Coconut Fiber Panel towards Acoustical Performance

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Abstract-- **In this research, the natural material fiber was intended to replace the synthetic fiber to reduce its dependency on synthetic materials. Basically, the use of natural material can minimize the cost in terms of materials and processing as well as to conserve the environment by reducing the waste of natural material. An experimental investigation was conducted to explore the sound absorption properties of coconut fiber with and without holes reinforced polyurethane (PU) for acoustic applications. The materials used in this study were coconut fiber as a reinforcement and PU as a matrix. The absorption coefficient of the acoustic panel was measured by using impedance tube and reverberation room testing. The results reveal that S3 shows good agreement in absorption coefficient value which is 0.75 between the frequencies of 3500 to 4000 Hz. The findings of this study also suggest that the absorption coefficient of CSM coconut fiber filled with PU without holes shows better perfomance compared to CSM coconut fiber filled with PU with holes 3 mm or 6 mm. Implications of the results and future research directions are also presented.**

Index Term-- **natural fiber, acoustical, coconut fiber, polyurethane.**

1.0 INTRODUCTION

This research is carried out to analyse the sound absorption properties of coconut fiber for acoustic applications. Moreover, the potential construction such as design, material and equipment used to manufacture the coconut fiber based sound proof panels must be affordable and suitable in Malaysia. Furthermore, the use of natural materials can help in small and medium industry (SMI) in the country. The agricultural waste such as coconut fiber (Cocos nucifera), rice fiber (Oryza sativa), and oil palm frond fiber (Elaeis guinnesis) are plentiful and usually burnt or used as an agricultural by-products (Danso, 2015). Lately, the natural fibers from agriculture are progressively being explored for assorted usage in many structural and non-structural applications in order to replace the synthetics fibers in composite materials and lining for automotive devices [1 – 2].

In this research, the rational of using natural or green materials as to replace the synthetic materials is to promote the effort of utilizing the natural product and indirectly to reduce the production of waste materials. Moreover, the processing cost also can be reduced and at the same time to preserve the environment. Frontczak and Wargocki [3] shows there are many parameters that should be considered in order to produce a good quality of sound insulator. For example the thickness of the panel, the porous level of the panel and also the arrangement of sandwich structure of the panel. This research will be focused on the perforated size of the panel. According to authors [4], the porosity or the hole of the perforated plate and the density of the porous material would significantly change the acoustic impedance and absorption coefficient of the acoustic absorber.

Nowadays, the sound proof material is very important in order to absorb the sound vibration from outside. The reverberation and vibration of noise or sound is mostly trapped inside the buildings as discussed by authors [5]. These phenomena can cause the unpleasant feeling of people in that area. As a solution, the panel or the insulator materials must be placed on the wall to allow the sound vibration to pass through the wall and absorbed to certain extent. Currently, the insulation material is made from the synthetic fibers such as glass wool and rock wool is widely used due to the good properties in the sound absorption as well as fire retardant materials. Basically, the synthetic materials are costly in terms of processing and harmful to the environment [6]. Therefore, the innovation of the natural materials is very important and at the same time can make use of the waste of natural materials. In addition, the initiative of using green material can help to reduce the dependency on the synthetic materials by adding the values to the waste product.

Noise control is one of the major requirements needed to improve the living surrounding. One of the techniques to improve noise control is to create a material or sound absorbing material. Generally, the multi-layer sound absorbers are used to absorb noise that was composed of perforated plates [7], air space [8] and porous materials [9]. However, effectiveness of the multi-layers sound absorbers effectiveness depends on their construction. Acoustic panel made from various material and physical properties are proved to be efficient. Nevertheless it's cost and difficult to manufacture, natural fiber had been the alternative to this synthetic materials.

Moreover, acoustic panel made from glass wool and rock wool is very costly and its abrasive properties can harm humans when the dust from the panel is inhaled by humans. This is supported by author [10]. Many researchers have found the use of natural fibers such as the coconut husk as a good sound absorbing material and the most common researches for the use of coconut fiber proved that coconut husk or also called coir has good sound absorbing coefficient. In other researchers by authors [11], they have proven that coir fiber has good sound absorbing coefficient but no scientific research has been conducted based on holes concept for acoustical properties. Therefore, this study aims to experimentally investigate the sound absorption properties of coconut fiber with and without holes reinforced PU for acoustic applications. The long term implications of this study will helps to reduce or replace the uses of synthetic fiber in acoustic application.

