Chapter 7

Utilizing Malaysian Natural Fibers as Sound Absorber

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1. Introduction

Previous researchers [1, 2, 3, 4] successfully produced sound absorption panels using agricultural wastes. These panels play important role both in noise absorption and heat insulation preserving the comfort of indoor living spaces. Yang et al. [4] produced rice straw-wood particle composite boards. They found that the sound absorption coefficient of these boards is higher than other wood-based materials in the 500-8000 Hz frequency range. Reason was the low specific gravity of composite boards having high amount of porosity compared to wood-based materials [4]. Another study by Davern [5] aimed at producing airspace layers and examined the influence of porosity on the acoustic properties of materials. He found that the porosity of the perforated plate and the density of the porous material would significantly affect the acoustic impedance and sound absorption coefficient of the panel, in which case, the frequency band near the resonance frequency achieved high acoustic absorption. In addition to Davern's study, Lee and Chen [6] reported that the acoustic absorption of multi-layer materials is better with a perforated plate backed with airspaces. Other usages of natural fibres are in reduction of sound propagation in automotive interior spaces, or to improve the control of outdoor noise propagation [7, 8]. Recent studies show that researchers are focusing on coir fibre and oil palm fibre in replacing synthetic-based fibres for sound absorption applications simply due to their abundance in tropical countries such as Malaysia.

Acoustics, as science, deals with sound creation and transmission through materials. Sound and light waves share same vibrational system as these waves creating pressure during propagation due to the nature of fluctuation in the material. However, unlike electromagnetic waves, sound cannot travel through a vacuum. Consequently, sound wave has become important in many applications in materials science, medicine, dentistry, oceanology, marine navigation, communications, petroleum and mineral prospecting, industrial processes, music and voice synthesis and animal bioacoustics. Sound in the audio frequency range of approximately 20 Hz–20 kHz can be heard by humans. Excessive levels of sound can cause permanent hearing loss while continuous exposure could be physiologically and psychologically deleterious to one's well-being. This study, amongst many others, is very important in ergonomics since it is closely related to the sense of hearing; the crucial in our daily routine whether we are in schools, factories, offices and theaters. These places are in high demand for materials that are able to reduce noise level at various frequency ranges. When sound propagates in an enclosed room, the frequencies and decibel levels are subjected to reflections which lead to echoes. An acoustic absorption panel can be used to prevent echoes and reduce the intensity of the sound that is heard outside the room. Acoustic absorption panels are normally filled up with porous layers of materials capable of controlling reverberation and background noise [9]. The energy of incident sound is transformed into heat and vibration of fibers, and eventually dissipated [10].

Acoustic absorption panel is placed on ceilings and walls to improve the comprehensibility of speech in the room. Commercial acoustic panels are made from synthetic fibers that may be hazardous to health and environment. Current trend is to replace them with natural fibers that are cheap, environmental friendly and free of health risks. Nowadays, the concept of green technology has been incorporated in many fields in the industry. Companies are constantly researching for alternatives to further improve their choice of materials that are more environmental friendly. These waste materials should have reasonable absorption performance compared to synthetic fibers. Studies are going on the sound absorption of coir (Cocos nucifera) and palm oil (Elaeis Guinnesis) fibers at various thicknesses and frequency bands [11]. On the other hand, there are still other local agricultural resources that their acoustical properties are yet to be determined like sugar cane (Saccharum), corn (Zea mays) and grass (Axonopus compressus) fibers. Hence, the focal point of this project is to study the sound absorption coefficient of four different fibers; coir, corn, sugar cane and dry grass with different panel thicknesses.

