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ORIGINAL ARTICLE

# Sound Absorption Characteristics of Composite Panel Made from Coconut Coir and Oil Palm Empty Fruit Bunches Fibre with Polyester

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**ABSTRACT** – The development of pure natural fibres as sound absorptive material remains overlooked due to their lack of mechanical and moist properties, low durability, and vulnerability to be damaged by the environment. Certain fibre treatments are needed to improve such disadvantages. This paper investigates sound absorption characteristics of coconut fibre (coir) and oil palm fibre made from empty fruit bunches (OPEFB) fibre bonded by polyester that can protect them from the ambient environment in order to increase their durability. Two types of fibre-polyester composites have been tested. The first is the fibre-polyester composite (FPC) type, which is totally coated with polyester as the composite matrix. Another type is the fibre-polyester bonded composite (FPBC), in which the polyester is brushed into slice by a slice of the fibre layer in order to coat and bond the fibre, although porous among the fibre remains possible. A two-channel impedance tube is used in the measurement within 200 Hz to 3000 Hz of the frequency range. It is found that FPBC type panel has almost similar sound absorption characteristics to its purely natural fibre as it is able to maintain the panel porosity. The coconut coir fibre panel and its composite have a maximum absorption coefficient of almost 100% within the frequency range 1500-2000 Hz, considerably better than the OPEFB fibre, with only about 80% of the absorption coefficient. If the FPC layer exists, the sound absorption is reduced, and the frequency peaks are also shifted. Additions of the FPC panel layer thickness produced lower sound absorptions and shifted the peaks to the lower frequency range. The FPBC panel type is viable to protect the fibre from the environment without changing its sound absorption characteristics.

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*Sound absorption coefficient; Natural fibre; Natural fibre composite; Coconut coir; Oil palm fibre*

## INTRODUCTION

Mechanical and electrical equipment growth has increased significantly, including automotive applications and home appliances. Most of the equipment produces unwanted vibration and noise [1–3]. Various methods and materials have been developed to reduce this problem by absorbing vibration and sound energy. This includes the application of absorber and soundproofing panels [4–6]. Sound-absorbent panels are the typical panels applied to reduce the noise on their transmission path. They reduce reflected sound that hits a rigid wall or surface. The panels absorb certain parts of the acoustic energy and reflected remains. There are some physical prosperities of materials that change the absorption behaviour, such as fibre type, fibre size, material thickness, density, airflow resistance, porosity and surface impedance [7,8].

Two methods are generally used in the sound-absorbing application, i.e., porous material [7–9] and micro-perforated panel (MPP) [10–12] or a combination of both types [13–15]. The porous material can be classified into fibrous, cellular, and granular based on its microscopic structures. Polyurethane, rock wool, glass wool, and polyester are fibrous materials that are commonly used for this purpose. However, the manufacture and application of these materials can have an adverse impact on the environment [12]. Because of this, some researchers have tried to develop natural fibres as sound-absorbent, which are naturally renewable and environmentally friendly. In particular, some natural fibres have been investigated for this purpose: kenaf, cork, cotton, wood, cane, cardboard, sheep wool, coconut coir, pineapple-leaf, and empty fruit bunches of oil palm fibre [16,17]. The disadvantages of using pure natural fibres include their lack of mechanical and moist properties, low durability, and vulnerability to be damaged by the environment. Regarding this, researchers have developed natural fibre composites to deal with this drawback using polyester and polylactic acid [4,18–20]. However, the hard surface of the composite can decrease the sound absorption coefficient of the panels.

In this paper, a composite panel of sound absorption characteristics made of natural fibre made from coconut coir fibre and oil palm empty fruit bunch (OPEFB) fibre with polyester are investigated. Both fibres have good sound-absorbing material [21–23] and large and mass production in tropical countries. The effect of the polyester addition on the fibre sound absorption characteristics will be observed. Two types of fibre-polyester composites will be studied. The first is the fibre-polyester composite (FPC) type, which is entirely covered with polyester as the composite matrix. Another type is the fibre-polyester bonded composite (FPBC), in which the polyester is brushed slice by slice into the

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fibre layer in order to coat and bond the fibre. The second type of panel is developed to protect the fibre from the environment by maintaining porosity among the fibre. The discussion in this paper is focused on the effect of the existing polyester in pure natural fibre on the sound absorption characteristics.

