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Preliminary study of the sound absorption of composite panels composed by natural fibers and polyurethane at low frequencies

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Abstract

Naturally sourced materials are becoming a valid alternative to traditional synthetic materials for applications in acoustic control in environments. In this paper, a preliminary study of the sound absorption of two types of composite panels made of natural fibers and polyurethane is presented. The natural fibers used are coconut husk fiber and sugar cane bagasse, both from agricultural waste, very common in Brazil. Polyurethane is a bicomponent formed by isocyanate and polyol obtained from castor oil. The samples were formed by two layers, one of fiber and the other of polyurethane, with approximately 17.0 mm thickness, 6 mm of fiber and 11 mm of polyurethane. The sound absorption of these composites was evaluated with the impedance tube and the results were compared with samples composed only of fibers and same thickness. The results are promising and showed that the samples of composite sugarcane fiber have better performance and an average gain of 0.3 in sound absorption between the frequencies of 700 and 1200 Hz, when compared only with fiber. In addition, they showed an absorption peak of 0.6 at 1000 Hz. However, the coconut husk samples showed an absorption peak of 0.57 at 790 Hz. Finally, a comparison between the samples with and without PU was carried out. The results show the sugar cane samples with PU have a higher performance for the frequency above 600 Hz.

Keywords: natural fibers, impedance tube, sound absorption

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1. INTRODUCTION

Polyurethane foams (PU) are the most used synthetic materials in noise control because they have high performance for acoustic absorption. On the other hand, they are harmful to the environment because they are materials of petroleum origin and when discarded they have an indefinite decomposition time. To minimize impacts, these materials can be chemically recycled through their depolymerization. However, this process uses highly toxic organic solvents and, in addition, other toxic by-products are obtained from the chemical reactions used. As an aggravating factor, the depolymerization is not economically viable, according to Uliana *et al.*[1].

With the purpose of reducing environmental impacts, materials that are less aggressive to the

environmental are studied all over the world. Some examples of this are materials classified as “partially eco-friendly biomaterials”. These composites consume less energy to obtain them, less petroleum derivatives and consequently are less polluting throughout their production chain, [2].

There are many researches involving the use of natural fibers for noise control. However, these fibers do not have the same acoustic efficiencies when compared to synthetic materials [3]. Therefore, this work aims to evaluate the acoustic efficiency of two types of composite materials formed by fibers and PU. The fibers used are coconut husk fiber and sugar cane bagasse, in addition to polyurethane - bicomponent formed from a polyol obtained from castor oil. The acoustic efficiency of the samples is described in terms of the sound



absorption coefficient (α), evaluated with the impedance tube according to the standard ASTM E1050 [4]. The composite samples produced have a total thickness of approximately 17 mm and diameter of 100 mm. The experimental evaluation was performed between the frequencies of 200 to 1600 Hz.

2. FUNDAMENTALS

Çelebi and Küçük [5] used tea leaf fiber to mix with a polyurethane base to produce a soft foam. The results showed an increase in sound absorption by 50% at low and medium frequencies. Zulkifli *et al.* [6] made a sandwich panel composed of a perforated plate of coconut fibers and polyester for evaluation in a reverberant room. The result showed sound absorption of 0.7 to 0.8 at frequencies from 1000 to 1800 Hz. Innace *et al.* [7] characterized fiber from the root of the *palmyra* through numerical and experimental analysis. The sound absorption coefficient was calculated with the numerical model using an algorithm based on an artificial neural network. The results showed high values for Pearson's correlation coefficient from 0.7 to 0.98 in the frequency ranges from 500 to 1500 Hz. Bittencourt *et al.* [8] studied samples of coconut fibers, sugar cane and sisal with thicknesses of 15, 20 and 30 mm. The samples were experimentally evaluated and the results were compared with classical analytical methods of Delany-Bazley [9] and Allard-Champoux [10]. The 30 mm thick sugar cane samples showed higher sound absorption compared to coconut, reaching a value of 0.7 at 1000 Hz. Besides that, in this study the analytical results underestimated the experimental results.

Ji *et al.* [11] characterized samples made from vegetable oil foam, bio-polyurethane and calculated the different microstructures based on the theoretical model of Johnson-Champoux-Allard [10] [12], using the finite element method. The predictions resulted that the greater number of pores influences the absorption, showing the absorption coefficient from 0.6 to 0.95 in the frequency ranges from 1000 Hz to 6000 Hz. Vale *et al.* [13] developed a foam from the liquefaction of industrialized products. The results showed that rigid foam has high

attenuation and physical quality. Tang and Yan. [14] did an extensive characterization review of multilayer samples made from nonwoven fabric (TNT) and PET (*polyethylene terephthalate*) mesh. It was verified that each fibrous material has different absorption mechanisms and when together they considerably improve acoustic absorption. Kairyte *et al.* [15] recycled sludge waste from paper production to fill rigid polyurethane foam, aiming to improve its rigidity and gas emission characteristics. The results showed that the sludge particles contributed to a sustainable production to the environment.

