27th ABCM International Congress of Mechanical Engineering
December 04-08, 2023, Florianópolis-SC, Brazil

COBEM-2023-2317
COMPARISON OF THE SOUND ABSORPTION COEFFICIENT FOR THREE NATURAL FIBERS USING THE IMPEDANCE TUBE

Ana Carolina Mendonça Mansur
Claudia Bittencourt
Marco Zeschotko
Nilson Barbieri
Key Fonseca de Lima
Pontifical Catholic University of Parana, Curitiba, Paraná, Brazil
anamendoncamansur@gmail.com, claudiabittencourt2010@gmail.com, marco.zeschotko@gmail.com, nilson.barbieri@pucpr.br, key.lima@pucpr.br

Abstract. *Every day, humans are exposed to a multitude of sounds from sources that differ in nature, frequency and amplitude. Long exposure to these sounds can cause irreversible health problems. To control this undesired exposure, the development of noise control applications using green materials has been growing in the last decade. This research paper aims to evaluate the acoustic efficiency of sugarcane bagasse, hay, and coconut husk coir fibers in terms of their sound absorption coefficient between 200 and 5000 Hz. The evaluated samples have density and thickness of 190 kg/m³ and 30 mm, respectively. The fibers were bonded with white glue (polyvinyl acetate), and with a fiber/glue ratio equal to 10:9. The sound absorption coefficient was assessed using an impedance tube based on the ASTM E1050 standard. Furthermore, the samples were arranged inside the impedance tube with and without an air gap, between the rigid termination and the samples. Ten samples of each fiber were manufactured, and the results showed that the sugarcane samples had higher absorption when compared to coconut and hay. However, the sound absorption peak for the three fibers was at 1600, 1200, and 800 Hz, respectively. Finally, the air gap addition at the back of the sample increased sound absorption after the first absorption peak and moved it toward the low frequency.*

Keywords: *sound absorption, natural fibers, air gap, coconut fiber, sugarcane fiber, hay fiber.*

1. INTRODUCTION

Continuous exposure to noise over the years can lead to effects such as increased blood pressure, muscle tension, headaches, and insomnia, among others (Canlon *et al*., 2012). Therefore, it can be said that noise reduction is one of the main requirements for human comfort. The development of materials for noise control in automobiles, as well as industrial and domestic environments, has to meet efficiency standards in terms of acoustic absorption and economic viability (Ersoy and Kuçuk, 2009).

Along with the problems generated by noise pollution, alternatives to the use of synthetic materials are sought. Polyurethane foam, for example, is harmful to the environment when discarded. Materials such as natural fibers are abundant in Brazil and are often underutilized or agricultural waste. Fibers such as sugar cane and coconut husk can be used both in the furniture construction, in the automotive industry, and can also be widely used as acoustic insulation materials (Fatima and Mohant, 2011).

The acoustic characterization of alternative materials is fundamental for the comparison and potential replacement of commonly used synthetic materials.

2. MATERIALS AND METHODS

Three types of natural fibers were selected for the manual manufacture of the samples: sugar cane, coconut and hay fibers. The samples followed the ratio of 10:9 of fiber and glue (PVA adhesive – Polyvinyl Acetate dispersed in H_2O). The Transfer Function Method (Chung and Blase, 1980), using 28 and 100 mm impedance tube, in addition to the flow resistivity bench standardized by ASTM C522-03 (2009), will be presented.

2.1 Sample manufacturing

The objective of this step was to manufacture 10 samples of each material for measuring the sound absorption coefficient in the impedance tube of 100 (low frequency) mm internal diameter. After performing these measurements, the samples were cut to 28 mm in diameter for the high frequency impedance tube, with the aid of a 15 tons hydraulic press.

Figures 1 and 2 show the samples with 100 mm in diameter and then reduced to 28 mm, respectively.

Figure 1. Samples: sugar cane, husk and coconut husk

Figure 2. Samples with 28 mm

2.2 Experimental bench

The transfer function method is one of the most traditional methods to characterize acoustic materials. One of the main advantages are the fast measurements for a wide frequency range. The procedure is standardized by the ASTM E1050-10 norm (from 2012) and considers only the propagation of plane waves inside the impedance tube - only normal incidence to the surface of the analyzed plane.

The transfer function can be interpreted by placing two microphones at known distances along the tube, with the objective of determining the cross spectrum and power spectrum. The tube of the constant circular section has one of its ends connected to a loudspeaker (random standing waves signals) and another where the sample is positioned, tangent to the rigid termination; as shown in Figure 3.