## MEASUREMENT METHOD

### Material Preparation

First, the coconut coir and OPEFB are harvested directly from the traditional farm and dried naturally by sundering and spreading the fibres under the sun. The fibres are then cleaned, sprayed with mineral water, and dried at room temperature without any chemical treatment to maintain their natural characteristics. The sample panels are designed cylindrically with a 54 mm diameter according to impedance tube inner diameter following the impedance tube designed based on ASTM E 1050. Fibres are combined with polyester to coat and protect them from the ambient environment. There are two types of fibre-polyester composite in this testing; the fibre-polyester composite (FPC), in which the fibre is fully covered with the polyester as the composite matrix, and the fibre-polyester bonded composite (FPBC), where the polyester is brushed into slice by a slice of the fibre layer before being compressed. Therefore, the fibre is coated and bonded by polyester so that the panel has more density. However, the fibre is intentionally left porous. It is evident that the porosity of the material has a significant effect on sound energy absorption [7,8]. The sample panels tested in this research are composed of single or double layers consisting of a purely natural fibre layer and composite layer. The compositions of the specimen panels are detailed in Table 1 to Table 4, while the model of the specimen is shown in Figure 1.

### Measurement Setup

The two-microphones impedance tube with a 54 mm inner diameter made of an aluminum pipe is used to measure the sound absorption coefficient from 200 Hz to 3000 Hz of the frequency range, as illustrated in Figure 2. The impedance tube is designed based on ASTM E1050. The sound absorption coefficient (α) is calculated by the equation below [24].

$$\alpha = 1 - |r|^2 \tag{1}$$

while $r$ is obtained by Eq. (2) by including wave number ($k$), the distance between specimen and microphone 2 ($l$) is in meter, and microphones distance ($s$) is in meter.

$$r = \frac{H_{12} - e^{-jks}}{e^{jks} + H_{12}} e^{j2k(l+s)} \tag{2}$$

where $j$ is an imaginary component, the transfer function is calculated by:

$$H_{12} = \frac{p_1}{p_2} \tag{3}$$

where $p_1$ and $p_2$ are sound pressure at the first microphone and second microphone, respectively.

The excitation source is a chirping sound with a frequency range of 100 Hz to 10 kHz. Two microphones of BSWA type MPA 215 are used to measure the sound pressure in two channels. Measured signals from both microphones are then recorded to a data acquisition card of NI 9234. The sound absorption coefficient is calculated by using the transfer function of these two microphones. The experiments are carried out for the fibres and its composite layer panel by varying each layer's thickness in 30 mm-total panel thickness based on Table 1 to Table 4. The test is conducted in two conditions: the panel of the fibre surface faces the sound source, and the composite surface faces the sound source.

**Table 1.** Coconut coir fibre and its fibre-polyester composite (FPC).

| Sample number | Pure coconut coir fibre thickness/layer thickness percentage | Coconut coir-polyester composite/ layer thickness percentage | Density ($g/cm^3$) |
|---|---|---|---|
| A-1 | 30 mm /100% | 0 / 0% | 13.178 |
| A-2 | 20 mm / 66.7 % | 10 / 33.3% | 23.611 |
| A-3 | 10 mm / 33.3 % | 20 mm / 66.7 % | 34.043 |
| A-4 | 0 mm / 0% | 30 mm / 100 % | 44.476 |

**Table 2.** Coconut coir fibre and its fibre-polyester bonded composite (FPBC).

| Sample number | Pure coconut coir fibre thickness/ layer thickness percentage | Coconut coir-polyester bonded / layer thickness percentage | Density ($g/cm^3$) |
|---|---|---|---|
| B-1 | 30 mm / 100 % | 0 mm / 0 % | 13.178 |
| B-2 | 20 mm / 66.7 % | 10 mm / 33.3 % | 11.714 |
| B-3 | 10 mm / 33.3 % | 20 mm / 66.7% | 10.249 |
| B-4 | 0 mm / 0 % | 30 mm / 100% | 8.785 |

**Table 3.** Oil palm empty fruit bunch (OPEFB) fibre and its fibre-polyester composite (FPC).

| Sample number | Pure OPEFB fibre thickness/ layer thickness percentage | OPEFB-polyester composite/ layer thickness percentage | Density ($g/cm^3$) |
|---|---|---|---|
| C-1 | 30 mm / 100 % | 0 mm / 0 % | 13.178 |
| C-2 | 20 mm / 66.7 % | 10 mm / 33.3 % | 23.611 |
| C-3 | 10 mm / 33.3 % | 20 mm / 66.7% | 34.043 |
| C-4 | 0 mm / 0 % | 30 mm / 100 % | 44.476 |