2. Methodology

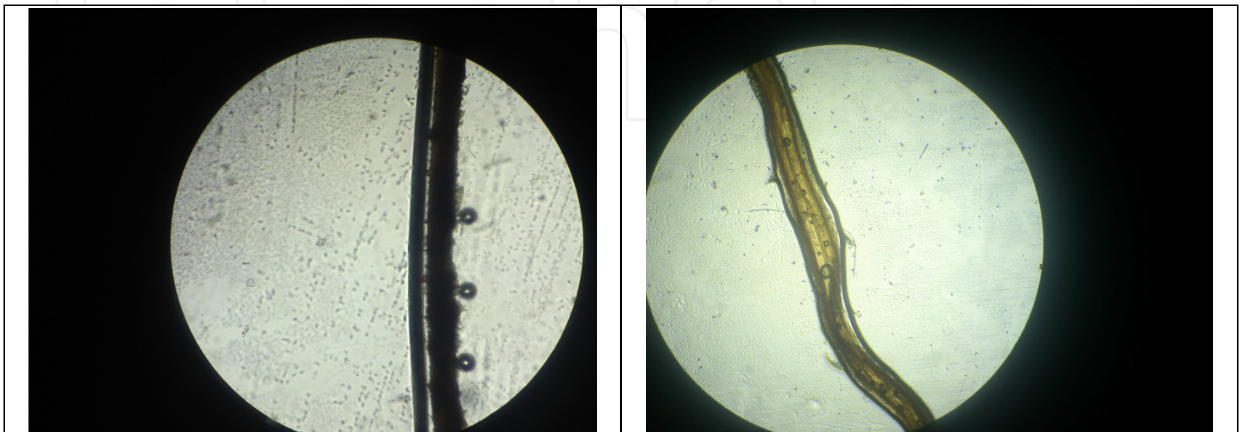
Coir, corn and sugarcane fibers were obtained from the wet market whereas grass was readily attained from a field and then dried out. Corn and Coir fibers were purchased in loose forms (see Figure 1 for coir and corn fiber). Samples were compressed separately into disks of diameters of 100 and 28 mm by fitting into molds of cylindrical shapes (Figures 2(a) coir fiber, (b) corn fiber) according to impedance tube diameter of 100 and 28 mm for low and high frequency measurements, respectively. In order to better observe the fiber structures, a magnified picture was taken for each type, see Figure 3(a) for coir fiber, (b) for corn fiber. Figure 4 shows the molds that were used to prepare samples in disk forms. Molds were manufactured using steel tubes while the punchers were made of wood. Samples were compressed using hydraulic compressor machine with an average pressure of 45 kg/cm^2. The absorption coefficient of fibers was evaluated using impedance tube apparatus as shown in Figure 5. For comparison of results, two different thicknesses of each sample were tested.

(a) Loose Coir Fiber | (b) Loose Corn Fiber

Figure 1. Loose forms (a) Coir Fiber (b) Corn Fiber

(a) Coir Fiber in Disk Form | (b) Corn Fiber in Disk Form

Figure 2. Fibers in disk forms (a) Coir fiber (b)Corn fiber



(a) Coir fiber under microscope | (b) Corn fiber under microscope

Figure 3. Fibers under microscope (a) Coir fiber (b) Corn fiber

Figure 4. Steel molds and wooden punchers were used to fabricate the samples.

