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Research Article

Determining the sound absorption coefficient of bagasse using the Two-microphone transfer function method

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Abstract
Noise pollution is ranked as the third environmental pollution that can interfere with communication, recreation, or concentration. Hence, choosing the best materials could be one way to resolve a sustainable solution for noise pollution problems. Materials like bagasse are suitable composite materials for construction. Its natural fiber properties exhibit a good absorber characteristic that would be used for acoustics barriers. Thus, this study aimed to investigate the sound absorption of bagasse using the two-microphone transfer function method. Using two different thicknesses for the samples, 2.0 cm and 4.0 cm, the measured sound absorption coefficients were considerably higher than the conventional concrete. The measurements revealed that the 4.0 cm samples exhibited better sound absorption behavior between the two thicknesses, having a noise reduction coefficient (NRC) of 40% to 80%. It can be noted that it has shown consistency in the energy absorption throughout the frequency range of 250 Hz – 3000 Hz. Meanwhile, for the 2.0 cm-thickness samples, bagasse's performance is less absorptive from 250 Hz-1000 Hz but becomes more absorptive as it goes to higher frequencies with a peak value of approximately 95%. Also, the material's density and the sample's thickness influence the measured sound absorption coefficients. The result implies that bagasse, a green waste, can be a suitable candidate for acoustic building applications. Its advantages included low-cost materials from renewable sources, non-toxicity, and comparably high performance compared to standard or commercial products. These types of barriers can positively impact the noise level in the areas.

Keywords: Bagasse, Noise reduction coefficient, Impedance tube, Sound absorption, Two microphone-transfer function method

INTRODUCTION

According to the World Health Organization (WHO), people who live in cities are vulnerable to traffic noise. Farooqi *et al*. (2020) reported that individuals exposed to noise higher than the standard limits can cause auditory and nonauditory effects on humans. Noise pollution is ranked as the third environmental pollution that can interfere with communication, recreation, or concentration (De Silva and Perera, 2018). Hence, choosing the best materials could be one way to resolve a sustainable solution for our cities' noise problem. Oancea *et al*. (2018) acknowledged that using industrial and agricultural waste materials to create panels as a noise barrier has great potential in its sustainability in addressing noise and waste problems. The advantages of using these types of wastes can be attributed to their wide availability, increased renewability, reduced costs, sustainability, thermal properties, and acoustic properties (Espinosa and Ceniza, 2019a; Malawade and Jadhav,2020; Kalasee *et al*.,2023).

In the Philippines, one of the agricultural waste products is "bagasse," a sugarcane waste product that is an excellent composite material for construction. Its natural fiber properties exhibit a good absorber characteristic that would be used to realise acoustics barriers (Oltean-Dumbrava and Miah, 2016; Sakthivel *et al*.,2021). Due to the natural fibers of bagasse, its interesting absorption ability could be a potential source of new material that may increase the acoustic performances needed in environmental protection against noise (Sakthivel *et al*.,2021; Mehrzad *et al*., 2022).

Hence, this investigation on bagasse would be highly significant, especially in designing our buildings by reducing the water/cement ratio and adding waste composites like bagasse fibers to the mixture to resolve a sustainable solution for waste and noise problems in Philippines cities while reducing spending too much on other materials. With these goals in mind, a study focused on bagasse's sound absorption coefficient at 250 Hz to 3000 Hz. Specifically, this experiment sought to determine and compare the effect of varying the thickness and density on its sound absorption coefficient

MATERIALS AND METHODS

Preparation of raw materials

The bagasse fibers, obtained from a province in the Western Visayas region of the Philippines, which is known as a prime producer and exporter of sugar, were mixed out of cornstarch using homemade glue and moulded into a cylindrical shape with a diameter of 5.80 cm, the same shape and area as the cross-section of the impedance tube. This is important to minimize the errors in the measured values due to accidental movement, air gaps, or compression of the bagasse samples throughout the test. These samples evaluated the dependence between the sound absorption coefficient and bagasse's thickness. Likewise, the density of each sample was also determined to investigate its effect on sound absorption.

Sample materials

The thickness of the sample materials to be investigated was 2.0 cm and 4.0 cm, respectively, as shown in Fig. 1. Three samples with varying densities, labelled Samples A, B, and C were determined and compared for each thickness.

White noise generation

Two white signals were employed to simulate the noise in a real-life situation: the *Uniform White Noise,* which had the same power spectral density at all frequencies, and the *Gaussian White Noise,* a stationary and ergodic with zero mean. These noise signals were generated from the LabVIEW^{TM} instrumentation system(Espinosa and Ceniza, 2019b).

Methodology

The bagasse's sound absorption coefficient was quantified using the Two-Microphone Transfer Function Method.

