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The Effectiveness of Coir Fiber and Bamboo Culm as a Sound Absorber

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ABSTRACT

Noise is sound pollution that can cause harmful effects on an individual. Synthetic sound panels are used to reduce the harmful effects of sound pollution. These panels harm our respiratory system when exposed for a long time. This study focuses on creating an eco-friendly sound absorption panel that can be a possible substitute for synthetic sound panels. In particular, two sound panels: bamboo sound panels and fiber-only sound panels. The former design begins with attaching the cut bamboo culm to the plyboard and putting the two layers of compressed coir fiber in accordance with the bamboo culm shape and will be covered by black cloth. The latter however excludes the bamboo culm. The effectivity of these panels in absorbing sounds was tested using Reverberation Room Method. A 100 decibel noise is generated inside the room then turned off and measured for the time it will take for the sound level to drop to 25 decibels. The result was statistically analyzed using ANOVA method and shows that both sound panels have significant difference compared to no sound panel. Refer to NRC table, the sound absorption panel comprises coir fiber, and bamboo culm is effective with an average noise reduction 0.25 which is considered good. The sound panel tested only four frequencies: 250, 500, 1000, and 2000 Hz and the maximum absorption coefficient of 0.36 was attained in the frequency of 500 Hz.

1. Introduction

Noise is a sound that is loud enough to cause a disturbance. Noise is also known as pollutant or sound pollution when it refers to an obnoxious sound that might cause physiological and psychological harm to an individual or group of individuals [1,2]. This pollution causes health-related severe problems like hearing loss in all ages [3]. Human activity, transportation, building public works construction, and industry are all significant sources of noise pollution [1]. However, despite the many causes of noise pollution circling people's daily lives, human ears only possess limited hearing frequencies. The World Health Organization only recommended a hearing tolerance limit of 65 dBA. Hence, at about 75 dBA, it can be harmful and painful at around 120 dBA. Accordingly, 2 hours' exposure to the human ear at 100 dB (noisy nightclub) needs at least 16 hours to recover, while a loud volume in headphones of more than 120 dB can damage cells, causing hearing loss [1].

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Ultimately, a sound that reaches 180 dBA can cause death. As such, the prevalence of noise exposure in people's daily endeavours has a variety of detrimental impacts not just in physical health damage but also in cognitive processing disturbance and mental health damage [4].

Infrastructures need to incorporate sound insulation panels in their building to reduce the unwanted noise affecting the employees. Likewise, though identifying noise will depend on someone's culture, society, and environment, noise disturbs the focus of everyone; the louder the noise, the bigger the disturbance it causes [5]. Among such scenarios, the need to control noise with sound insulation panels available in the market serves as a countermeasure to solve such a dilemma. However, standard sound panels in most markets are made of synthetic materials that cause serious health problems. The powders from these materials can harm our respiratory system when exposed for a long time and irritate our skin [6,7]. Aside from the harmful health effects of using synthetic materials as sound panels, it also negatively impacts our environment [8]. Among synthetic materials, foam glass and glass wool materials have been discovered to be dangerous to human health. Such materials also pollute the environment and contribute to global warming [9]. Fiberglass, one of the available synthetic fibers available, raised concerns not just about the increased emissions of greenhouse gasses, but using it also raises concerns about the health and safety of living things [10]. Generally, synthetic materials harm both people's lives and the environment, which depicts the dilemma of providing a solution to solve noise pollution but pushing our health and environment at stake.