**Table 4.** Oil palm empty fruit bunch (OPEFB) fibre and its fibre-polyester bonded composite (FPBC).

| Sample number | Pure OPEFB fibre thickness/ layer thickness percentage | OPEFB-polyester bonded / layer thickness percentage | Density ($g/cm^3$) |
|---|---|---|---|
| D-1 | 30 mm / 100% | 0 mm / 0 % | 13.1781 |
| D-2 | 20 mm / 66.7 % | 10 mm / 33.3 % | 11.7139 |
| D-3 | 10 mm / 33.3 % | 20 mm / 66.7% | 10.2497 |
| D-4 | 0 mm / 0% | 30 mm / 100% | 87.854 |

(a) Full fibre (b) FPBC panel (c) FPC panel

**Figure 1.** Fibre panel samples; coconut coir and its polyester composite.

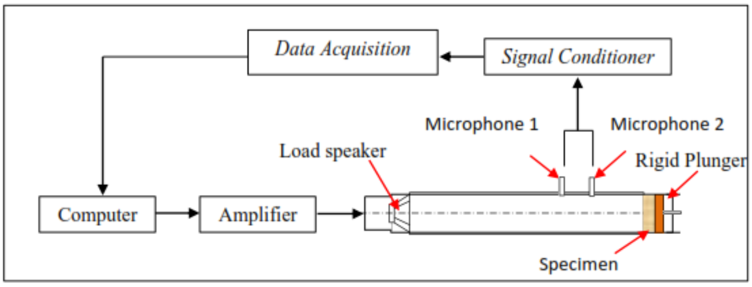


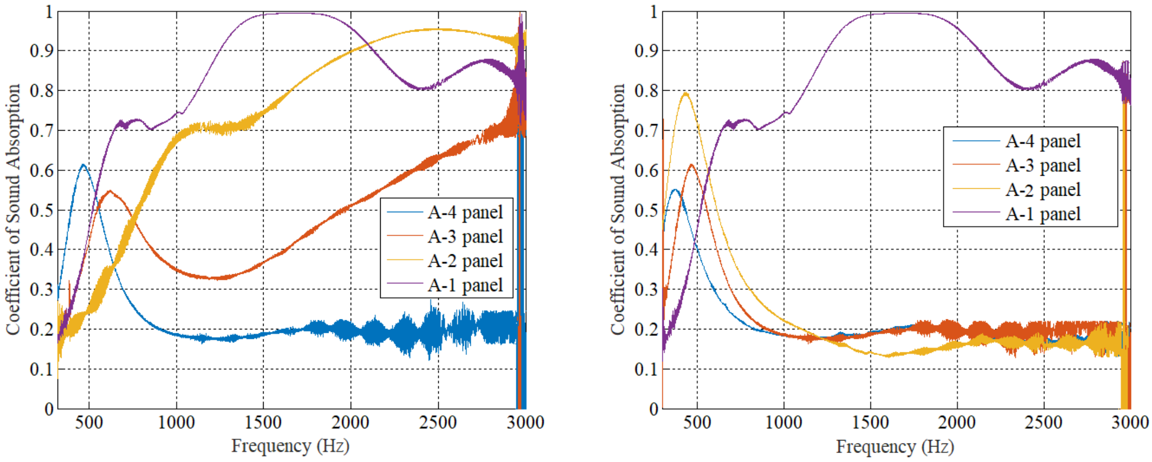

**Figure 2.** Two-channel impedance tube set up.

## RESULTS AND DISCUSSION

### Coconut Fibre

The first experiment is carried out for coconut fibre and its FPC layer panel by varying each layer's thickness in 30 mm-total panel thickness (A-1 to A-4 panel sample in Table 1). The test is conducted in two conditions: the panel of the fibre surface faces the sound source, and the composite surface faces the sound source. Figure 3(a) shows the sound absorption coefficient of A-1 to A-4 panel with the fibre surface facing the sound source. The figure shows that the coconut fibre and its FPC have relatively good sound absorption at the low-frequency range. The A-1 panel composed of coconut fibre produces excellent sound absorption (almost 100%) at 1700 Hz and good absorption at a frequency range of 700 Hz to 3000 Hz. Previously, it was found that the coconut fibre panel has good sound absorption in relatively high frequency. Thicker and denser fibre panels increased the capacity of the coconut fibre panel in amplifying the sound absorption coefficient and shift the frequency peak to a lower frequency [22], and it is also found in other fibrous materials [8, 16, 21, 23].