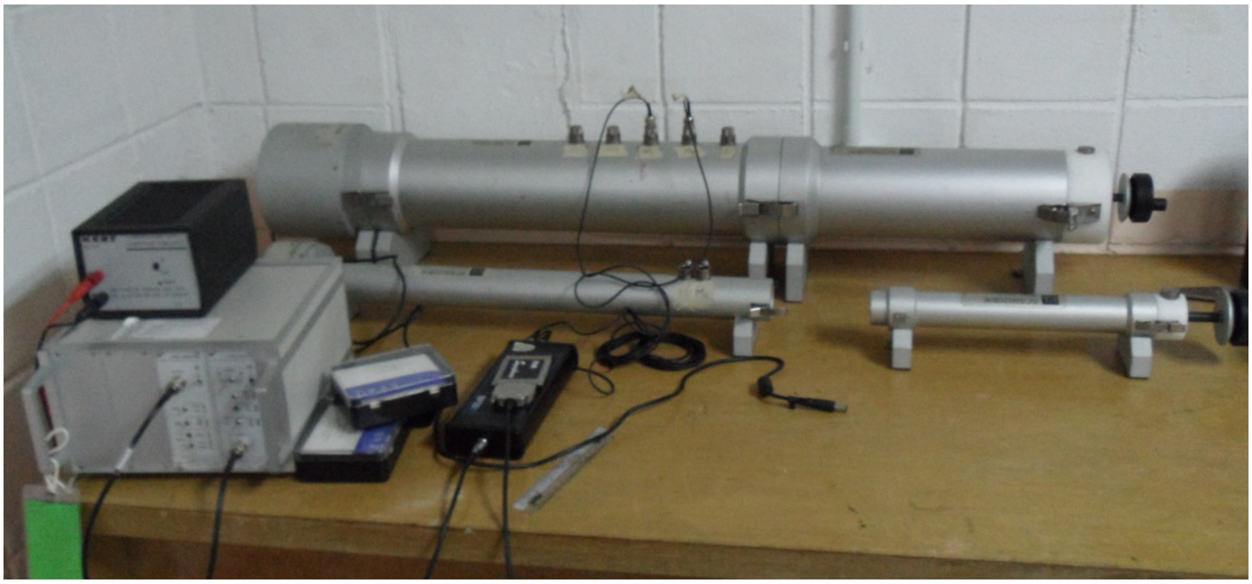


Figure 5. Measurement apparatuses consisting of impedance tubes, noise generator and 01dB analyzer.

Porosity is the ratio of the volume of openings to the total volume of the sample and affects the absorption efficiency of each sample. Mass, thickness and fiber diameter of each sample determines the porosity and can be calculated using Eq. (1):

$$\varphi = 1 - \frac{\rho_{bulk}}{\rho_{fiber}} \tag{1}$$

where ρ_{bulk} and ρ_{fiber} are the bulk density of sample and fiber density, respectively. The quantity ρ_{bulk} is the ratio of mass and volume of each sample as a disk, whereas ρ_{fiber} depends on physical properties of the fiber itself.

The impedance tube (Figure 5) creates sound by a generator mounted at one end, in the form of broadband stationary random waves. The generated sound travels to hit the sample which is attached at the other end. The sound pressure is measured at two fixed points using two ¼″ microphones. An analyzer calculates the complex transfer function in order to obtain the sound absorption coefficient of material. The sensitivity of microphones was calibrated utilizing calibrator type GRAS-42AB at 114 dB levels and 1 kHz. The frequency span of experiment was 100-4500 Hz with 3 Hz resolution and it took approximately 10 seconds for the instrument to achieve the absorption spectrum. Based on Delany-Bazley model, the acoustic absorption coefficient, α can be defined as [12]:

$$\alpha = \frac{4R_r/\ \rho_0 C_0}{(R_r/\rho_0 C_0\ +1)^2 + (X_r/\rho_0 C_0)^2} \tag{2}$$

where, C_0 is speed of sound, ρ_0 density of air, R_r and X_r real and imaginary components of surface acoustic impedance.

3. Results & discussion

First step was to obtain the physical characteristics of fibers. Masses of samples were measured by a precise electronic balance. Length and diameter were measured by caliper and used to calculate each fiber's volume assuming that they have perfect cylindrical shape. The last column in Table 1 is the ratio of mass and volume as the fiber density (ρ_{fiber}). A number of 15 samples from each batch were selected and results averaged. The quantity ρ_{bulk} was calculated based on mass and volume of a disk-shape sample and together with ρ_{fiber} were put in Eq. (1) to calculate the porosity of the sample. They are presented in Table 2 and 3 for 1 and 2 cm thicknesses, respectively.

Figure 6 and 7 show that acoustic absorption of fiber was improved as thickness of sample increased. The reason is observable from Table 2 and 3; in which, the porosities of fibers are decreased as the corresponding thicknesses increased. Basically more amounts of fibers were used to fabricate the 2 cm thickness samples and they have higher bulk density compared to 1 cm samples. According to Eq. (1), the increase in bulk density reduces the porosity of sample; i.e. less perforation exists which improve the absorption coefficient of sample and moves the resonance peaks to lower frequencies. Therefore resonance peaks of sugar cane and corn fiber samples were shifted from 3800 and 3200 Hz in Figure 6 to 1000 and 2800 Hz in Figure 7, respectively. Coir and grass do not show significant absorption behavior in Figure 6 but it is very much improved for higher thickness in Figure 7 as both having resonance peaks around 2000 Hz.