On the other hand, using natural materials in making sound insulation panels has been extensively employed to develop ecologically friendly sound panel materials [9]. Due to its nature, using natural materials is beneficial since it is biodegradable. It is also safe for the environment and humans as it contains no harmful materials [6,11]. Further, since it is easily accessible, natural materials such as coir fiber and bamboo trees are not hard to find given that it is abundant in nature, grow fast, and are easy to harvest [12,13]. In comparison, natural materials are also cheaper than the synthetically made sound panels available in the market. Hence, due to its advantages, several studies have been explored to assess the usefulness of natural materials as an alternative to synthetically made sound panels [14]. A study of the sound panel using coir fiber found that coir fiber's porous and hollow area may effectively absorb sound [15]. These air-filled pores will vibrate, resulting in energy loss, and, as a result, they will absorb sound [16]. As a result, the development of natural fibers as a sound absorption material is being used as a substitute for synthetic sound insulators [8]. Another study demonstrated that usable egg cartons and coir fiber meet the criteria for making an effective sound absorption panel through a reverberation test [15]. This reverberation test refers to the sound that lasts for a long time [17]. The test results showed that utilizing a sound-absorbing panel made of coir fiber may lower reverberation duration from 5.63s to 3.60s. Accordingly, the coir fiber serves as the main sound absorber, while the egg tray's shape helps improve the insulator's medium and high-frequency sound absorption. Another study used another natural material [15]. Using corn husks and egg trays concluded that these natural materials also possessed good sound absorption properties [18].

Moreover, flame retardants are used to treat the natural fiber against fire hazards. Although this treatment will not eliminate the risk of fire, it will improve the flammability resistance of the fiber [19]. Hence, compared to synthetic sound panels on the market, using natural fibers as the major material in sound absorption panels offers the potential to solve environmental and health issues. This natural fiber could be the answer for making green sound absorbers while also caring for our health [20].

Creating a sound absorption panel out of natural materials creates an edge, especially since our country is rich in natural resources. However, some studies concentrated on combining natural fibers and egg trays as they are readily available [18]. Egg trays cannot maintain their shape as a container for fibers, especially when accidentally hit by certain hard materials or even humans. Furthermore, since egg trays are made from recycled paper, their composition can easily be subjected to decay [21]. Also, the mentioned experiments primarily focus on variants of natural fibers and egg trays. However, in a record, no studies emphasize replacing egg trays in making sound insulation panels, allowing the need for this gap to be studied even more. Additionally, there are a small number of studies about utilizing natural fibers as sound insulation in the Philippine context. Thus, the mentioned gaps led to the creation of a study using bamboo culm as a replacement for egg trays, leading to the development of a longer-lasting sound insulator.

The main goal of this research is to design and make an eco-friendlier sound absorption panel utilizing bamboo culm and coir fiber materials. The specific objectives of this study are as follows: (1) to create sound panels made of natural materials that can be a possible substitute for synthetic fiber-made sound panels available in the market; (2) to test the noise reduction coefficient of sound absorption panel; (3) to compare the effectivity of sound panels for each frequency.

The study can be used as reference data to conduct new studies on making sound absorption panels from natural materials. Furthermore, employing natural fibers as a sound-absorbing material reduces the danger of using synthetic fibers, which are detrimental to the environment and individuals. Moreover, individuals will feel comfortable having a peaceful occupational and non-occupational environment since their surroundings will not be excessively noisy. Furthermore, the commercial sector will benefit from green innovation to find new opportunities to profit from reusing natural fibers.

2. Methodology

2.1 Materials and Resources

The materials used for the sound absorption panel are coir fiber, bamboo culm, ply boards, and black cloth. The coir fiber is the primary material in the sound panel that will absorb the sound. The bamboo culm will serve as a base for the coir fiber, specifically in the first design. Both the coir fiber and bamboo culms are collected around the Island Garden City of Samal. Furthermore, the diameter of the bamboo is approximately 50mm, and its age is between 2-5 years old. The ply board is the foundation of the sound panel; it will carry the bamboo culm and coir fiber. The ply board are purchased from the local store. The black cloth can reduce the sound wave to a minimal level, but its primary purpose is to cover the sound panel.

2.2 Noise Reduction Concept

The process starts when the sound energy hits the sound absorption panel. It consists of two concepts: Absorption and Diffusion of sound (Figure 1). In this study, the coir fiber will absorb the sound, and the bamboo's shape will help attain the idea of diffusion, eliminating the echo and reverberation.