2.0 EXPERIMENTAL

The acoustical testing is conducted to measure the acoustic performance of the chopped strand mat (CSM) coconut fibre, PU foam, CSM coconut fiber filled with PU without hole, CSM coconut fiber filled with PU with 3 mm holes, PU foam with 3 mm holes, CSM coconut fiber filled with PU with 6mm holes, PU foam with 6 mm holes as shown in Table 1. American Society for Testing and Materials (ASTM) standards were required which is ASTM E 1050 and ASTM C 384 for all procedures involving standard tools, techniques, and testing.

Table I
Types of materials

Samples	Materials
S1	CSM coconut fibre.
S2	PU foam.
S3	CSM coconut fiber filled with PU without holes.
S4	CSM coconut fiber filled with PU with 3 mm holes.
S5	PU foam with 3 mm holes.
S6	CSM coconut fiber filled with PU with 6mm holes.
S7	PU foam with 6 mm holes.

2.1 Coconut fiber

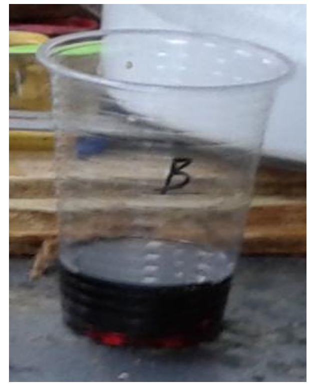
The raw material used was coconut fiber which is in the form of CSM coconut fiber. Figure 1 show the CSM coconut fiber which was obtained from the local supplier, Malaysia. The thicknesses of the CSM coconut fiber were about 8 to 10 mm. The CSM coconut fiber was pressed under hydraulic cold press machine in order to make sure that the thickness of the coconut fiber is similar. The pressure used during pressing the CSM coconut fiber was 1 tonne.

Fig. 1. The CSM coconut fiber.

2.3 Polyurethane

Basically, the mixture of the liquid PU is the combination of the liquid Polyisocyanate and Polyhydroxyl. The mixture must be mixed thoroughly before pouring into the CSM coconut fiber. Natural fiber acoustic panel is made from the CSM coconut fiber as the fiber and the PU as the matrix of the composite. Next, the mixture of PU was immediately poured onto the CSM coconut fiber.

The volume of liquid PU used for the composite is highly dependent on the weight of the coconut fiber. In short, the resin over reinforcement ratio was set as 1:1.4 (A:B) as shown in Figure 2. In general, PU reveals low corrosion resistance to strong acids and alkalis, and to organic solvents.



(a) (b)

Fig. 2. The PU foam (a) part A and (b) part B.

2.4 PU foam preparation

The PU foam part A and B is mixed and vigorously mixed to make sure that the solution is well mixed. Then, the mixture of PU foam is poured into the mould and quickly pressed under hydraulic cold press machine for half an hour. The mixing and pressing process of the PU foam must be done quickly because the chemical reaction between Part A and B is too fast and it solidifies easily. The gel coat is applied to the surface of the mould in order to prevent the sample from sticking at the mould during removal of the PU foam. Figure 3 shows the mixture of PU foam is poured into the mould.

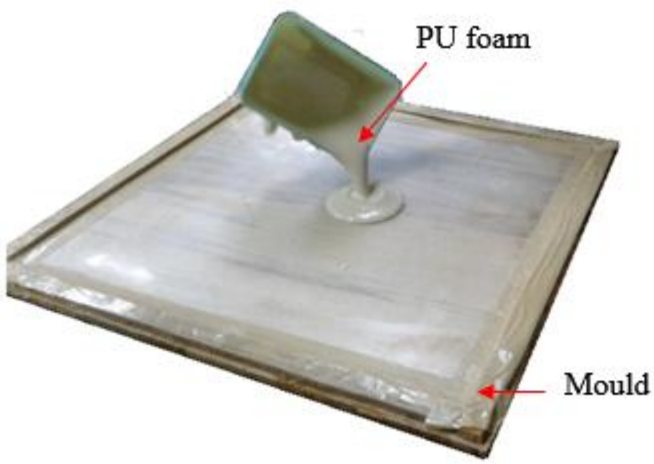


Fig. 3. The mixture of PU foam is poured into the mould.