Fig. 7 is chosen to compare the absorption coefficient of fibres as the patterns are more significant in this plot. Coir and grass absorbed more than 70% of incident sound at frequencies higher than 1300 Hz whereas corn presented similar behaviour above 1800 Hz. For sugar cane absorption is generally lower than 70% except for a small region around 1000 Hz that the structural resonance happens because the diameter of sugar cane fibre is around 400 μm which is larger than the rest. A sample made of fibre with larger diameter does not show significant elastic behaviour; also have lower flow resistivity because there are more hallow spaces when putting fibres together. Reduction in flow resistivity decreases the absorption coefficient of sample.

Sample No.	Mass (mg)	Length (mm)	Diameter (μm)	Volume (mm^3)	Density (kg/m^3)
1	0.8	151	450	5.44	147.17
2	3	180	350	5.04	595.24
3	3.4	190	380	5.78	588.64
4	3.2	185	390	5.77	554.40
5	2.8	159	370	4.71	594.93
6	3.2	162	350	4.54	705.47
7	3.3	191	370	5.59	590.08
8	3.5	195	400	6.24	560.90
9	3.6	202	370	5.98	602.09
10	2.9	183	350	5.09	569.22
11	3.1	191	350	5.35	579.66
12	3.8	217	350	6.08	625.41
13	2.5	181	330	4.78	523.19
14	1.3	175	290	4.03	322.42
15	1.8	170	260	3.59	501.34
Average Diameter (μm):			357		
Average Density (kg/m^3):			537		

Table 1. Physical characteristics of corn fiber

Type of Fiber	Porosity (%)	
	Sample Diameter	
	100 mm	28 mm
Coir	89.38	93.41
Corn	97.83	97.50
Sugar Cane	96.32	95.20
Grass	96.93	96.86

Table 2. Porosities of samples with thickness of 1 cm.

Type of Fiber	Porosity (%)	
	Sample Diameter	
	100 mm	28 mm
Coir	88.67	89.68
Corn	96.12	96.24
Sugar Cane	95.91	94.71
Grass	94.22	96.07

Table 3. Porosities of samples with thickness of 2 cm.

Comparing the synthetic materials in Table 4 with natural fibres in Table 5 proves the possibility of implementing these natural materials in acoustic panels. Apart from fibre glass board; carpet, plywood and drapery generally have lower absorption coefficient than the selected natural fibres throughout the frequency spectrum which the difference is even more significant above 1000 Hz.