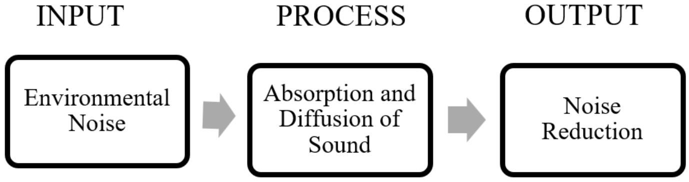

Fig. 1. Conceptual Framework

The sound absorption process happens when the sound's energy hits the fiber's porous structure. This energy will cause a vibration of fibers. The vibration will divide the energy into the pores and make it absorb. On the other hand, the Sound diffusion process happens when the sound energy hits an uneven surface. The sound energy is distributed in a different area, resulting in faster sound reduction.

2.3 Sound Panel Design

There were two designs for acoustic sound panels. The first design is shown in Figure 2. It consists of bamboo culm, coir fiber, ply board, and a piece of cloth. The dimension of the first design was 0.5m x 0.5m x 12mm thick ply boards in an alternate position and putting the 25mm compressed coir fiber at the top of the bamboo culms. Afterward, another ply board was installed at the perimeter of the panel. The whole panel then was covered with black cloth. The coir fiber used was not combined with any fiber like rubber. The bamboo culm was arranged in an alternate position to create a pattern. And the fabric used was a cotton.

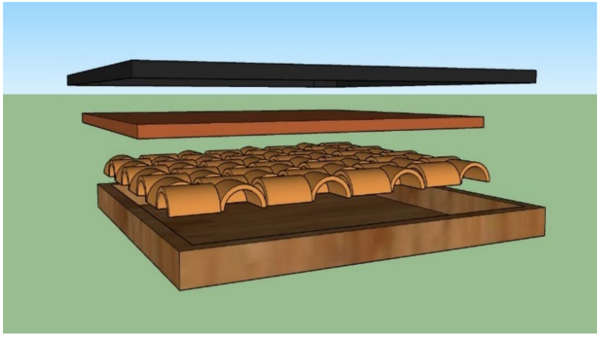

Fig. 2. Sound Panel with Bamboo and Fiber

Shown in Figure 3 is the second design of the sound panel that was made up of coir fiber, ply boards, and cloth. Fiber was directly attached to the base of the ply board. Also, its perimeter was installed with another ply board. Finally, a piece of fabric was wrapped over the panel. The inclusion and exclusion of bamboo culms is the fundamental distinction between the two panels.

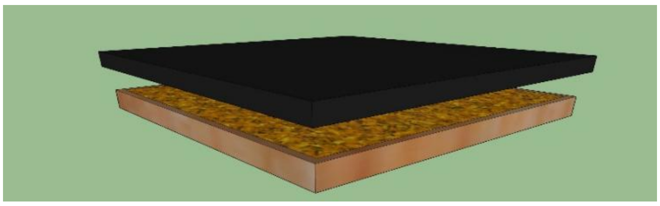

Fig. 3. Sound Panel with Fiber only

2.4 Methods and Procedures
2.4.1 Bamboo

Bamboo is prone to insect and fungi attacks. It should undergo treatment to improve its durability and prolong its useful life. The bamboo used in this research is treated with Solignum. Solignum is a wood preservative chemical that will protect from fungal decay, wood rot, and insects. The process started with collecting bamboo culms of at least 0.5 meters per piece, approximately fifty (50) mm in diameter, and at two (2) to five (5) years of age. Then, bamboo culms were washed and cut into 50 mm length. Afterward, bamboo culms were soaked in running water for four (4) days and four (4) nights. Let it dry for at least five (5) to seven (7) days. Soaked again to water with Solignum for sixteen (16) hours. Mixed Solignum with a 1:14 ratio with water. Dried it for 2-3 days. Then, split the dried bamboo culm into half.

