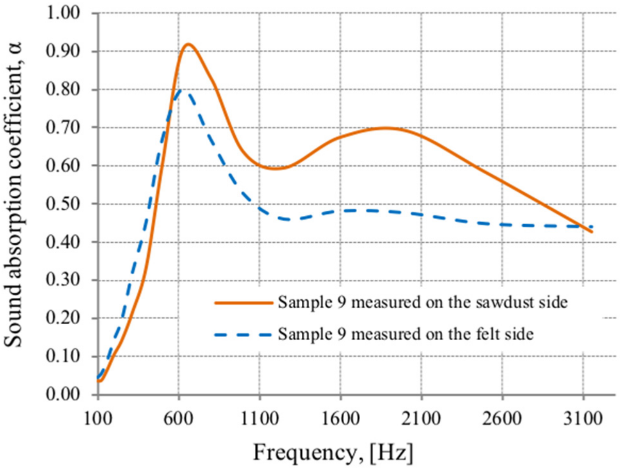

Figure 6. Sound absorption coefficient of Sample 9

3.2. Number of layers influence on the acoustic absorption coefficient of the multilayered composites

The absorption coefficient of porous material increases with thickness of the material, since particle velocity is maximum at a quarter wavelength from the substrate [14]. The increase of composite materials layers also means that the composites have more chance to contact with the sound wave. This causes more resistance by means of friction of viscosity through the vibration of the air [29].

Figures 7 and 8 show the variation of the acoustic absorption coefficient according to the frequency for materials with variable number of layers to analyze the influence of the number of layers.

Figure 7 shows the influence of the number of layers for multilayered composites consisting of layers of cork and layers of sawdust with polyurethane as binder. At frequencies less than 1100 Hz, the three and four layered materials (Sample 5 and Sample 7) show a significant improvement in absorption coefficient values, which means that with the increase in the number of layers, the sound absorption properties improve at low frequencies. Results are confirmed by other research [13, 14].

In the case of multilayered composites made of felt layer and sawdust with polyurethane as binder, the acoustic absorption coefficient has better values than a single layer material, at frequencies below 1600 Hz, as seen in Figure 8.

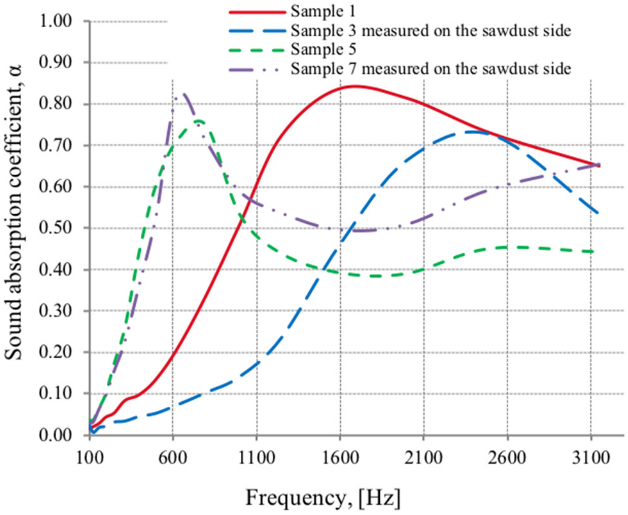

Figure 7. Sound absorption coefficient of Samples 1, 3, 5 and 7 - measured on the sawdust side

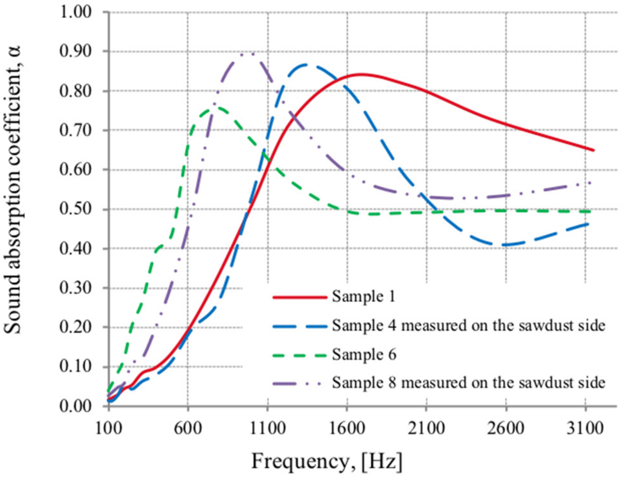

Figure 8. Sound absorption coefficient of Samples 1, 4, 6 and 8 -measured on the sawdust side

As seen in Figures 7 and 8, the improvement of the acoustic absorption properties of multilayer materials is also because with the increase of the number of layers the thickness of the multilayered composites increases according to Table 1. Displacement of absorption maximum to lower frequencies is solely due to sample thickness increase [30].

3.3. Influence of the separation layer type between two layers of sawdust with binder

Figure 9 shows the influence on the acoustic absorption coefficient of placing the cork layer for Sample 5 and the felt layer for sample 6, between two layers of sawdust with bicomponent polyurethane foam. At frequencies below 700 Hz the cork / felt layer has very little influence. At frequencies above

700 Hz, the acoustic absorption coefficient has higher values for the composite with felt layer (Sample 6) compared to the Sample 5 with cork layer.