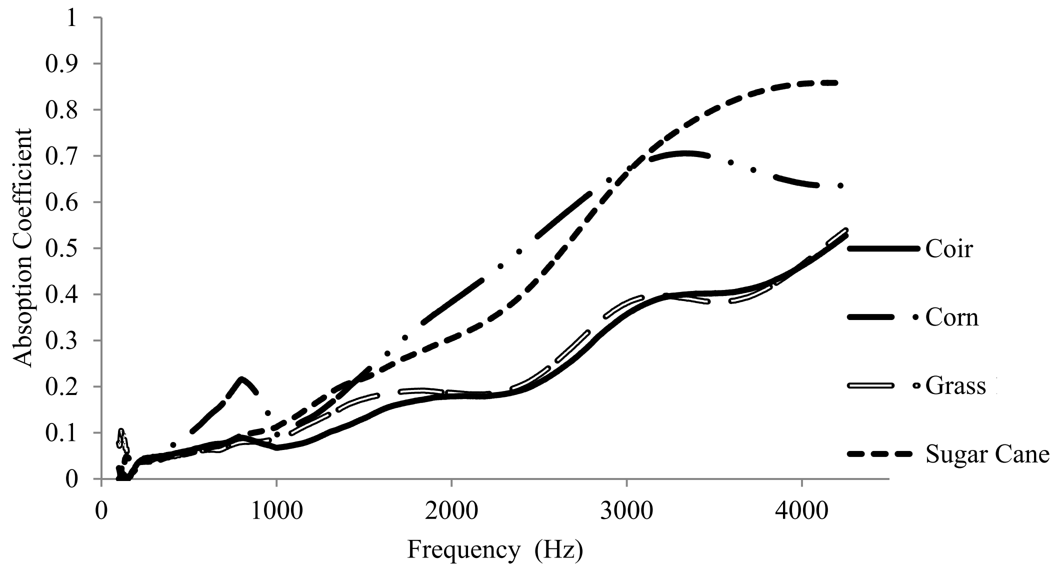


Figure 6. Acoustic absorption coefficient of 1 cm sample for the four types of fibers.

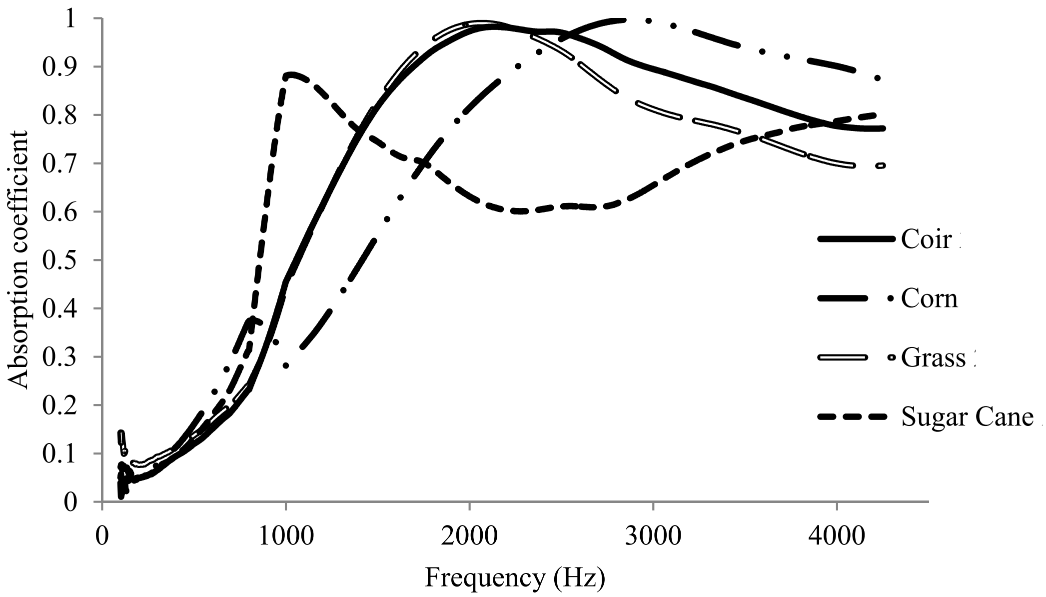


Figure 7. Acoustic absorption coefficient of 2 cm sample for the four types of fibers.

Synthetic Materials	Frequency (Hz)					
	125	250	500	1000	2000	4000
Carpet	0.01	0.02	0.06	0.15	0.25	0.45
Plywood (19 mm)	0.2	0.18	0.15	0.12	0.1	0.1
Drapery (340 g/m^2)	0.04	0.05	0.11	0.18	0.3	0.35
Fiberglass board (1" thickness)	0.06	0.2	0.65	0.9	0.95	0.98

Table 4. Absorption coefficients of some common building and acoustic panel materials in octave bands [13].

Natural fibres	Frequency (Hz)					
	125	250	500	1000	2000	4000
Coir	0.04	0.06	0.12	0.46	0.97	0.78
Corn	0.04	0.06	0.16	0.28	0.81	0.90
Grass	0.11	0.08	0.14	0.45	0.98	0.70
Sugarcane	0.07	0.05	0.13	0.88	0.63	0.78

Table 5. Absorption coefficients of natural fibres of thickness 20 mm obtained from tests in octave bands.