Then, the upper part of the mould is closed and pressed under 1 tonne pressure for half an hour. After that, the solidify PU foam is removed from the mould and the testing sample is prepared. Figure 4 shows the solidification of PU foam.

Fig. 4. The PU foam in solid form.

2.5 Coconut CSM preparations

CSM coconut fiber is produced by cutting continuous strands of filaments into shorter length of about 2 inches and spread in a two-dimensional random pattern to form of chopped strand mat. The CSM coconut fibers poured with the liquid PU was immediately pressed by using the hydraulic cold press machine with 1 tonne pressure at room temperature for approximately 1 hour.

Furthermore, the CSM coconut fiber was cut into desired size which is 50 X 50 mm of the length and width. Then, the CSM coconut fiber was placed into the mould. Figure 5 shows the mixture of PU foam is poured into the CSM coconut fiber before pressed. After it is due, the coconut fiber filled with PU is removed from the mould. The excess polyurethane which occupies the empty spaces of the sides is removed by using proper equipment.

Fig. 5. Mixture of PU foam is poured into the CSM coconut fiber.

2.6 Sample preparation for impedance tube testing

The natural fibre foam, PU and coconut fibre, were cut into desired diameter which was 33.3 mm. In addition, the diameter of the sample testing must be accurately cut in order to fit with the tube during testing. After that, the side of the sample was filed by using the needle file set in order to get the smooth surface of the sample especially on the side of the sample. Next, the hole of the natural coconut foam and pure solid of Polyurethane, PU sample will be drill by using drilling machine. The suggested diameters of the perforation or hole were 3 mm and 6 mm.

In this research, the different diameter in a specimen also was making in order to compare the performance of the different diameter with the absorption coefficient. Figure 6 shows the schematic diagram of the assembly of the sound absorption measurement system with an impedance tube.

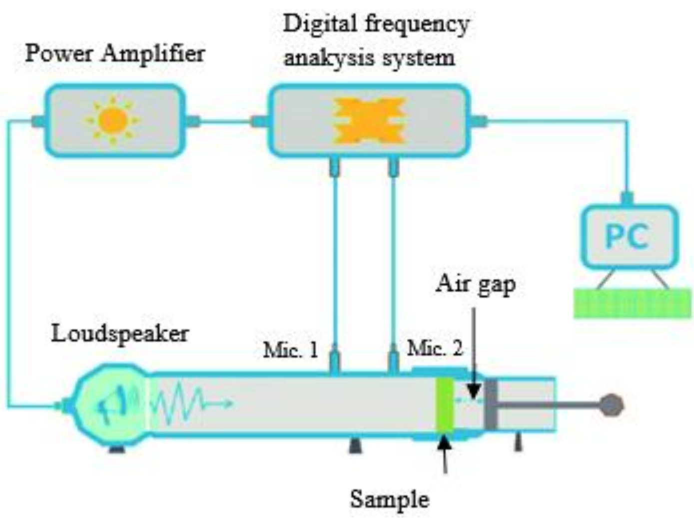


Fig. 6. Schematic diagram of impedance tube [12]

The range of the frequency use in the impedance tube testing was from 1 Hz to 5000 Hz. For this research the suggest frequency is from low frequency to the medium frequency which is below 2400 Hz. In addition, before the experiment is conducted the impedance tube testing must be calibrated. This is to make sure that the equipment is well functioning as well as to avoid errors occur during testing. Every sample is tested for two times in order to obtain the correct and reliable data of the testing.

