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# STUDY OF THE SOUND ABSORPTION OF TWO COMPOSITES MADE WITH POLYURETHANE AND NATURAL FIBER LAYERS AT LOW FREQUENCY USING AN IMPEDANCE TUBE

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**Abstract.** *Porous synthetic materials with low density are often used for acoustic surface treatment because they have high sound absorption. In the last decade, so-called green materials have been emerging ground in research in the noise control field. For example, natural fibrous material from agricultural waste or a by-product from another industrial transformation process. However, they have a different efficiency compared to synthetic materials. To improve the acoustic performance of natural fibers, it is necessary to add some synthetic material to the fibers, forming a composite. In this work, samples of thin composites classified as eco-friendly made by polyurethane (isocyanate + polyol obtained from sugar cane), coconut coir husk, and sugar cane bagasse fibers bonded with polyvinyl acetate (white glue). The two materials involved were arranged in layers and glued with white glue. Ten samples of each material with a diameter of 100 mm were made. In addition, they were manufactured with polyurethane and fiber thicknesses of 5 and 10 mm, respectively. The sound absorption coefficient of the samples was evaluated between 180 and 1600 Hz, with the transfer function method based on the ASTM E1050 standard. The samples were inserted inside the tube so that the incidence of the sound waves occurred on the polyurethane face and with the fiber side on the rigid termination. The results showed that adding polyurethane increased the sound absorption in the range between 800 and 1000 Hz of the composites created compared with the samples formed only by natural fibers. When evaluating the results, fluctuations appeared in the sound absorption curves caused by the vibration of the composite when excited by the sound waves inside the impedance tube. This phenomenon does not occur when the samples are made only with natural fibers..*

**Keywords:** *sound absorption, composite, transfer function method, coconut husk fiber, sugar cane bagasse fiber.*

## 1. INTRODUCTION

Polyurethane (PU) foam is commonly used on surfaces or in sandwich walls for noise control. It is a product of petroleum origin that, in its production line, has a high consumption of embedded energy for extraction of the leading chemical products such as isocyanate and polyol. In addition, the environmental impacts generated by the extraction of this material can be reduced when vegetable-origin materials replace part of it. Polyol and isocyanate, when mixed, form petrochemicals or, commonly known as PU foam. However, when the polyol is made from sugarcane and associated with isocyanate, a bio-composite eco-friendly material is formed with characteristics similar to petrochemical PU. In addition, it is possible to add other materials to this foam through layers to increase sound absorption at low frequencies and contribute to reducing environmental impacts.

In this work, samples were made to be measured in layers, being samples of polyurethane with sugar cane polyol (PUCA) with a thickness of 5 mm with a layer of coconut husk fiber sample, or of sugar cane bagasse fiber, the fiber samples being approximately 10 mm thick. Therefore, this article aims to evaluate the sound absorption of the samples through experimental measurements in an impedance tube with the transfer function method in accordance with ASTM 1050-2012 (American Society for Testing and Materials).

## 2. THEORETICAL FOUNDATION

Porous samples have a structure that, depending on their density, can present flaccid characteristics and thus compromise the result of absorption, Panneton (2007). Olney and Panneton (2008) evaluated the sound absorption coefficient samples of foam, glass, and rock wool using experimental and empirical methods. In this study, the authors

assessed that the vibration of the frame causes errors in the measurements due to the lack of rigidity of the samples. Thin pins were inserted transversely in the samples to reduce the vibration during measurements and improve the results.

Çelebi and Küçük (2012) used tea leaf fiber with a polyurethane base to produce a soft and rigid foam to compare their sound absorption coefficient. The results showed an increase in sound absorption by 50% in the medium frequency. Chen and Jiang (2016) evaluate the acoustic properties of a foam composite made from the polyurethane matrix with bamboo leaf fragments. The authors assessed the sound absorption coefficient and transmission loss in an impedance tube and flow resistivity. The results showed that the bamboo leaf particles increased the proper absorption and acoustic insulation of the PU in many frequency ranges. Tang and Yan (2017) examined the characterization of multilayer samples made from nonwoven fabric (TNT) and PET mesh targeted for acoustic absorption. With this, it was verified that each fibrous material has different absorption mechanisms, and when together, they improve the acoustic absorption of the material.