Fibreglass shows better results in comparison with the abovementioned natural fibers. Unfortunately, there have been serious health issues related to fiberglass that may occur immediately or within a few days of exposure such as skin irritation and redness, eye, nose and throat irritation. Not only that, breathing in fiberglass dust may result in coughing, bronchitis, shortness of breath, and even permanent lung disease if exposure is too excessive [14]. Therefore fiberglass is not a good option despite its good acoustical absorption characteristics. Natural fibers not only exhibited good absorption behavior but also play an important role in design for ergonomics. They maintain a comfortable environment by reducing noise level and health risks at the same time.

There are possible measurement errors due to deformation and expansion of samples in impedance tube. The reason is absence of binder that enhances surface strength of the sample and maintains fibers together. This study was aimed at solely investigating the properties of pure natural fibers and any use of additives was prohibited.

4. Mechanism for the process

In Physics, resonance is defined as ”the increase in amplitude of oscillation of an electric or mechanical system exposed to a periodic force whose frequency is equal or very close to the natural undamped frequency of the system”[15]. All structures have natural frequencies and when a similar vibrational mode exists, resonance occurs. Guitars and electronic devices are designed to resonate with external mode in order to detect that specific mode of frequency. When resonance occurs, the corresponding systems are able to store and easily transfer energy at resonance frequency modes. As the energy transfer between these modes, it is expected that the system losses some energy which entirely depends on damping factor. If the damping factor is small, the resonance frequency is approximately equal to the natural frequency of the system. Resonance phenomena have become the corner stone of so many applications in medicine, science and technology such as nuclear and electron spin resonance.

The study of the resonance phenomena in fibers is essential in improving their acoustical properties. Design of sound absorbers depend on the resonance frequency of the fiber or, in more complicated system, a perforated fiber panel. One of the factors that considerably change the acoustic impedance and absorption coefficient of the acoustic absorber is the porosity. Baranek and Ver [16] presented a compact expression for acoustic impedance of perforated plates. The expression indicated that the influence factor include thickness of the sample, hole radius, hole pitch, and porosity of the perforated plates and air contained in the holes. For porous material, the complex wave propagation constant and characteristic impedance could be expressed in terms of the flow resistivity, wave number, air density, and sound frequency. Sound absorption characteristic of porous material is not so much a function of type material but airflow resistivity and how well material construction can be executed to achieve desirable properties for sound absorbers [17].

Research is not only focusing on measuring the resonance frequency, but also its prediction. Within the frame of this approach, mathematical models were presented showing how the acoustical properties of fibrous materials are related to their characteristic impedance. The Delany-Bazley and Miki [17] models are well known as conventional prediction models. The methodology of preparing these models and subsequent mathematical formulas are not so different from each other when it comes to the scientific basis but they are different only in the values of coefficients and degrees in the formulas. The acoustic panel exhibits a shift of the absorption coefficient peak to lower frequency range when the thickness of the samples is increased. This mechanism depends on the physical properties of the fibers such as diameter and density.

5. Conclusions and recommendations

Current trend in green technology is to replace synthetic materials with natural alternatives that have similar functionalities. This study aimed at enlightening the acoustic behavior of natural fibers seeking possibility of implementing them as absorbers in acoustic absorption panel. The selected fibers were coir, corn, sugar cane and grass that are vastly available in tropical countries such as Malaysia. They were compressed into cylindrical samples prior to be tested in impedance tube. Physical characteristics of samples were measured and used to calculate their porosities. By using the same compression ratio, samples with larger thickness possessed lower porosity value. Impedance tube measurements revealed that samples with 1.0 cm thickness had generally absorption coefficient below 70% in the frequency span of 3000 Hz. Increasing the thickness to 2.0 cm reduced their porosity and improved the absorption coefficient. For this thickness; coir, corn and grass absorbed more than 70% of the incident sound at $f > 1300$ Hz. Sugar cane had same amount of absorption only for a narrow band around 1000 Hz and was not considered as a good absorber. Comparing the absorption coefficient of coir, corn and grass (20 cm thickness) in various octave bands with common building and acoustic panel materials showed that they are outstanding alternatives. Fiberglass was an exception; it had best absorption coefficient among the all but also known to have risks to health and environment and is advised to be replaced in the future.

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