When the fibre-polyester composite layer is placed behind the fibres-only layer (A-3 and A-4 panels), the sound absorption decreases. The frequency peaks also shift into a lower frequency range. Two peaks appear for almost all specimens except the A-4 panel. The air cavity behind the composite causes the first peak at a lower frequency, and airflow resistance among the fibres causes the second one at a higher frequency. When the fibre-only layer thickness reduces, the peak caused by airflow resistance also decreases, and the frequency peak moves to a higher frequency. Meanwhile, another frequency peak shifts to a lower frequency range if the fibre-only layer thickness is reduced. The addition of the PFC layer thickness has the effect of shutting the pores and reducing the airflow resistance.

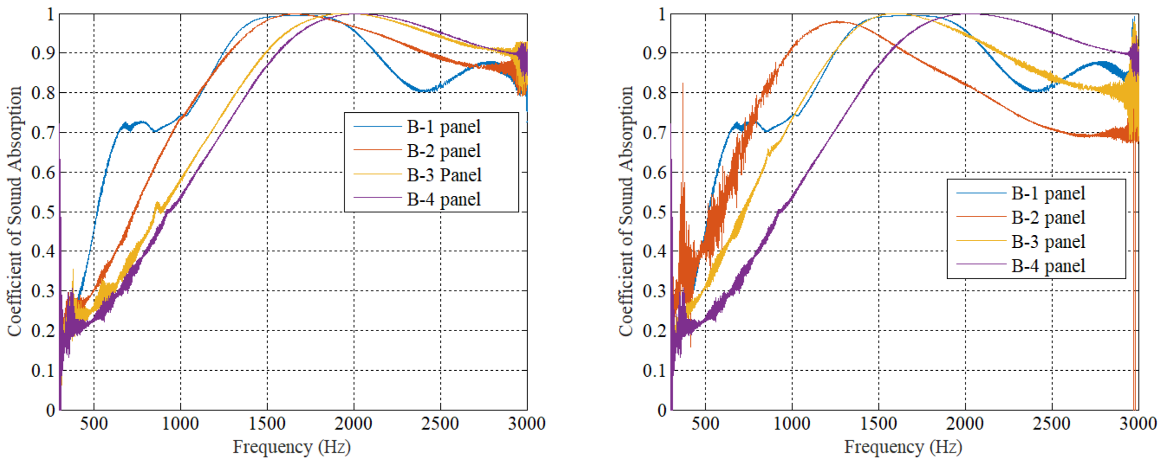



(a) (b)

**Figure 3.** The coefficient of sound absorption of coconut fibre and FPC panel with (a) pure fibre layer, and (b) FPC surface facing the sound source.

Furthermore, when the opposite surface faces the sound source where the hard surface of composite in front of the sound source is located, the sound absorption coefficient peaks are only limited at the narrowband low-frequency range, as in Figure 3(b). This trend indicates that the thicker the FPC layer, the lower the sound absorption and the lower the frequency range. The surface impedance of the composite has a significant role in the sound absorption of the composite hard surface. The raising of the fibre number increases the sound absorption peak. The air cavity and pure fibre panel placed behind the FPC layer significantly affect shifting frequency peak and improving the absorption coefficient at very low frequency, reducing sound absorption at a higher frequency.

The second testing is conducted for coconut fibre and its FPBC panel by varying 30 mm-total panel thickness (B1-B4 panel samples in Table 2.2). The measurement is also carried in two conditions: the fibre surface layer faces the sound source, and the fibre-polyester composite surface faces the sound source. Figure 4(a) shows the coefficient of sound absorption of B-1 to B-4 panel with the fibre surface facing the sound source. It is shown that the coconut fibre and its FPBC produced very good sound absorption at a relatively wideband frequency range. They perform excellent sound absorption (almost 100%) at 1500 Hz – 2000 Hz frequency range. Moreover, the peaks also only make insignificant differences. Increasing the FPBC layer thickness moves the peak to a higher frequency. It is likely in proportion with the increase of fibre stiffness by the thin polyester coating the fibre.