To produce samples of vegetable foam bio-polyol from the nanocrystal extracted from rapeseed straw and cellulose, the foam was prepared by liquefying the straw in microwaves (Huang et al., 2018). The results showed that the foam presented a better physical-mechanical behavior in density and reticulation than petroleum-based foams. Furthermore, the higher the percentage of bio-polyol, the better the acoustic performance of the foam. Ji et al. (2020) characterized samples made of vegetable oil foam and bio-polyurethane and calculated the different microstructures in the theoretical acoustic absorption methods of Johnson-Champoux-Allard, with finite element analysis in the cell unit periodicals under ideal conditions. The results demonstrated that the more significant number of pores influences better sound absorption.

## 2.1 Mathematical equations

The  $H_{12}$  transfer function method developed by Chung and Blaser (1980) is base of the ASTM E 1050-2012 standard. This technique has been used to determine the material's acoustic properties through pressure measurements on the two-phase samples at two different points inside the impedance tube with two microphones. The impedance tube consists of a tube that has a sound source at one end and another end, a rigid termination (Figure 1). Transfer function method developed by Chung and Blaser (1980) is base of the ASTM E 1050-2012 standard. This technique has been used to determine the material's acoustic properties, through pressure measurements on the two-phase samples, at two different points, inside the impedance tube with two microphones. The impedance tube consists of a tube that has a sound source at one end and another end, a rigid termination (Figure 1).

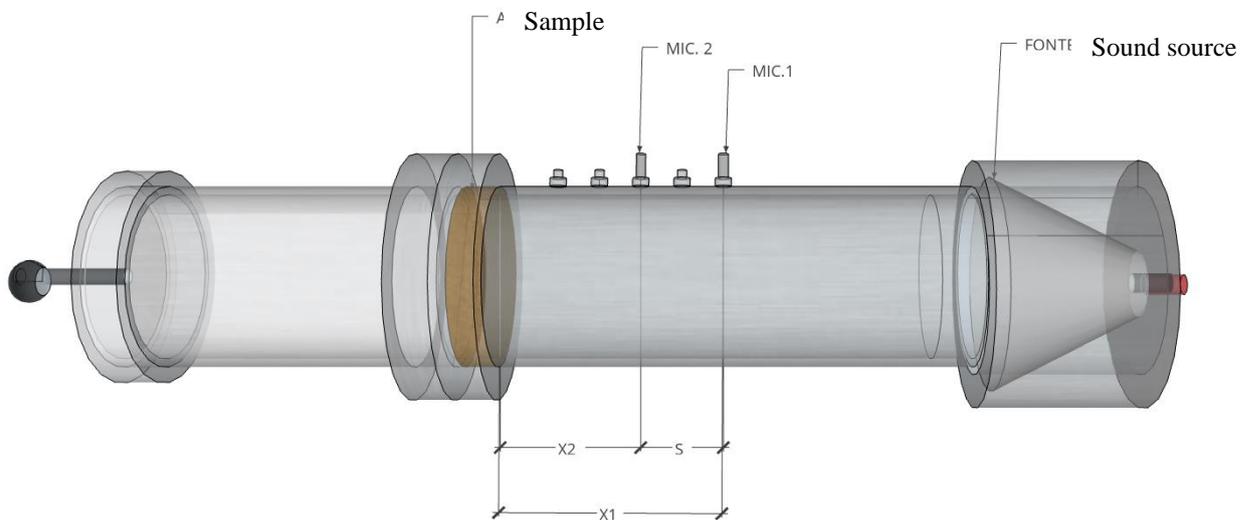


Figure 1. SCS 9020B/K impedance tube scheme.

The transfer function method is one of the most traditional methods for the acoustic characterization of materials. One of the main advantages concerns the fast measurements for an extensive frequency range. The procedure is standardized by ASTM E1050-10 (2012) and considers only the propagation of plane waves inside the impedance tube, that is, only normal incidence to the surface of the analyzed sample. The impedance tube has a constant circular section with one of its ends connected to a loudspeaker and the other, where the sample is positioned, a rigid termination, Figure 1. With the transfer function  $H_{12}$  between microphones 1-2 as a function of the sound pressures measured by microphones 1 and 2, the reflection coefficient of the material  $R_x$  is obtained by:

$$R_x = \frac{e^{ik_0s} - H_{12}}{H_{12} - e^{-ik_0s}} e^{2ik_0L} . \quad (1)$$

In eq. 1,  $k_0$  represents the wavenumber of propagating waves in the medium,  $s$  is the spacing between microphones 1 and 2, and  $L$  is the distance between microphone 2 and the front face of the sample. Furthermore, with the complex reflection coefficient  $R_x$  in hand, the sound absorption coefficient  $a$  can be obtained by