Two microphone–transfer function method

The measurement and data processing were done in the program created in the LabVIEW^{TM} from which the transfer functions of the signals were evaluated. This program was used for the measurement of the signals detected by the two microphones and computed the transfer function as:

$$\frac{\text{Cross spectrum of mic 1 to mic 2}}{\text{Auto spectrum of the mic 1}} \quad \text{Eq. 1}$$

This procedure was adapted to ISO 10534 – 2 standards (Espinosa *et al*., 2019), which uses an impedance tube with a sound source connected to one end and the test sample mounted at the other end of the tube with the rigid termination. The amplifier was connected to the speaker of the impedance tube and to the PC with LabVIEW^{TM} program where the excitation signal was generated. The microphones mounted in the tube were connected to the digital analyzer connected to the PC. The LabVIEW^{TM} generates white noise in the tube, and the decomposition of the interference field was achieved by the measurement of acoustic pressures at two fixed locations and subsequent calculation of the complex acoustic transfer function of the acoustic material (Espinosa and Ceniza, 2019b).

Experimentation procedure

As shown in Fig. 2, the bagasse sample (1) was securely mounted at the end of the impedance tube. A sound source generated from the PC was emitted through a speaker (2) connected to the opposite end of the tube. Within the tube, two microphones (3) were installed: Microphone 2 was carefully positioned 80 mm from Mircrophone 1 and at a distance of one lateral diameter from the rigid end of the tube where the sample was fixed.

The transfer function ($\boldsymbol{H12}$) between the two microphones was measured using an FFT analyzer (4). This measurement process involved connecting the microphones to data acquisition hardware, which was interfaced with the PC (5). A program written in LabVIEW^{TM} was employed to automatically compute the average ($\boldsymbol{H12}$) from 100 trials.

Finally, the absorption coefficient (α) was calculated using a custom MATLAB script (6) providing the necessary data for further analysis.

As illustrated in Fig. 2, the experimental set-up for measuring the absorption coefficient (α) of the bagasse sample involves several key components:

Impedance Tube: A cylindrical tube through which the sound wave propagates. The bagasse sample is mounted at one end of this tube, while the sound generated by the speaker at the opposite end travels through the tube.

Amplifier: Generates sound and is connected to an impedance tube speaker.

Microphones: Mounted in the tube, Microphone 2 is positioned 80 mm from Mircrophone 1 and one lateral diameter away from the rigid end where the sample is fixed.

Data acquisition hardware: A device that captures and digitizes analog signals from the microphones, converting them into a digital format for PC processing. It man-

ages the initial collection and conversion of raw data.
LabVIEW™: Produce white noise within the tube and decompose the interference field by measuring the acoustic pressure at two fixed points and then calculating the material's complex acoustic transfer function.

Data analysis

Noise Reduction Coefficient (NRC), or the Sound Absorption Average, was utilized in this study to make it easier to compare different materials. Based on the literature (Echeverria *et al*., 2019; Oancea *et al*., 2018), it is useful to use a single number to describe the sound absorption coefficients of each material. This arithmetic average of the absorption coefficients for a specific material, depending on the frequency and defined by the ISO140-3 standard, is intended to be a simplified indicator and can be considered as a percentage. The NRC values ranged from 0.00 (perfectly reflective) to 1.00 (perfectly absorptive).

By definition, sound is the medium's disturbance and is classified as a mechanical wave. When this mechanical wave (sound wave) hits a barrier, especially acoustic absorber material, a portion of that wave is reflected at the interface and some of the mechanical wave is transmitted into a new medium (Nozahic *et al*., 2012). This phenomenon happens during the interactions of the wave and the acoustic material, which is usually associated with the ability of the material to absorb sound and the mechanical vibrational energy of the acoustic wave. The reflected wave will have destructive interference with the incident wave, resulting in a good sound quality from a source. Hence, sound absorption is the amount of acoustic energy dissipated in a material as a sound wave passes through it. The sound absorption coefficient α of a material is a dimensionless number valued between zero and one over a range of frequencies that represents a percentage of sound energy absorbed based on a unit area exposed to the sound(Lawrence and Jiang, 2017)

Impedance Tube Theory-Transfer Function method using two microphones

Total sound pressure at any point in the tube:

$$P(X) = Ae^{-jkx} + Be^{jkx}$$ Eq. 2

The propagation of complex sound pressure propagating in the incident and reflected direction.

$$P(X) = P_I e^{(-jkx)} + P_R e^{(jkx)}$$ Eq. 3

Where:
k = real wave number in air
x = position of the microphones in the tube front outcomes of the samples

The present research used the general true form of a transfer function used by Chung and Blaser, as cited in Espinosa *et al*. (2019), defined as the ratio of the sound pressure of microphones 1 and 2.