The above paragraphs show that composite materials and natural fibers have the potential to be applied in noise control.

3. DEVELOPMENT

3.1 Sample manufacturing

Circular samples were manufactured using the ratio of 6.3 g of fiber to 5.4 g of adhesive (polyvinyl acetate – PVA). PU is a polymer made from the reaction of two substances: an isocyanate and a polyol obtained from castor oil. The proportion of these components used was 8/10. First, samples of natural fiber were manufactured. The fibers mixed with the adhesive were deposited in a closed mold, remaining for four hours in a stove at 42°C. After removed from the mold it was necessary to remain at room temperature for another 12 hours for complete drying of the compost.

The bi-components that gave rise to the polyurethane were spilled on the surface of the discs in an open mold for expansion of the PU. Figure 1 shows the fabricated samples.



Figure 1: Composite sample (fibers + PU), A – sugar cane fiber and B – coconut fiber

3.2 Experimental Method

An impedance tube was used to evaluate the samples. The tube is characterized by having a source and a rigid termination at the ends. Two microphones are positioned along the tube, as shown by Figure 2.

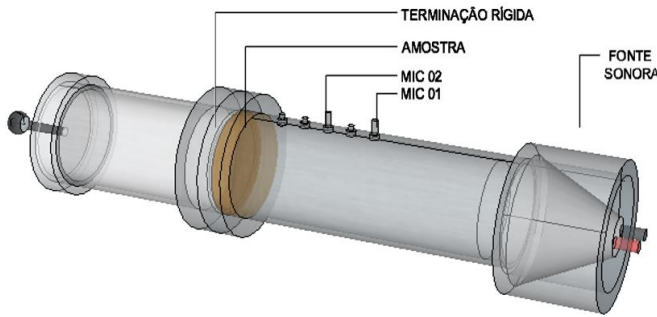


Figure 2: Impedance tube illustration

The impedance tube used is from the brand SCS 9020B/K with 100 mm diameter. The signal analyzer and generator is from Brüel & Kjær Type 3160-A-042 with six channels – four input channels and two output channels. The microphones used to acquire the signals were Brüel & Kjær Type 4935 of 1/4" with nominal sensibility of 5,6 mV/Pa. The measurement results were analyzed using the software Matlab® (2022 version).

Measurements were performed using the transfer function method for Chung & Blaser em 1980 [16], [17]. Based on this method, the sound reflection coefficient R can be obtained by

$$R(f) = \frac{H_{12} - e^{-iks}}{e^{iks} - H_{12}} e^{2ikx_1} \quad (1)$$

$$H_{12} = p_2(f)/p_1(f) \quad (2)$$

In equations 1 and 2, H_{12} represent the transfer function, x_1 the position of microphone 1 in relation to the face of the sample, k the complex wave number.

In this case, the sound absorption coefficient α for normal incidence can be calculated as a function of the reflection coefficient:

$$\alpha = 1 - |R(f)|^2 \quad (3)$$

This method considers only the propagation of plane waves inside the tube. As a result, the maximum frequency (f_c) for this to occur can be calculated by:

$$f_c < \frac{1,84c}{\pi d} \quad (4)$$

The Equation 4 considers only the diameter of the tube and the speed of sound. In order to minimize the error associated with the position of the microphones (distance s), it is recommended that the analysis frequency range f be calculated as [16]:

$$\frac{0,1c}{2s} < f < \frac{0,8c}{2s} \quad (5)$$

For the $s = 100$ mm distance, the following frequency range is considered

$$171 < f < 1370 \text{ Hz} \quad (6)$$

with $f_c = 2010$ Hz.

4. RESULTS AND DISCUSSIONS

From the results obtained in measurement and with the use of the Matlab® software, it was possible to generate the graphs of the sound absorption α of the samples. Figure 3 shows the measurement bench made up of an impedance tube connected to the signal generator and also to the software for obtaining and interpreting the results.

For a better interpretation of the results, the mean physical characteristics can be seen in Table 1. Three samples were manufactured with each fiber.