An extended frequency range may be obtained by using tubes with various diameters and microphones spacing. By this method acoustical parameters like absorption coefficient, reflection coefficient and surface admittance for a small samples exposed to plane waves can be determined. The reflection coefficient (R) of the sample can be obtained from the Equation (1).

$$R=\frac{Hl-Hi}{Hr-Hl}e^{j2k(l+s)} \quad \text{...} (1)$$

Where *Hl* is Frequency Response Function (FRF) of the impedance tube, *Hi* is FRF associated with the incident wave components, *Hr* is FRF associated with the reflected wave components, *k* is wave number, *l* is distance between the microphone and the sample and *s* is spacing between the microphones. By using Equation (2), normal sound absorption coefficient, NAC (α) can be determined.

$$\alpha = |1 - R|^2 \quad \text{..} (2)$$

3.0 RESULTS AND DISCUSSION

3.1 CSM coconut fiber

The S1 used in the impedance tube testing is CSM coconut fiber with the thickness of 6.5 mm as shown in Figure 7. During testing is conducted, make sure that the sample does not contain any impurities like dust and dirt before the sample is inserted into the tube. This is to avoid the inaccurate collection of data during testing as well as to get the most reliable results.

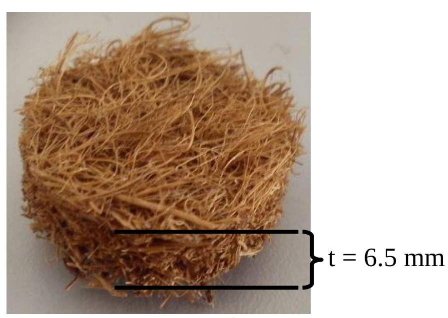


Fig. 7. CSM coconut fiber.

Figure 8 shows the simulation values of absorption coefficient of the sample when placed inside of the impedance tube. From Figure 7, the absorption coefficient of S1 is measured at every frequency range. The highest peak at every frequency range is recorded and the result for S1 is compared with the following samples.

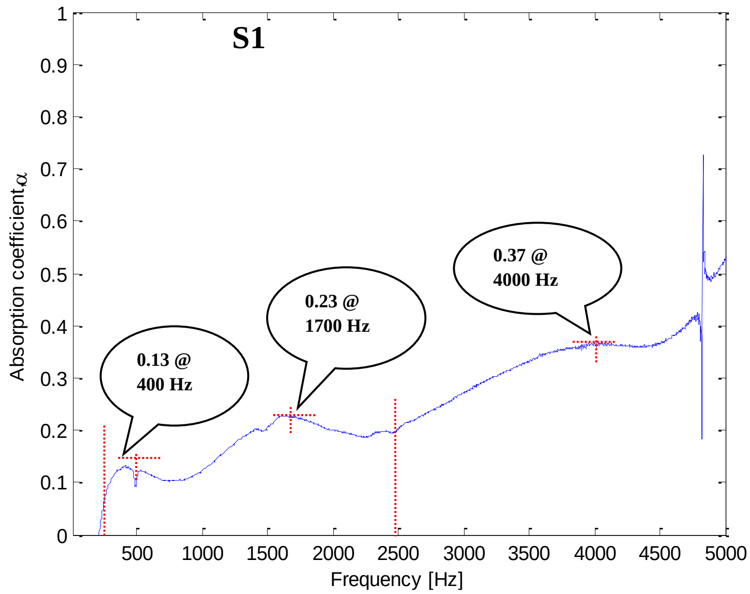


Fig. 8. The graph of absorption coefficient against frequency.

The highest absorption coefficient is 0.37 which plotted between 4500 Hz to 5000 Hz. At medium frequency which is between 1500 Hz to 2400 Hz the absorption coefficient is 0.23. This shows that the S1 have low absorption coefficient at low, medium and high frequency. Meanwhile, the absorption coefficient is less than 0.15 at low frequency which is below 1000 Hz.

According to authors [13] the airspace layer will enhance the absorption coefficient in the low frequency range. In addition, from Figure 8, the absorption coefficient is below than 2.0 at low frequency which has no air space layer during the test. This means the absorption coefficient for the sample without air space is less effective in terms of absorption properties compared to that which contains airspace layer.