$$H_{12} = \frac{P(X_1)}{P(X_2)}$$ Eq. 4

The transfer function between points 1 and

$$H_{I2} = \frac{\hat{p}_I e^{(-jkx_2)} + \hat{p}_R e^{(jkx_2)}}{\hat{p}_R e^{(jkx_2)} + \hat{p}_R e^{(jkx_1)}} = \frac{e^{-j(kx_2+\varphi)} + Re^{j(kx_2-\varphi)}}{e^{-j(kx_2+\varphi)} + Re^{j(kx_2-\varphi)}}$$ Eq. 5

The reflection coefficient of the material at the surface of the material can be derived as

$$R = \frac{H_{12} - H_1}{H_{12} - H_{12}} e^{jkx}$$ Eq. 6

Where 1 is the distance from mic 2 to the sample's surface and the impedance tube is assumed to be in an acoustically closed system, this must imply that the part of the incident- propagating area that is not reflected by the material must be absorbed. Hence, the equation can be derived as

$$\alpha = 1 - |R^2|$$ Eq. 7

RESULTS AND DISCUSSION

Table 1 and Fig. 3 show the sound absorption coefficient of bagasse with varying thickness and densities.
From the plots in Fig. 3, it can be observed that the sound absorption coefficient (α) of the three samples in the 4.0 cm bagasse revealed a high absorption coefficient of 0.4 to 0.85 in the 500 Hz-3000 Hz frequency range. This NRC of 0.40 to 0.85 meant that 40% to 85% of the energy of incident sound waves reaching the bagasse was absorbed and was not reflected. However, varying characteristics were observed for the bagasse samples at 2.0 cm thickness. At a lower frequency range of 250 Hz-1000 Hz, Sample C exhibited more absorptive properties of about 10% to 70%. Then, as frequencies increased, a different trend was observed. Sample A displayed higher sound absorption performance than samples B and C, at 2000 Hz – 3000 Hz, indicating a 70% to 95% energy of sound waves absorbed.
With these results, it can be inferred that the thickness

Fig. 1. *Bagasse samples used for measuring the sound absorption coefficient*

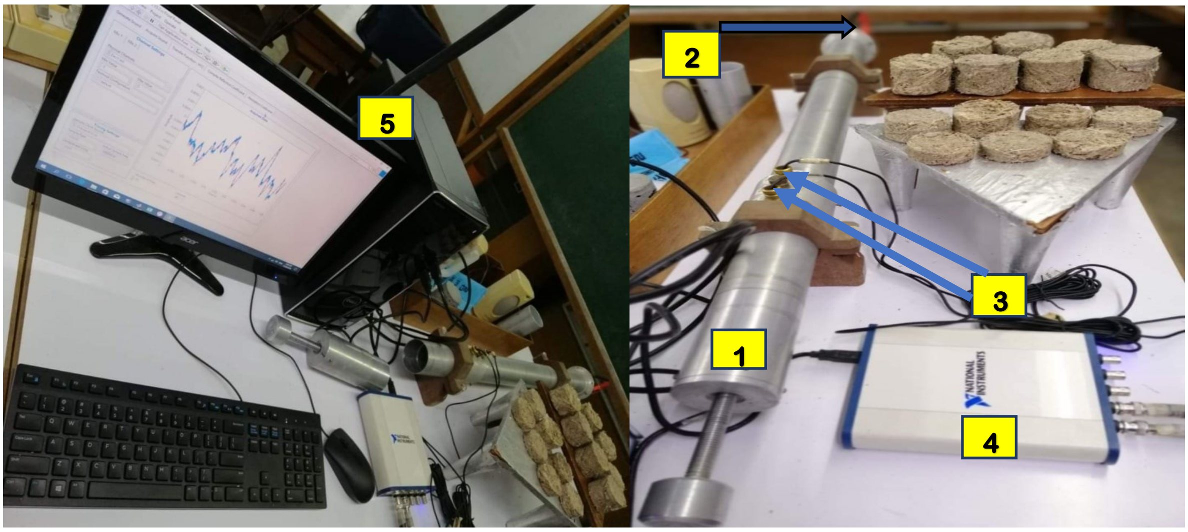
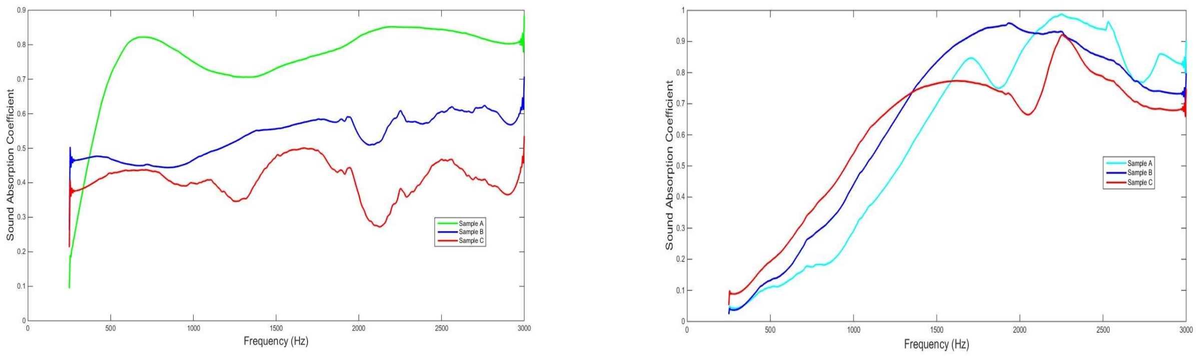