$$a = 1 - |R_x|^2 . \quad (2)$$

The plane wave cutoff frequency  $f_c$ , the maximum frequency at which only plane-front waves propagate inside the impedance tub, is determined by Eq. 3. As can be seen, this equation takes into account the speed of sound  $c$  in propagation and the internal diameter  $D$  of the tube:

$$f_c < \frac{1,84 c}{\pi D} \quad (3)$$

Eq. 3 considers only the tube diameter and the sound velocity inside it. Another analysis is the valid frequency range for measurements depending on the spacing between microphones used (Abom and Boden, 1988). The confidence interval is given by:

$$\frac{0,1 c}{2s} < f < \frac{0,8 c}{2s} \quad (4)$$

When considering the cutoff frequencies, maximum and minimum frequencies for each tube, an interval of 200 to 1,600 Hz was considered for the 100 mm apparatus and from 1000 to 5000 Hz for the 28mm. For graphical analysis, a polynomial interpolation between the results is performed to make the junction between the absorption generated by the two tubes between 1,000 and 1,500 Hz.

### 3. METHODOLOGY

Ten assessed samples were made, five with PUCA + coconut husk coir fiber and five with PUCA + sugar cane bagasse fibers. The samples had natural fiber, adhesive based on Polyvinyl Acetate (PVA), and water. Figure 2 demonstrates the handling of the process. The approximate amount of materials used to manufacture the samples is shown in Table 1. The fiber was weighed, mixed with PVA and water, placed in a mold, and pressed to cure at 40°C.

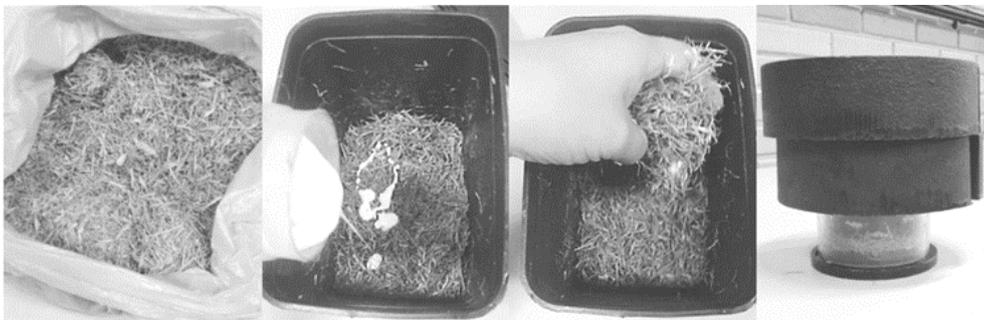


Figure 2. Manufacturing stages of the natural fiber sample.

The fiber samples produced are approximately 10 mm thick and 100 mm in diameter. The samples from PUCA followed a simple handling of the mixture of isocyanate and polyol from sugar cane in a proportion of 1/1; after the samples were made, they were cut with a 5 mm thick blade. The PUCA foam samples were attached with PVA to the samples of natural fiber, creating a new sample with two textures and a total thickness of approximately 15 mm, Figure 3

Table 1. Proportion of fiber, PVA adhesive and water for samples thickness 10 mm

Composite Properties	Materials	
	Coconut Sugar Cane	Polyurethane
Fiber [g]	6	-
PVA [g]	4	-
Water [g]	4	-
Isocyanate [kg]	-	13
Polyol [kg]	-	13
Density [kg/m <sup>3</sup> ]	105,16	45

The samples, after completion, Figure 3, with the two layers joined, were evaluated in an impedance tube with the transfer function method, Figure 1. For the measurements, a random noise was used as excitation. A space of 100 mm between the microphones was used for the tube with the largest diameter. In both analyses, the following equipment was required for signal acquisition and processing: the Brüel & Kjaer Type 3160-A-042 signal generator and analyzer with four input and two output channels; Two Brüel & Kjaer Type 4935 ¼" free-field pre-polarized microphones with 5.6 mV/Pa sensitivity.



Figure 3. Sample with 10mm sugar cane fiber layer and 5mm PUCA layer.

Ten measurements of each sample were made with the transfer function method. Inside the impedance tube, the sound is incident on the foam face of the sample. When analyzing the results, it was observed that the sound absorption presented multiple absorption peaks, leading to erroneous measurements. This problem can be caused by vibration in the structure during the propagation of sound waves. Pins were inserted into the samples to increase their rigidity in this condition. When a sound wave passes through the thin porous sample, it causes small vibrations in the cross-section of the PU (membrane effect), leading to unreliable results, (Olny & Panneton, 2008), Figure 4. The sound absorption coefficient was assessed using an impedance tube based on the ASTM E1050 standard.