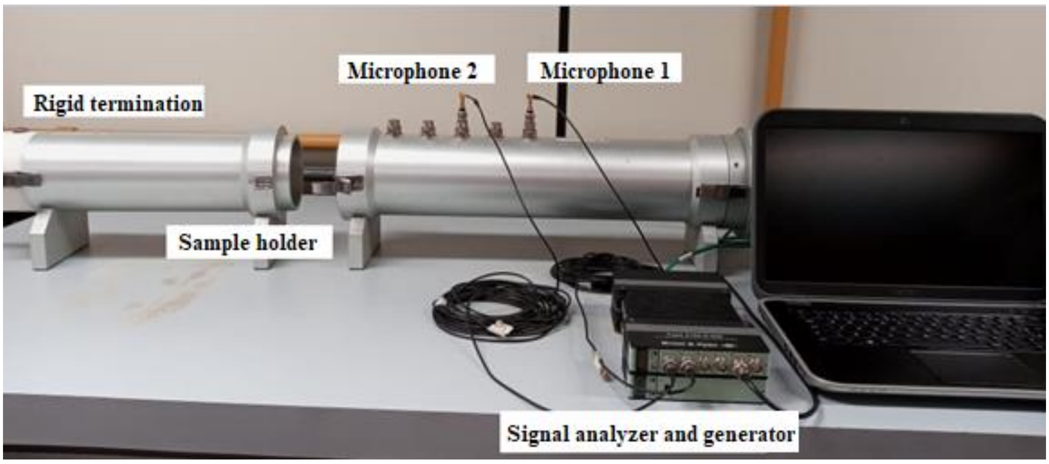

Figure 3. Impedance tube setup for the Transfer Function Method

In the first analysis, a low frequency tube was used for samples with a diameter of 100 mm. Afterwards, the experimental procedures were repeated for higher frequencies, using a tube with a diameter of 28 mm. In both cases, as shown in Figure 4, two microphones were used, based on the Transfer Function Method developed by Chung and Blaser (1980).

Figure 4. 28mm and 10mm diameter impedance tubes

For the tube with the largest diameter, a space of 100 mm between the microphones was used. As for the 28 mm tube, 20 mm between the microphones. 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.

2.3 Transfer Function Method

The sound pressure field inside the tube can be described as:

$$p(x,t) = C_1 e^{i(\omega t - k_0 x)} + C_2 e^{i(\omega t + k_0 x)}, \tag{1}$$

when,

C_1 and C_2 are the sound amplitudes of the incident and reflective waves [Pa], ω is the angular frequency [rad/s], k_0 is the wave number $[m^{-1}]$, t it´s time [s], x is the longitudinal coordinate and i is the imaginary unit and has a value equal to $\sqrt{-1}$. The first term of the equation refers to the incident wave, or in the negative direction for the x axis – observe the arrangement of the impedance tube with regard to rigid termination and sample position.

The second term presents the reflected wave which, in turn, deals with the positive direction. The ratio between the pressure measured on microphone 2 with that measured on microphone 1, can be defined as a transfer function:

$$H_{12}(f) = \frac{p_2(t)}{p_1(t)} = \frac{C_1 e^{i(\omega t + k_0 x_2)} + C_2 e^{i(\omega t - k_0 x_2)}}{C_1 e^{i(\omega t + k_0 x_1)} + C_2 e^{i(\omega t - k_0 x_1)}} \tag{2}$$

Equation 2 can be simplified, obtaining:

$$H_{12}(f) = \frac{p_2(t)}{p_1(t)} = \frac{C_1 e^{ik_0 x_2} + C_2 e^{-ik_0 x_2}}{C_1 e^{ik_0 x_1} + C_2 e^{-i k_0 x_1}} \tag{3}$$

From the ratio referring to the amplitude values of the reflected and incident waves, it is possible to obtain the coefficient of reflection R(f) (Munjal, 1987; Allard and Atalla, 2009):

$$R(f) = \left|\frac{C_2}{C_1}\right| \tag{4}$$

According to Chung and Blaser (1980), Seybert and Soenarko (1981) and Chu (1986), the sound absorption coefficient (α) as a function of frequency can be obtained by:

$$\alpha(f) = 1 - |R(f)|^2 \tag{5}$$

The plane wave cutoff frequency fc, the maximum frequency at which only plane-front waves propagate inside the impedance tube is determined by Eq. (6). As can be seen, this equation takes into account the speed of sound c in propagation and the internal diameter D of the tube.

$$f_c < \frac{1{,}84\,c}{\pi D} \tag{6}$$

Equation 6 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:

$$\frac{0{,}1\,c}{2s} < f < \frac{0{,}8\,c}{2s} \tag{7}$$

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 the frequencies of 1,000 and 1,500 Hz.