Figure 9 shows the SEM image of CSM coconut fiber. From the figure, the structure of coconut fiber is porous and the size of CSM coconut fiber is not identical and the size range of the coconut fiber is between 240 μm to 376 μm. A porous absorbing material is a solid that contains cavities. These cavity, channels sound waves to go through them. The thicker, denser and heavier materials have higher transmission loss and porous materials are more effective at sound absorption [14]. Therefore, the thickness of the CSM coconut fiber also is very important in order to absorb the sound vibration.

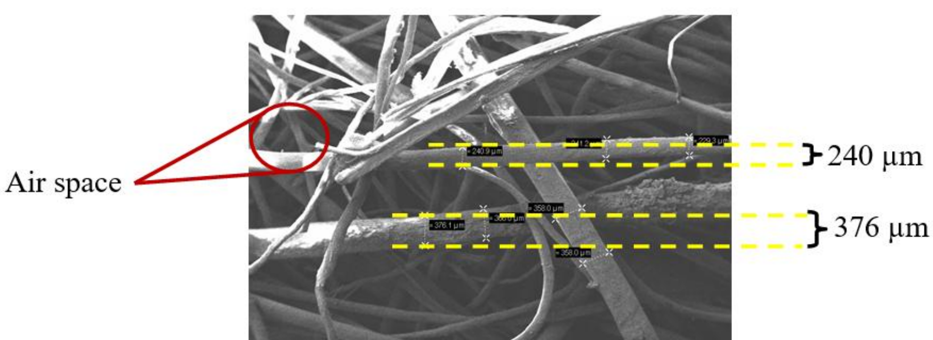


Fig. 9. SEM image of CSM coconut fiber.

In addition, the thickness of the sample used in the impedance tube testing is quite thin which only 6.5 mm. However, in the research [15], the absorption coefficient is 0.80 at low, medium and high frequency when thickness of the coconut fiber used during impedance tube testing is 20, 30, and 45 mm. This means, if the thickness of the samples is higher, then the absorption coefficient value also higher. According to the graph in Figure 8, S1 shows lower absorption coefficient value due to the lower thickness. Thus, the thickness of the CSM coconut fiber should be more than 6.5 mm of thickness in order to be used as a sound barrier material.

3.2 PU foam

Sample 2, S2 in Figure 10 shows the solid PU foam sample without perforated on the surface. The thickness of the sample is about 6.5 mm.

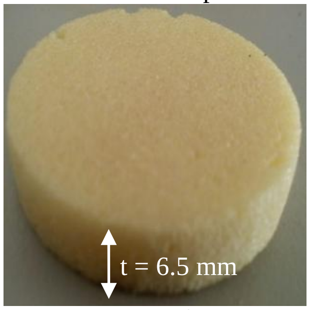


Fig. 10. PU foam.

Figure 11 shows the simulation values of absorption coefficient of the sample when placed inside of the impedance tube. The highest absorption coefficient of S2 is 0.40 which is between 2400 Hz to 5000 Hz. The absorption coefficient at medium and low frequency is slightly low which is 0.20 at medium and 0.10 at low frequency.

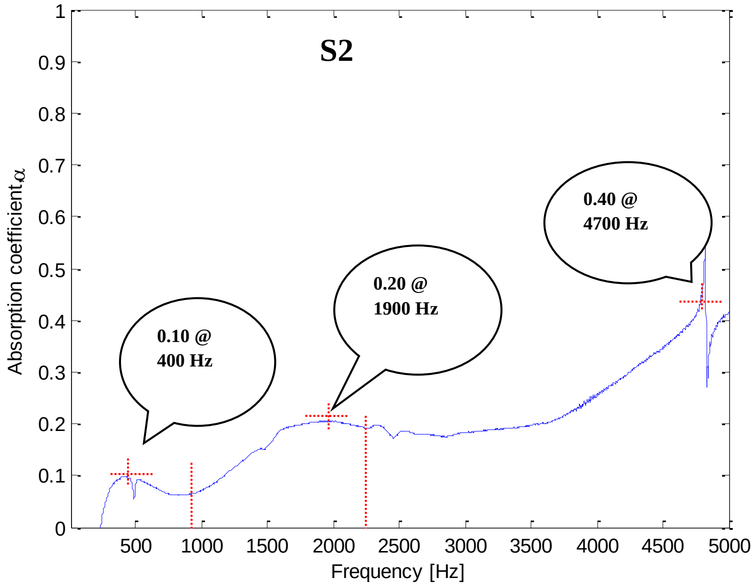


Fig. 11. The graph of absorption coefficient against frequency.