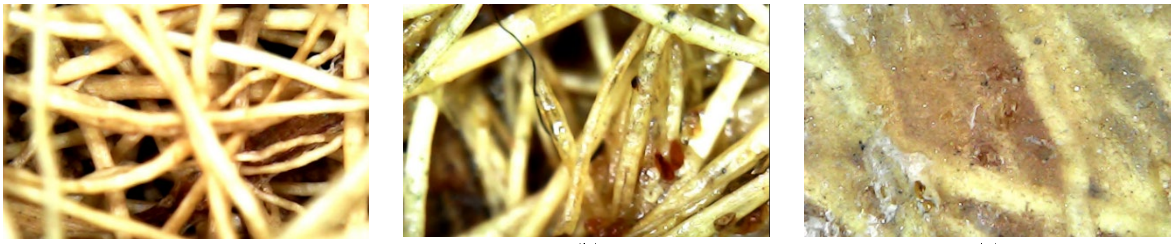



(a) (b)

**Figure 5.** The coefficient of sound absorption of coconut fibre and its FPBC panel with (a) pure fibre layer, and (b) FPBC composite facing the sound source.

Similarly, when the opposite surface faces the sound source where the slightly harder surface of the FPBC is placed in front of the sound source, the panel sound absorption coefficient acts very well at wideband frequency. The peaks increase to a higher frequency by raising the fibre-polyester bonded layer thickness, as shown in Figure 5(b). The B-4 panel, containing a fibre fully bonded and coated by polyester, has a higher peak frequency. Furthermore, the acoustic energy is absorbed by the porous material, including the fibre affected by several mechanisms: airflow resistance, surface impedance, and air cavity. Fibres interlocking is the frictional element that provides acoustic wave motion resistance. If a sound wave enters these materials, its amplitude is decreased by friction as the waves try to move through the tortuous passages. Thus, the acoustic energy is converted into heat [8]. It is found that the existence of polyester changes the mechanism of sound absorption by the material.

Fibre bonded or coated by polyester has a significant role in maintaining and increasing the panel airflow resistance. Figure 6 shows that the fibre-polyester bonded panel maintains good enough porosity and tortuosity to absorb acoustic energy. The thin polyester that coated the fibre will increase the fibre damping characteristic; therefore its absorb more energy at a higher frequency. On the other hand, if the polyester covers the porous among the fibres and leaves limited pores present, the sound absorption coefficient is consequently reduced, and surface impedance and air cavity take a role as the mechanism in sound absorption.

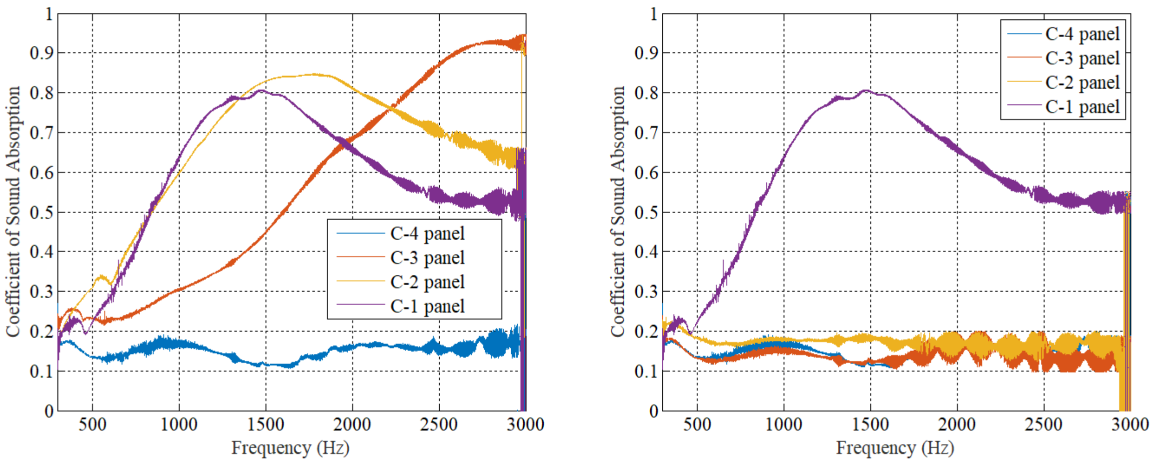


(a) (b) (c)

**Figure 6.** Coconut coir (a) fibre, (b) fibre-polyester bonded composite – FPBC, and (c) fibre-polyester composite – FPC.