3. RESULTS AND DISCUSSION

Figure 5 presents the averages referring to the 10 measurements for each set of presented thicknesses. In a simplified way, to obtain the curve that represents the thickness of 30 mm, 10 measurements were taken, combining the samples of each fiber individually every three - since each sample has a thickness of 10 mm.

It appears that sugarcane and hay fibers have a more relevant low frequency absorption peak compared to coconut. Although coconut fibers have the lowest absorption at lower frequencies, are the material whose peak is close to 4000 Hz and achieves absorption close to or equal to unity at this point.

For sugarcane and hay fibers, the absorption peak is found at lower frequencies. The sound absorption coefficient shows a decay after the peak, followed by a growth and subsequent reduction. Although the materials show different results depending on the frequency, it can be said that the behavior presents the same trend. The sound absorption peak for the three fibers was at 1600, 1200, and 800 Hz, respectively.

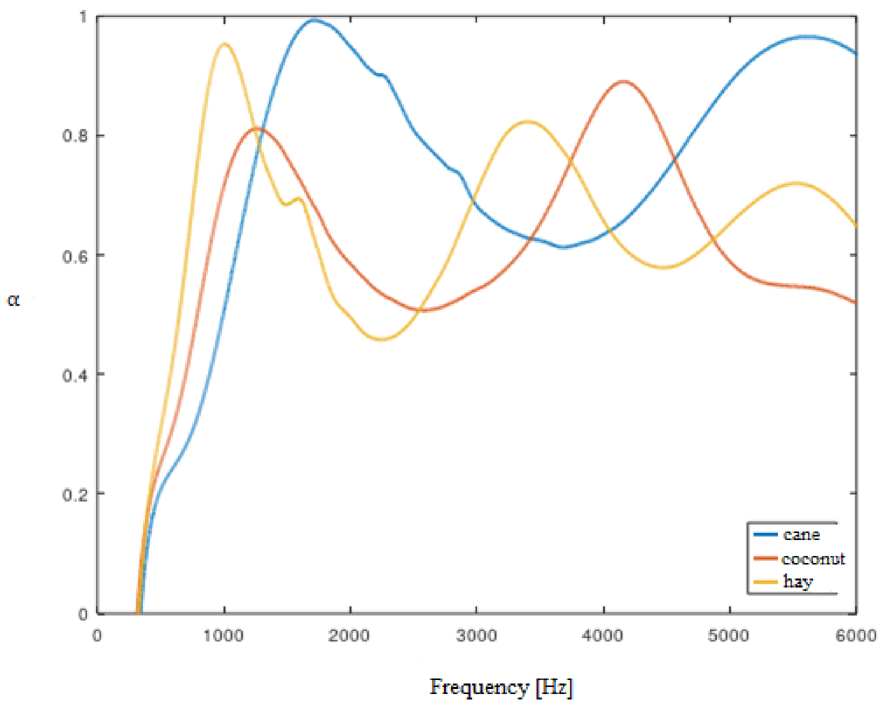

Figure 5. Absorption coefficient with 30 mm thickness without air gap

There is an improvement in absorption at lower frequencies when increasing the thickness to 40mm – especially for cane and hay fibers. Furthermore, a reduction in the interval between absorption peaks for all materials is identified, as shown in Figure 6.