2.4.2 Coir fiber

Coir fiber is vulnerable to fire since it is a flammable material. Borax is applied to the coir fiber to improve its fire resistivity. A Borax is a fire-retardant chemical that prevents or slows down the spread of fire in case the fiber is burned. The dried treated fiber is pressed between steel plates. Then the steel plates are exposed to flame at a temperature of 130 °C. Also, the duration of flame exposure should be only 5 minutes. Exceeding the 130 °C temperature and 5-minute duration will burn the fiber making them unusable. The process on how the coir fiber sheet was created from raw coconut husk started with extracting coir fiber from coconut husk. Dried the coir fiber one (1) day to remove its water content. Then, diluted 19 grams of Borax into one (1) liter of water. Coir fiber was then dipped in the solution for ten (10) minutes and dried for three (3) minutes for five cycles. Dried again the treated coir fiber for one day. The coir fiber was then pressed between a steel plate having a dimension of 0.5m x 0.5m. Then, heat was applied to the steel plates to flatten and compress the coir fiber.

2.4.3 Noise reduction coefficient testing

ASTM C423 [17] or the Standard Test Method for Sound Absorption and Sound Absorption Coefficients by the Reverberation Room Method will be used as shown in Figure 4 to get the noise reduction coefficient or the effectivity of the sound absorption panels. Table 1 below presents the classification of Noise Reduction Coefficients (NRC) into corresponding effects, ranging from "Very High" for an NRC of 0.80, to "Low" for NRC values of 0.10 or less, indicating the material's efficiency in sound absorption. Absorption of the sound in a room is tested. A 100-decibel noise with a frequency of 250, 500, 1000, and 2000 hertz is generated throughout the room, then turned off and measured for the time it will take for the sound level to drop to 25 decibels. Repeat the test 50 times for each given frequency. The sound absorption level is measured ten times at each of the five microphone positions. The "Empty Room" absorption is generated from the average result of the five microphone locations. Next, sound absorption panel is installed and the absorption rate is tested just like the previous procedure. This measurement will be referred to as "Full Room" absorption. Absorption coefficient will be determined by the difference between "Empty Room" and “Full Room” absorption and dividing by the wall panel area.

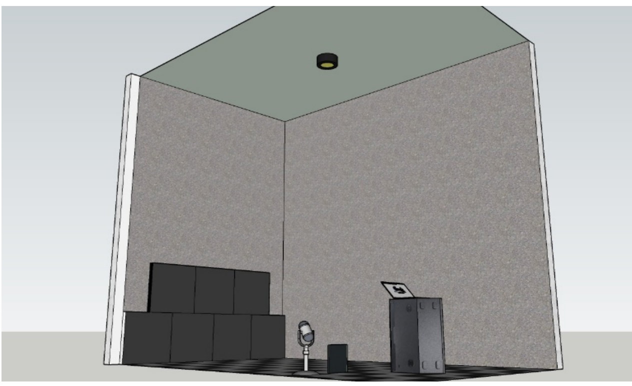

Fig. 4. ASTM C423 testing

Table 1
Noise reduction coefficient

Noise Reduction Coefficient (NRC)	Effect
0.80	Very High
0.50	High
0.20	Considerable
0.10	Significant
≤0.10	Low

The room used in testing has a length of 2 m, 3 m width, and a height of 2.3 m. The room is made up of concrete and a hardiflex ceiling. Furthermore, the sound type generated in the room is a sonic type and ranges from 250 hertz to 2000 hertz. As shown in Figure 4, seven panels of 0.5 m length and 0.5 m width are used in testing the absorbing capability of the panels.

$$(\mathrm{NRC}) = \frac{A\,(empty\ room) - A\,(full\ room)}{Total\ area\ of\ sound\ panel} \quad (1)$$

$$A = 0.9210Vd/c \quad (2)$$

where
A = sound absorption, m^2
V = reverberation room volume, m^3 or ft^3
c = speed of sound, m/s or ft/s,
d = decay rate, dB/s