## Oil Palm Empty Fruit Bunch Fibre

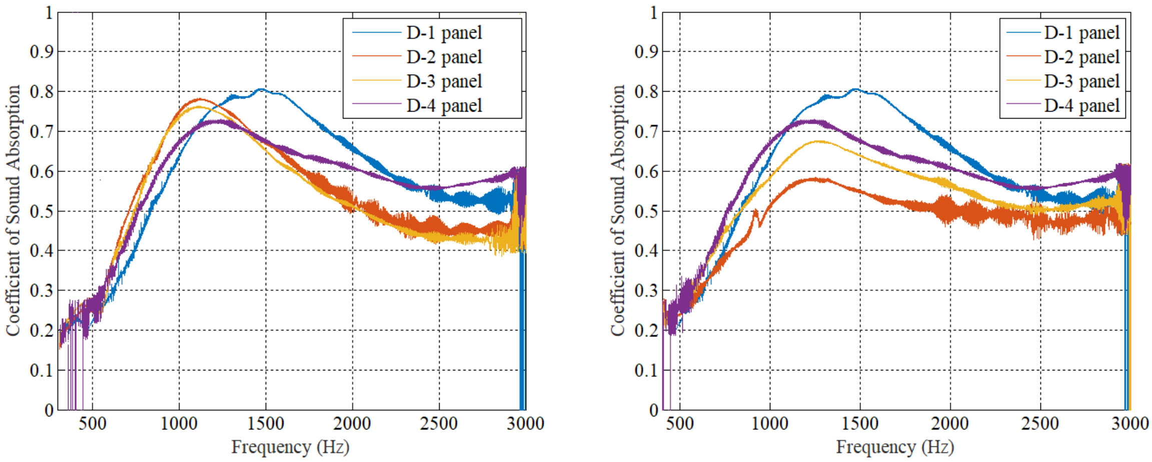
The first experiment is carried out for OPEFB fibre and its fibre-polyester composite layer panel by varying the fibre-polyester composite of 30 mm-total panel thickness (C-1 to C-4 panel sample in Table 3). The test was conducted in conditions where the fibre layer surface and composite surface face the sound source. Figure 7(a) shows the coefficient of sound absorption of C-1 to C-4 panel with the fibre surface facing the sound source. It is observed that the OPEFB fibre and its composite have relatively good sound absorption at a low-frequency range. The C-1 panel, composed of pure natural fibre, has relatively good sound absorption at 1500 Hz. If the fibre-polyester composite layer was placed behind the fibres-only layer, the sound absorption slightly increased. The frequency peak also shifts to a higher frequency due to the reduction of the fibre panel thickness. However, if the fibre was fully coated by polyester as the composite matrix, the sound absorption coefficient decreased to almost zero. Furthermore, when the opposite surface faces the sound source where the hard surface of the composite is in front of the sound source, the sound absorption coefficient drops into a very insignificant value, as shown in Figure 7(b).




(a) (b)

**Figure 7.** The coefficient of sound absorption of OPEFB fibre and its FPC panel with (a) pure fibre layer, and (b) fibre-polyester composite facing the sound source.