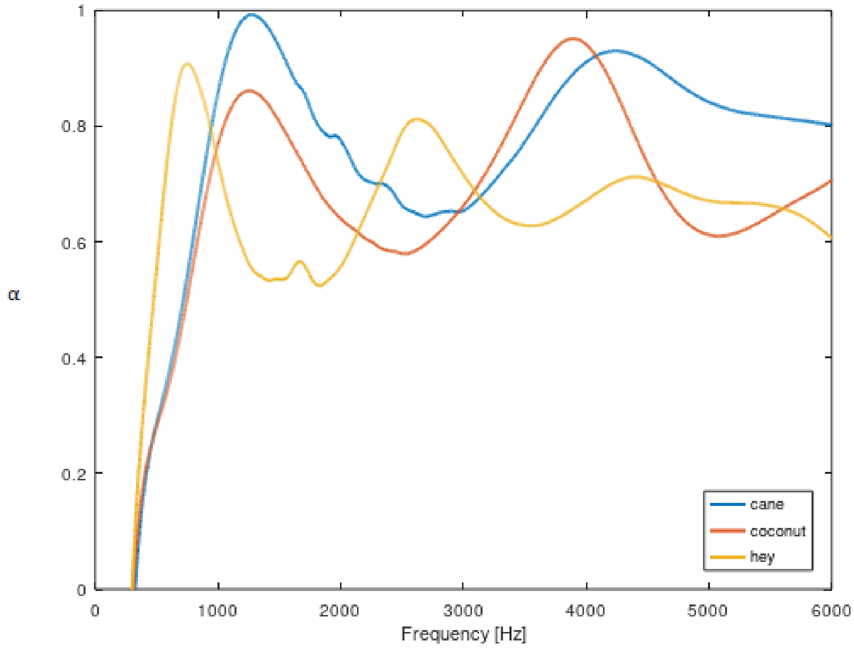

Figure 6. Absorption coefficient with 40 mm thickness without air gap

A slight decay for the hay sample is observed in the 1700 Hz range. One of the hypotheses presented for this decay concerns resonance due to the viscous effect of the fluid. Geslain *et al*., (2011) suggest the absorption coefficient for various degrees of compression when analyzing foam samples inside the tube. The authors show that the compression suffered by the material with the variation of this modulus of elasticity.

Figure 7 shows a second analysis was performed considering 20 mm of air gap between the samples and the rigid end of the tube. In general, hay is the material with the lowest absorption, with the exception of frequencies close to 2000 Hz. For all materials, it is understood that the increase in thickness contributes to better absorptions at lower frequencies.

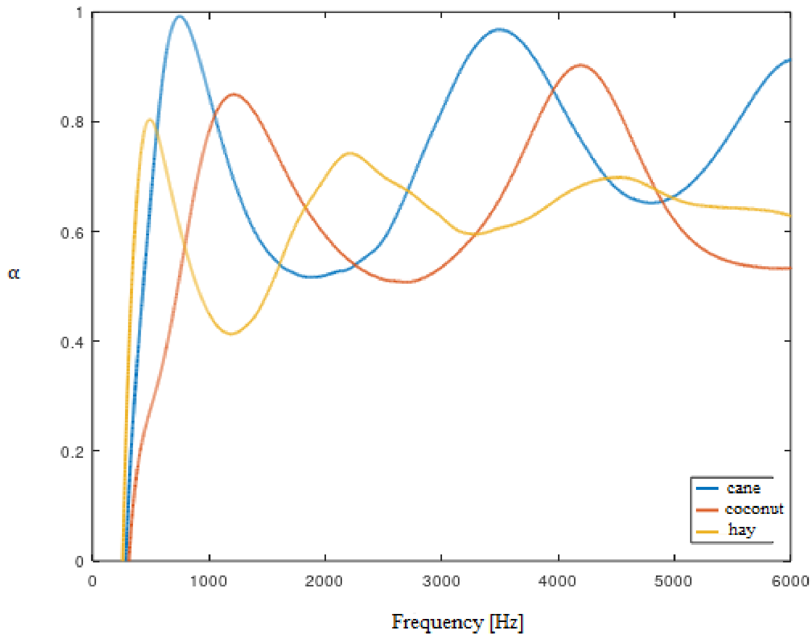

Figure 7. Absorption coefficient with 30 mm and 20 mm of air gap

By increasing the material thickness to 40 mm and reducing the air gap to 10 mm, few variations are observed in Figure 8. The variations occur due to the speed of the particles being very small near the rigid end. The sound absorption improves if the samples are placed in a higher velocity region. Absorption increases with the increase of the fiber particles' kinetic energy when vibrating – transforming them into heat due to viscous friction.