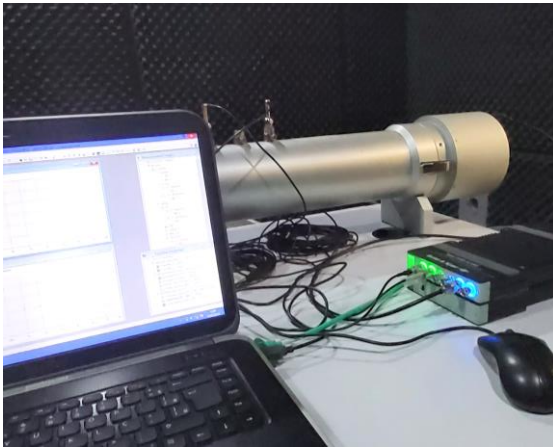


Figure 3: Impedance tube measurement

Figure 4 shows the sample of coconut husk and sugar cane bagasse without the addition of PU. The graph presented in Figure 5 shows the average sound absorption coefficient for the two types of fibers with the addition of PU. As for Figure 6, the comparison of the sound absorption coefficient between samples with and without PU can be evaluated. In these graphs, the red lines represent the coconut fiber samples and the blue lines represent the sugar cane fiber samples. The solid and dashed lines represent the sample with and without PU, respectively.

Table 1: Sample properties

Samples	Thickness [mm]	Mass [g]	Density [kg/m ³]	Variance [kg/m ³]
Sugar cane + PU	18	27	190.6	±4.53
Coconut + PU	20	25	161.5	±4.62
Sugar cane fiber	15	24	200.8	±10.8
Coconut fiber	17	28	202.3	±14.6

Evaluating the samples with PU, it can be observed that the coconut samples showed an absorption peak of 0.58 at the frequency of 790 Hz and below 0.18 for the other frequencies. Sugar cane samples showed an absorption peak greater than 0.4 for a frequency range between 850 and 1300 Hz. In addition, it achieves a sound absorption of 0.6 at the frequency of 1170 Hz.

For the comparison between the samples with and without PU shown in Figure 6, it can be observed that the sugar cane samples with PU have a higher performance for the frequency above 600 Hz.



Figure 4: Samples formed only by fibers, A - Coconut husk and B - Sugar cane.

5. FINAL CONSIDERATIONS

Based on the measurements, it was possible to observe that the sample with polyurethane and sugar cane fiber showed better results in terms of sound absorption. It should be noted that the results are preliminary compared to the research that will be developed.

The PU used in the samples has the isocyanate with an aromatic chain. Therefore, the material

has low porosity and high rigidity. To enhance absorption, a saturated or aliphatic cyclic chain isocyanate is recommended.

5. ACKNOWLEDGEMENT

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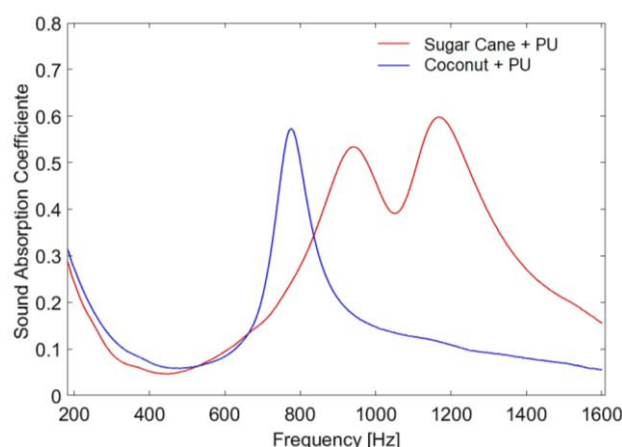


Figure 5: Absorption coefficient for the PU samples

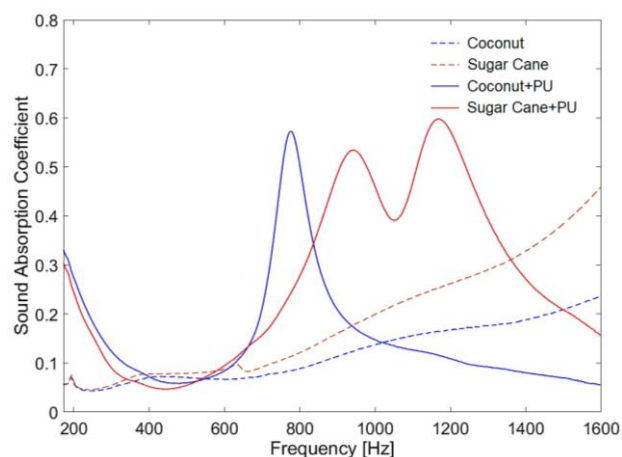


Figure 6: Comparison between the results for samples with and without PU

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