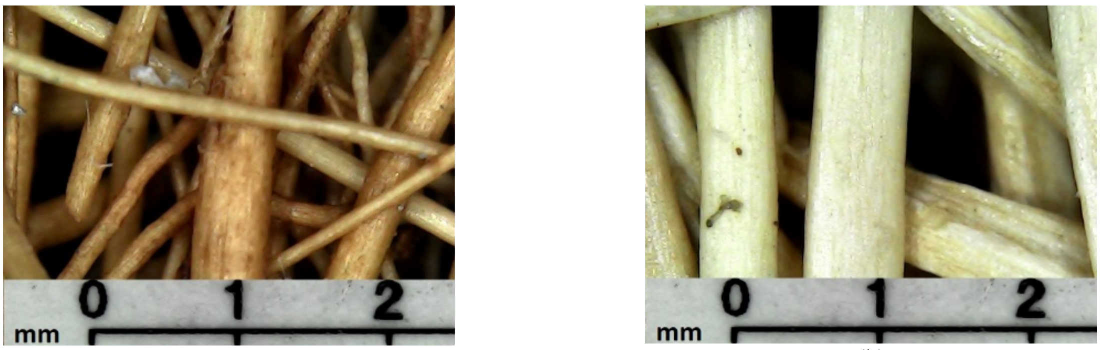
The next testing is carried out for OPEFB fibre and its fibre-polyester bonded layer panel by varying the layer of 15 mm-total panel thickness (D1-D4 panel samples shown in Table 4). The measurement is conducted in two conditions: the fibre surface of the panel faces the sound source and the composite surface faces the sound source. Figure 8(a) shows the coefficient of sound absorption of D-1 to D-4 panel with the fibre surface facing the sound source. It is shown that the OPEFB fibre and its fibre-polyester bonded panel make good sound absorption at a relatively wideband frequency range. They have maximum sound absorption (70%-80%) at 1000 Hz – 1500 Hz frequency range. The peaks show insignificant differences. Increasing the fibre-polyester bonded layer thickness slightly moves the peak to a higher frequency. It is likely due to the increase of fibre stiffness caused by thin polyester covering the fibre. Likewise, if the opposite surface facied the sound source, where the slightly harder surface of the fibre-polyester bonded surface is in front of the sound source, the panel sound absorption coefficient is very good at wideband frequency. The peaks increase to the higher frequency by raising the fibre-polyester bonded layer thickness, as shown in Figure 8(b). D-4 panel, the fibre fully bonded and coated by polyester, retains a relatively higher frequency of the peak.




(a) (b)

**Figure 8.** The coefficient of sound absorption of OPEFB fibre and its FPBC panel with (a) pure fibre layer, and (b) fibre-polyester composite facing the sound source.

Compared to the coconut fibre, the OPEFB fibre has a larger fibre diameter, as illustrated in Figure 9. Increasing the fibre diameter will decrease the sound absorption coefficient as smaller diameter fibres can move more easily than larger fibres on sound waves. Larger diameter fibre has more stiffness, so it needs more energy to push or move the fibre by airflow to absorb the sound energy. Moreover, in fine fibres diameter, more fibres are required to equal more fibres for the same volume density, so more fibres will contact the airflow caused by sound pressure, resulting in a more tortuous path and higher airflow resistance. Figure 5(a) and 8(a) show that more OPEFB fibre diameter has a lower sound absorption coefficient than coconut fibre one. The coconut fibre panel and its composite have the best sound absorption ability, almost 100% within the frequency range 1500-2000 Hz, considerably better than OPEFB fibre, with only about 80% sound absorption coefficient.




(a) (b)

**Figure 9.** Natural fibres under microscope for (a) coconut coir and (b) oil palm empty fruit bunches.

## CONCLUSION

This study investigates the measurement and analysis of a composite panel sound absorption characteristics made of natural fibre coconut coir fibre and OPEFB fibre with a different polyester volume. The coconut fibre panel and its composite produce a better sound absorption coefficient than OPEFB fibre one from the result and discussion. It is found that the coconut fibre panel and its composite have almost 100% sound absorption coefficient within frequency range 1500-2000 Hz, considerably better than OPEFB fibre, with only about 80% sound absorption coefficient. The OPEFB fibre has a larger diameter. Increasing fibre diameter will decrease the sound absorption coefficient.

When the fibre-polyester composite layer is placed behind the fibres-only layer, the sound absorption decrease, and the frequency peaks also shift into a higher frequency range. If the fibre-only layer thickness reduces, the peak caused by airflow resistance also decreases, and the frequency peak moves to a higher frequency. The thicker the fibre-polyester composite, the lower the sound absorption and the lower the frequency range. The composite surface impedance plays a significant role in sound absorption of the hard surface of the composite, and the air cavity and purely natural fibre panel behind the fibre-composite layer play a significant role in shifting frequency peaks and increasing the peaks.

Furthermore, if the fibre-polyester bonded composite FPBC is applied, the sound absorption peaks have insignificant differences. Increasing fibre-polyester bonded layer thickness slightly moves the peak to a higher frequency. It is likely due to the increase of fibre stiffness caused by thin polyester covering the fibre. The peaks increase to a higher frequency by raising the fibre-polyester bonded layer thickness. The FPBC type panel has almost similar sound absorption characteristics to its purely natural fibre as it is able to maintain the panel porosity.

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