In overall, the absorption coefficient decreases as the frequency decreases. The sound absorption coefficient of the PU foam can be improved by using open pore cell structure [4]. Figure 12 shows the SEM image of the PU foam. According to authors [4], the sound absorption properties of porous medium were mainly influenced by its porous cell size and structure.

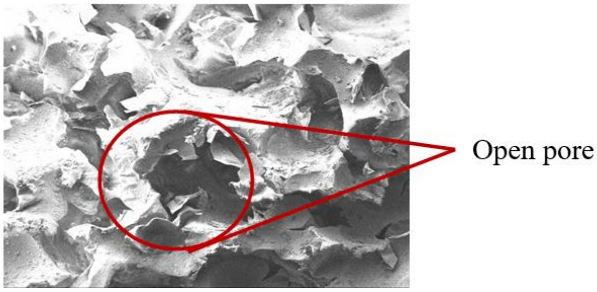


Fig. 12. The SEM image of PU foam.

Figure 13 shows the results of the influences of pore cell sizes on sound absorption coefficients of closed cell PU foams.

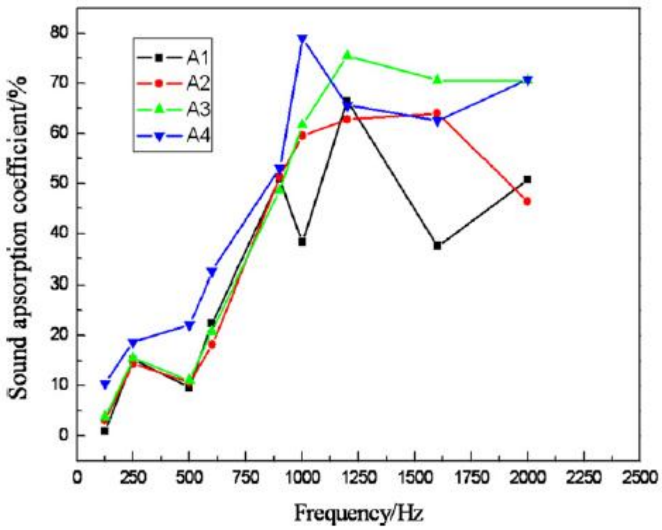


Fig. 13. The influences of pore cell sizes on sound absorption coefficients of closed cell PU foams: A1- 0.35 mm pore cell, A2- 0.67 mm pore cell, A3 - 0.77 mm pore cell, A4 – 1.05 mm pore cell [4].

Figure 13 shows the absorption coefficient is achieve 0.8 at 1000 Hz 1.05 mm pore cell (the larger pore cell size). However, by comparing with the results obtained in Figure 11 shows that only 0.08 of the absorption coefficient value at 1000 Hz. This shows that, the absorption value of the PU sample used in this research is not effective as well as have smaller size of pore cells.

3.3 Sample 3

Sample 3, (S3) used is the solid natural foam which is the CSM coconut fiber filled with PU without perforation on the surface. The thickness of the sample is 6.5 mm.

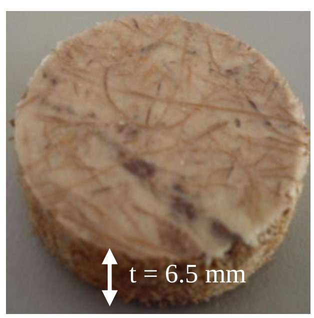


Fig. 14. CSM coconut fiber filled PU.