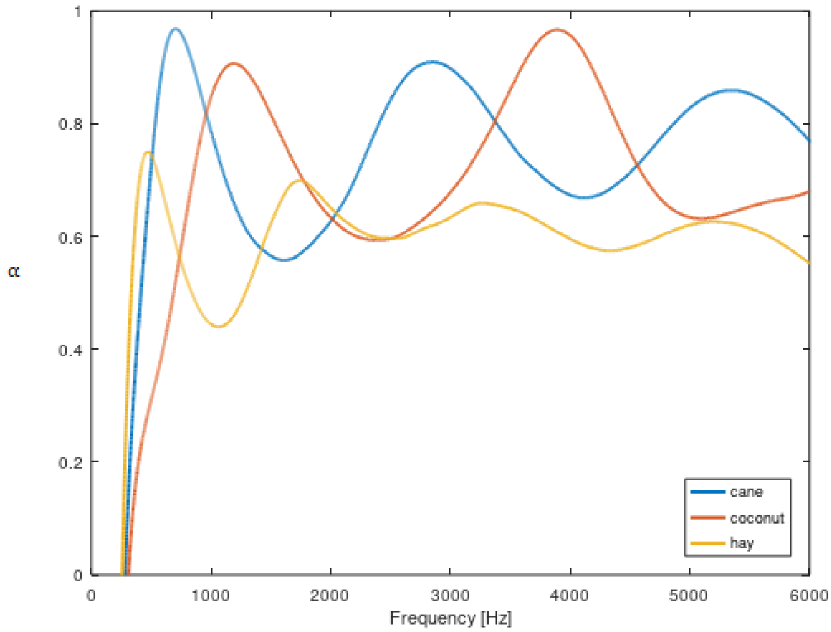

Figure 8. Absorption coefficient with 40 mm and 10 mm of air gap

4. CONCLUSION

The sound absorption coefficient of natural fibers, including sugar cane, coconut, and hay, was measured and analyzed using the Transfer Function Method in the 100 mm diameter impedance tube and the flow resistivity bench, following the ASTM E1050 standard (2012) guidelines. The results were obtained by reducing the samples to 28 mm in diameter and evaluating them in the high-frequency impedance tube.

Upon analyzing different fibers with and without an air gap, it is observed that the sound absorption diverges and oscillates in larger frequency bands. This observation allows to assert that the optimal proposal and material depend on the frequency of interest. Including an air gap resulted in the peak shift at low frequencies. The best results demonstrate that air gap sugar cane achieves sound absorption close to unity for 30 and 40 mm samples at 1750 and 1500 HZ, respectively. With the addition of the air gap between the sample and the rigid termination, these frequencies decrease to 750 Hz. Comparing the behavior of the three fibers studied with the inclusion of air gap, a similarity is observed between sugarcane and hay fibers. Hay exhibited the lowest absorption, except for frequencies close to 2000 Hz.

5. ACKNOWLEDGEMENTS

The authors are grateful for the support of the Coordination for the Improvement of Higher Education Personnel – Brazil (CAPES).

6. REFERENCES

Allard, J. F., Atalla, N., 2009, *Propagation of sound in porous media – modeling sound absorbing materials*, John Wiley & Sons Ltd, second edition.

ASTM E1050-10, 2012, *Standard Test Method for Impedance and Absorption of Acoustical Materials Using a Tube, Two Microphones and Digital Frequency Analysis System, American Society of Testing Materials*.

Canlon, B., Theorell, T., Hasson, D., 2012, Associations between stress and hearing problems in humans, *Hearing Research*, vol. 295, pp. 9-15.

Chu, W. T., 1986, Transfer function technique for impedance and absorption measurements in an impedance tube using a single microphone, *Journal of the Acoustical Society of America*, vol. 80, pp. 555 – 560.

Chung, J. Y., Blaser, D. A., 1980, Transfer function method of measuring in-duct acoustic properties: I. Theory, II. Experiment, *Journal of the Acoustical Society of America*, vol. 68, pp. 907 – 921.

Ersoy, S., Küçük, H., 2009, Investigation of industrial tea-leaf-fiber waste material for its sound absorption properties, *Applied Acoustics*, vol. 70, pp. 215 – 220.

Fatima, S., Mohanty, A. R., 2011, Acoustical and fire-retardant properties of jute composite materials, *Applied Acoustics*, vol. 72, pp. 108 – 114.

Geslain, A., Dazel, O., Groby, J. P., Sahraoui, S., Influence of static compression on mechanical parameters of acoustic foams, *Journal of the Acoustic Society of America*, vol. 130, pp. 880 – 825.

Munjal, M. L., 1987, *Acoustics of ducts and mufflers with application to exhaust and ventilation system design*, 1st Edition, John Wiley & Sons.

Seybert, A. F., Soenarko, B., 1981, Errors analysis of spectral estimates with application to the measurements of acoustic parameters using random sound field in ducts, *Journal of the Acoustic Society of America*, vol. 69, pp. 1190 – 1199.

7. RESPONSIBILITY NOTICE

The authors are the only ones responsible for the printed material included in this paper.