2.4.4 Fire resistivity testing

Following ASTM E69-02 or the Vertical burning test, a Pyrex cylindrical test tube was used as shown in Figure 5. The tube was 25mm in diameter and can hold up to 200mL. The non-treated coir fiber and treated with Borax were then inserted into the cylindrical tube with a weight of 8 grams for ten samples. The test tubes with the samples were then lit up with a gas burner at a distance of 6mm from the bottom of the test tube to the top of the burner. The burner is adjusted to give a constant blue flame. After 4 minutes of vertical burning, the test samples were weighed again and recorded the final weight [22]. The formula for the loss of weight is given as follows

$$\%\ \text{weight loss} = \frac{W_i - W_f}{W_i} \quad (3)$$

where
W_i = Initial weight
W_f = Final weight

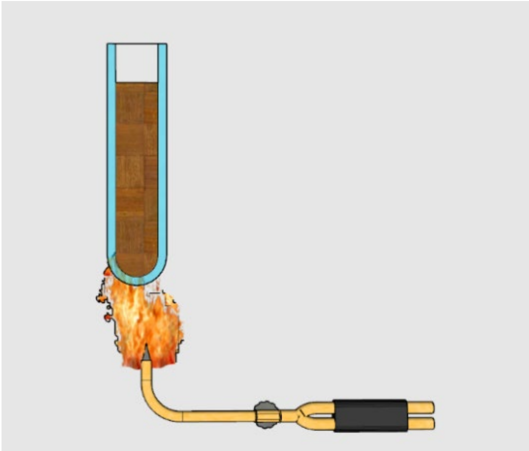

Fig. 5. Vertical Burning Test

3. Results and Discussions

3.1 Significant Difference between No Sound Panel and Bamboo/Coir Fiber Panels

In this section, the significant difference among the three (no sound panel, bamboo sound panel, and fiber-only sound panel) was presented in textual and tabular forms and are examined and discussed in detail. The researchers used four sound frequencies (250Hz, 500Hz, 1000Hz, and 2000Hz) to determine the significant difference, as depicted in the table below. Similarly, the study utilized the ANOVA method to determine if there was a significant difference between the three samples. Table 2 shows that for all frequencies ranging from 250 to 2000 hertz, there is a significant difference.

Table 2
Analysis of Variance Table Result

Frequency (Hz)	p-value	Remarks
250	3.89E-23	Significant
500	1.76E-21	Significant
1000	4.36E-11	Significant
2000	4.91E-08	Significant

3.2 Significant Difference between with Bamboo Sound Panel and Fiber Only Sound Panel

This section presents the significant difference between the two types of sound panels (bamboo sound panels and fiber-only sound panels). The study used four sound frequencies (250Hz, 500Hz, 1000Hz, and 2000Hz).

Compared to synthetic materials found in the market, the sound panel with bamboo and fiber only were in general, both good in terms of its noise reduction coefficient (NRC). NRC refers to the sound absorption capacity of material. A value of 0 means there is no absorption and 1 means perfect absorption [18]. Synthetic sound panels have NRC up to 0.20 to 1.0 and may even go higher depending on frequency. Several researches proved that some other natural composite absorber like egg tray with sugarcane and egg tray with corn husk produced good NRC [15,23]. In Figure 6, a comparison between with bamboo and fiber only panel is shown. Hence, both the bamboo with fiber and fiber only sound panel is effective for frequencies 500, 1000 and 2000 hertz. Both sound panels were inferior for 250 Hz frequency. On the average, the absorption coefficient of sound panel with bamboo and fiber is 0.2556 while that of bamboo only is 0.2555. Maximum absorption coefficient for both panels was in the frequency of 500 Hz with a value of 0.36. A bamboo can absorb frequencies higher than the frequencies used in the study. In fact, it worked better in the range of 1250 to 5000 Hz, having an absorption coefficient of 0.41 in 2500 Hz [14]. Another study used same frequencies as 250, 500, 1000 and 2000 Hz obtained an average of 0.46 absorption coefficient [24]. On the other hand, a study for the sound absorption capability of coconut fiber was recorded to have noise reduction coefficient in the range of 0.31 and 0.58 [25]. Bamboo and coconut fibers are good sound absorber [26].