Figure 15 shows the simulation values of absorption coefficient of the sample when placed inside of the impedance tube. From graph, there are three peaks at low, medium and high frequency. The absorption coefficient between the frequencies of 500 to 2400 Hz is below than 0.42. However, the absorption coefficient is higher at 3900 Hz which is 0.75. Thus, the results shows that S3 have little absorption coefficient at low and medium frequency but have good absorption coefficient at high frequency.

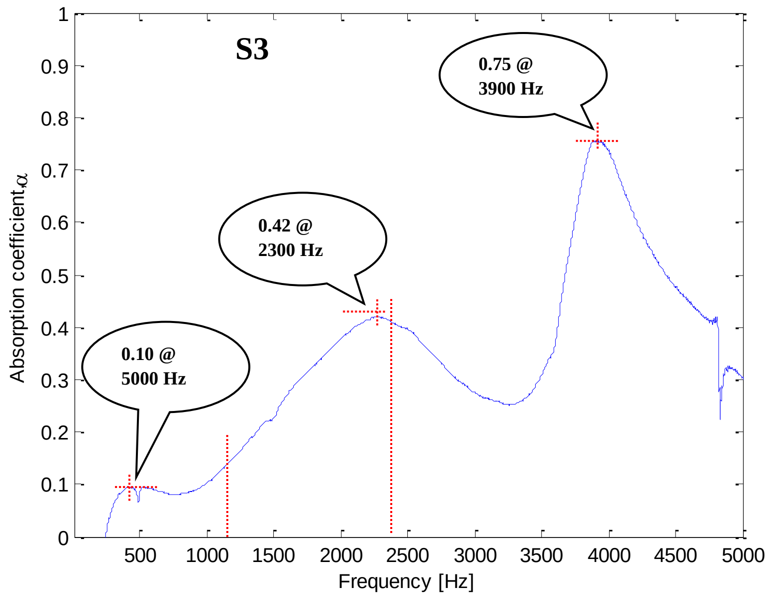


Fig. 15. The graph of absorption coefficient against frequency of S3.

The results in Figure 11 shows that the absorption coefficient of the PU is lower compared to the absorption coefficient of CSM coconut fiber filled with PU. Furthermore, the PU foam and coconut fiber can be clearly seen under SEM. By comparing the SEM image in Figure 9 and 16, the structure of CSM coconut fiber filled PU foam is relatively rigid compared to the CSM coconut fiber without PU foam.

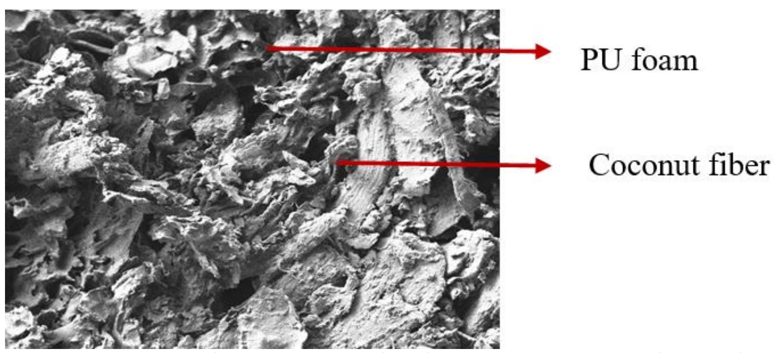


Fig. 16. The SEM image of the CSM coconut fiber filled with PU at the magnification of 100X.

3.4 Sample 4

Figure 17 shows the CSM coconut fiber filled with polyurethane with 3 mm perforated or holes on the surface of the sample 4, (S4). The distance of the holes on the sample surface is constant which is 10 mm. The thickness of the sample is about 6.5 mm. According to authors [13], the micro perforated and air space layer reveals more efficient absorption coefficient towards the sound absorption of multi-layer structure.

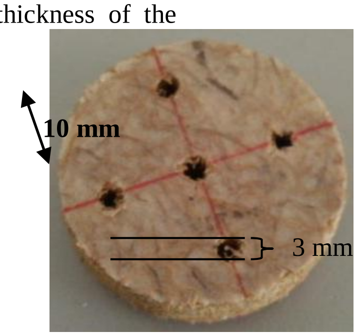


Fig. 17. CSM coconut fiber filled with polyurethane (3 mm).