Figure 4, PUCA + Coconut husk coir fiber sample with pin inserted.

#### 4. RESULTS

Figures 5 and 6 show the averages of the 5 measurements of the two samples. The PUCA+Coconut samples reached a sound absorption coefficient of 0.7 for the frequency of 700 Hz (Figure 4) and the PUCA+Sugar Cane samples the value of 0.75 at 850 Hz (Figure 5). In addition, the results of the PUCA+Sugar Cane samples showed a plateau of 0.6 between 620 and 100 Hz, while the PUCA+Coconut between 600 e 800 Hz. Furthermore, the inclusion of pins, as shown in figure 4, proved efficient in reducing fluctuations in the sound absorption coefficient measured for the two samples. Furthermore, these figures show with dashed lines the average result of 5 samples of sugar cane and coconut with 15 mm thickness evaluated without the addition of PU.

Comparing the results, it can be easily noted that the addition of PU is necessary to increase the sound absorption efficiency of the samples.

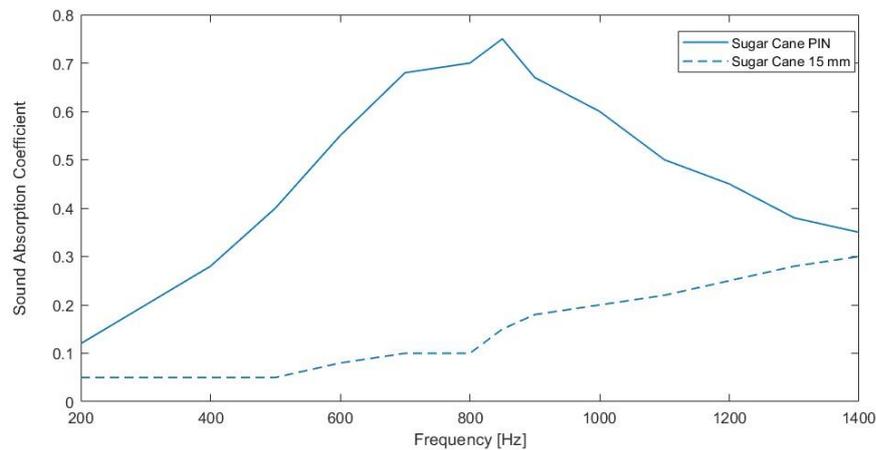


Figure 5: Sound absorption coefficient - PUCA+Sugarcane.

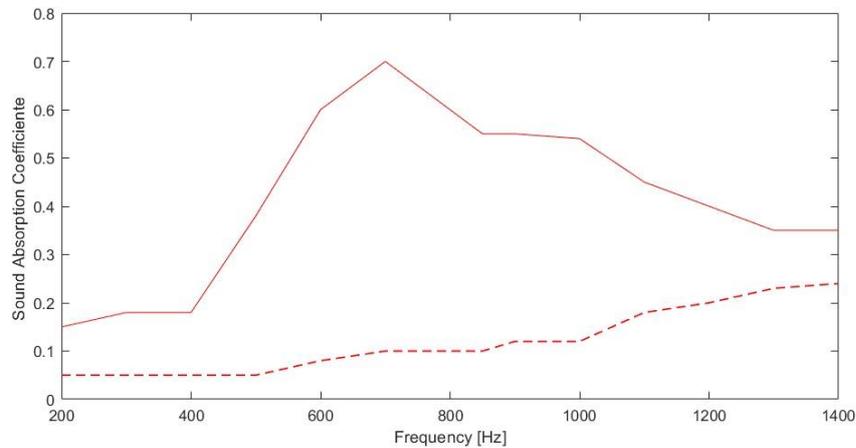


Figure 6: Sound absorption coefficient - PUCA+Coconut.

## 5. CONCLUSIONS

Comparing the two materials evaluated, it can be said that the composite made with PUCA and sugar cane bagasse fiber has a better acoustic efficiency than the one formed with coconut husk coir fiber.

This preliminary study shows the potential of eco-friendly composites for engineering applications in noise control. Adding a small thickness of PU is necessary because natural fibers have low acoustic performance. These samples are an alternative material with reasonable low-frequency absorption compared to pure synthetic acoustic materials (100% PU). In addition, it is worth noting that in the samples studied, only 5 mm of PUC was used; that is, only 33.3% of the sample thickness is synthetic. The final composites, although polluting, require less petroleum and less energy for their manufacture.

## 6. ACKNOWLEDGEMENTS

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