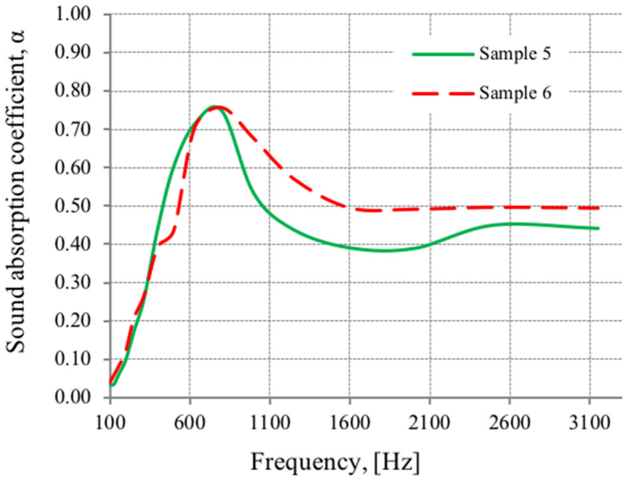

Figure 9. Sound absorption coefficient of Sample 5 and Sample 6

3.4. Influence of alternation of cork / felt layers versus unilayer material

Figure 10 shows the influence of cork / felt layers placed between the layers of sawdust and polyurethane foam. Samples 7 and 9, with the cork layer placed as second layer, were observed at frequencies below 1100 Hz. The sound absorption coefficient values were approximately constant over time. In the 1100÷2500 Hz frequency range, Sample 9 shows better properties because the last layer is the felt layer.

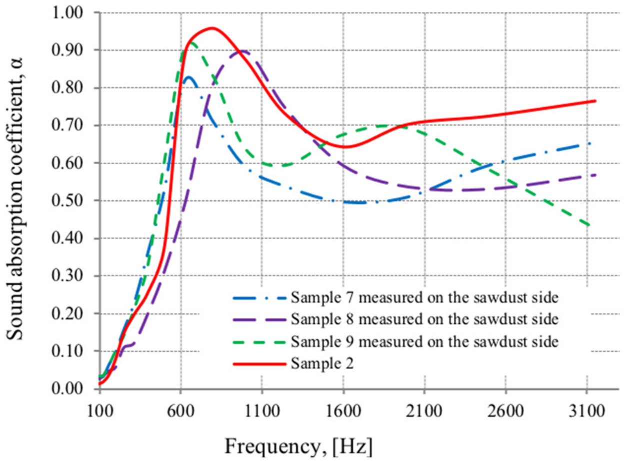

Figure 10. Sound absorption coefficient of Samples 7, 8, 9 and 2 -measured on the sawdust side

The shape of the absorption curve at frequencies greater than 600 Hz for Sample 8 differs from samples 7 and 9, mainly due to the second layer, made of felt.

Regarding Sample 2, which is made of a single layer of mixture of sawdust with 30% polyurethane foam, it has slightly lower acoustic absorption properties when compared to the multilayered materials analyzed in Figure 10, in the 100÷600 Hz and 900÷2000 Hz ranges, while in the rest of the frequency ranges has better properties. Again, the results obtained are consistent with other research [14].

Sound absorption coefficient of Sample 2 reached a maximum value of 0.95, which is the “peak absorption coefficient”, at the frequency of 800 Hz; see Figure 10.

As seen in Figure 10, the multilayered composite with four layers have sound absorption coefficient values over 0.65 in a large range of frequencies between 300÷3150 Hz for the sample 2; over 0.6 in a large range of frequencies between 300÷2500 Hz for the sample 9; and over 0.5 in a large range of frequencies between 300÷3150 Hz for the samples 7 and 8. According to other studies [32], this material acoustic absorption coefficient is over 0.5 for almost the entire frequency range; therefore it is often used as sound absorbing material.

4. CONCLUSIONS

New multilayered composite obtained in this study have good sound absorption properties on a large frequency range, especially the samples measured on the sawdust side, which provide to be advantageous when it comes to reducing the noise of many types of noise sources.

Using cork as a surface layer improves sound absorption in the frequency range of 100÷1400 Hz and decreases it at higher frequencies, while the felt material doesn’t significantly change the sound absorption properties.

An important advantage of multilayered materials with cork as surface layer is that for the same material we can have different uses depending on the frequency we are interested in. To obtain effective noise absorption over a wide range of frequencies, panels or walls can be made of one material, that can be alternately faced with one of the two faces (cork or sawdust with polyurethane binder) toward the noise source.

Designing materials with multiple layers of the same type or of different types leads to obtaining an effective sound absorption on a wider range of frequencies.

Due to the composition, the materials used in this research are recommended to be used inside the buildings, as acoustic treatments of the enclosures (on the interior / floor walls) to regulate the reverberation time.

Materials used in this study has a lower manufacturing cost. The other properties like resistance to external environmental factors (frost / thaw, saline exposure, exposure to UV / Xenon radiation, etc.) and mechanical strengths (compression, impact resistance / shock, etc.) will be analyzed in future researches.

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