Fig. 2. *Actual experimental set-up: 1) Impedance Tube; 2) Amplifier; 3) Microphones; 4) Data acquisition hardware; 5) LabVIEW™*



(a) (b)

Fig. 3. *Sound absorption coefficient of the three samples for 4.0 cm (a) and 2.0 cm (b) thickness*

of the material has played an important role during acoustic absorption (Malawade and Jadhav, 2020; Amares *et al*., 2017). Between the two samples, the 4.0 cm bagasse has shown consistency in its absorption process, with had begun a sound absorption of about < 10% at a lower frequency level.

Moreover, as shown in Table 1, the different densities of the 4.0 cm and 2.0 cm thickness could also greatly influence the sound absorption of the bagasse material. Among the 4.0 cm thickness samples, Sample A had the highest sound absorption coefficient (α), with an 80%-85% peak value.

Sample A which has the lowest density followed by Sample B and C, respectively has a more absorptive property than the others. This high sound absorption, which has low density, can be explained by the high porosity, a key parameter in sound absorption. Increasing the sound absorption with decreasing in density (or increasing in porosity) of materials has been observed in other studies(De Silva and Perera, 2018; Haryono *et al*., 2018).

According to literature (Mamtaz *et al*., 2016; Luu *et al*., 2017; Malawade and Jadhav, 2020), natural fibers have a very low density and a complex vascular pore structure that affects the anisotrophic transport properties governing the visco-inertual and thermal losses of sound waves through the fiber structure. This coaxial arrangement, in effect, increases the flow resistivity of the overall material for acoustic absorption because the air moves more easily between thin fibers than thick fibers in sound waves, which causes vibration in the air, and this enhances absorption using more viscous losses due to air vibration. Meanwhile, for the bagasse sample at 2.0 cm thickness, Sample C, which had the

Table 1. Difference densities of the samples at 4.0-cm and 2.0-cm thickness

Bagasse Thickness (cm)	Density (ρ) (g/cm^3)		
	Sample A	Sample B	Sample C
4.0	0.1452	0.1536	0.1889
2.0	0.1367	0.1524	0.1530

highest density, showed more absorptive properties in the lower frequency level (250 Hz-1000 Hz) and subsequently decreased its absorption properties at higher frequencies when compared to Sample A and B, respectively. This result, which was also manifested in the study of Taban *et al*. (2019), could be explained by tortuosity. Accordingly, this property of fibers can affect the resonance within the materials and thus determines the absorption performance. The complexity of the acoustic path in a porous material could influence its sound energy loss in the material.

Nevertheless, a change in its absorption coefficient was observed in higher frequencies from 1500 Hz and above. Sample A and B, which have lower densities than Sample C, became more absorptive, implying the influence of the increased porosity, a pattern found in the 4.0 cm thickness samples.

Conclusion

Based on the present study, using bagasse as an environmental protection against noise showed an encouraging absorption performance. Bagasse's natural fiber is an important material parameter and is directly related to the sound-absorbing characteristics. Using two different thicknesses for the bagasse samples, 2.0 cm and 4.0 cm, the measured sound absorption coefficients were considerably higher than the other studied materials (e.g. normal concrete, palm fibers and corn husk). The measurements revealed that the 4.0 cm samples exhibited better sound absorption behavior between the two thicknesses with a noise reduction coefficient (NRC) of 40 - 80%. It has shown consistency in energy absorption throughout the 250 Hz – 3000 Hz frequency range. For the 2.0 cm thickness samples, bagasse's performance was less absorptive, from 250 Hz to 1000 Hz, but it became more absorptive as it went to higher frequencies with a peak value of approximately 95%. There is, thus, a dependence between the material's density and the sample's thickness to influence the measured sound absorption coefficients. Therefore, it was concluded that a green waste bagasse can be a suitable candidate for acoustic building applications. Its advantages include low-cost materials from renewable sources, non-toxicity, and comparably high performance compared to standard or commercial products. These types of barriers can positively impact the noise level in the areas.

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Conflict of interest

The authors declare that they have no conflict of interest.

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