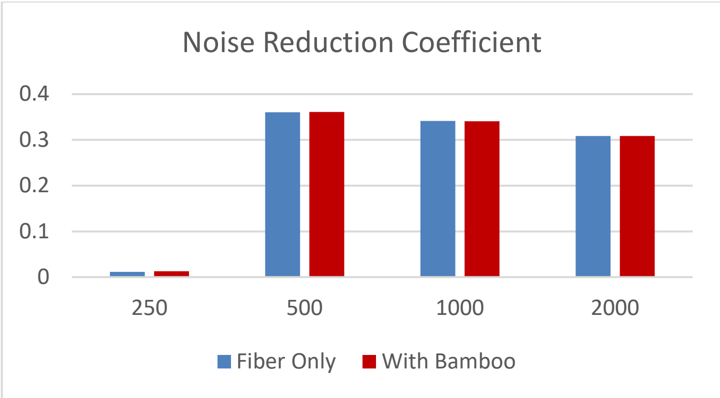

Fig. 6. Comparison for effectivity

3.3 Vertical Burning Test

An acoustic sound absorption panel should have fire resistance property. In testing the fire resistivity of the coir fiber, test was conducted on the treated and untreated coir fiber. The test determines the weight loss percentage, which measures the combustibility of the specimens. There are ten samples (5 treated and 5 untreated) weighing 8 grams. The flame-retardant chemical used in this experiment is Borax. After conducting the vertical burning test, Table 3 shows the percentage of mass loss of the treated coir fiber, while Table 4 shows the mass loss of the untreated coir fiber. The formula used to get the percentage of mass loss is based on Eq. (3).

Table 3 and 4 show that the average weight loss of treated coir is only 20%, while the untreated coir fiber has 40% weight loss. The coir fiber treated with Borax has less weight loss than untreated coir fiber. Furthermore, the difference in the physical appearance of the sample can also be observed. Figure 7(a) shows the appearance of untreated coir fiber. While Figure 7(b) shows the appearance of treated coir fiber after the test, it has a lesser charred part.

Table 3
Weight Loss of Treated Coir Fiber

Initial Weight (grams)	Final Weight (grams)	Weight Loss (%)
8	6	25
8	6	25
8	6	25
8	7	12.5
8	7	12.5
Average Weight Loss =		20

Table 4
Weight Loss of Untreated Coir Fiber

Initial Weight (grams)	Final Weight (grams)	Weight Loss (%)
8	5	37.5
8	3	62.5
8	5	37.5
8	5	37.5
8	6	25
Average Weight Loss =		40

Fig. 7. (a) Untreated Coir Fiber and (b) Treated Coir Fiber

The t-test statistical tool results show a significant difference between treated and untreated coir fiber, as shown in Table 5. The data were tested with a 0.05 level of significance, where the p-value is equal to 0.019256. Hence, the Borax that was used to treat the coir fiber to strengthen its fire resistivity is effective.

Table 5
Weight loss of untreated coir fiber

	Untreated Coir Fiber	Treated Coir Fiber
Mean	20	40
Variance	46.875	187.5
Observations	5	5
P(T≤t)two-tail	0.019256	
T Critical two-tail	2.306004	

4. Conclusions and Future works

Refer to NRC table, the sound absorption panel comprises coir fiber, and bamboo culm has been effective. The sound panel tested only four frequencies: 250, 500, 1000, and 2000 Hz. Both the sound panel with bamboo and coir fiber, and sound panel with coir fiber only were effective for frequencies 500, 1000 and 2000 Hz. The average sound absorption coefficient for the two set up is 0.25, which is considerable. At the same time, both also were inferior for absorbing 250 Hz frequency. On the other hand, the test for the fire resistivity of coir fiber shows that using fire retardant lessens the combustibility of the treated material. The researchers suggest trying and testing the effectiveness of other natural fibers available. Also, to determine how the sound change, it is suggested to test the physical properties of sound. Lastly, future researchers should consider using other fire retardants.

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