Therefore, 3 mm perforated sample has been tested in order to analyse the absorption potential of the perforation of the acoustic panel. Besides that, the perforation shape, size of perforation and distribution of the perforation can improve the absorption behaviours of acoustic panel as mentioned by authors [16].

Figure 18 shows the simulation values of sound absorption coefficient when the sample is placed inside of the impedance tube. The absorption coefficient of S4 is 0.49 at range 3500 Hz to 4000 Hz of the frequency. The absorption coefficient is below 0.23 at medium and low frequency. By comparing with the results in S3 the absorption coefficient of S3 is better at low, medium and high frequency compare to the results in S4.

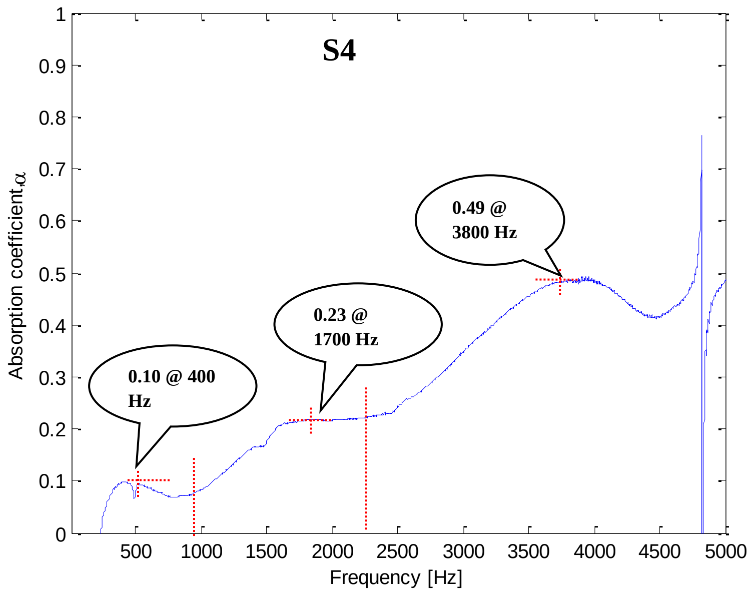


Fig. 18. The graph of absorption coefficient against frequency of S4.

Although, the perforation sample can increase the absorption coefficient of the acoustic panel, however the absorption of S4 is lower compared to S3 due to the reflection occurs during sound wave travels into the sample during testing. This means, some of the sound vibration is absorbed by the sample (S4) and some of the sound vibration is passed through the sample.

In addition, 3 mm of the perforation size of the sample is not effective to be used as the acoustic panel. Since the perforation size also can influence the sound absorption of the sample, thus the single layer of 3 mm perforation of CSM coconut fiber filled with PU foam is not applicable due to the lower absorption value.

3.5 Sample 5

Figure 19 shows the polyurethane foam with 3 mm perforated or holes. The distance between holes is constant which is 10 mm. The thickness of the sample is about 6.5 mm.

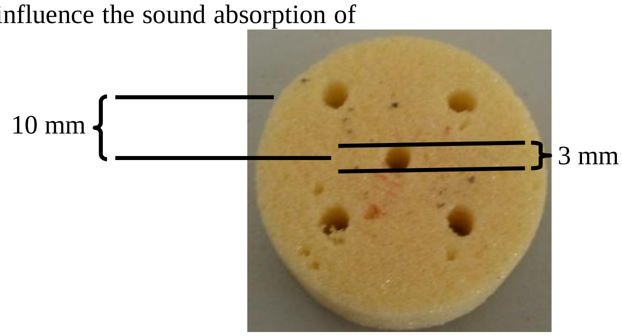


Fig. 19. Polyurethane foam (with 3 mm hole).

Figure 20 shows the simulation values of sound absorption coefficient when the sample is placed inside of the impedance tube. The absorption coefficient between 4500 Hz to 5000 Hz is only 0.29. Moreover, the absorption coefficient is below 0.20 at medium and low frequency.

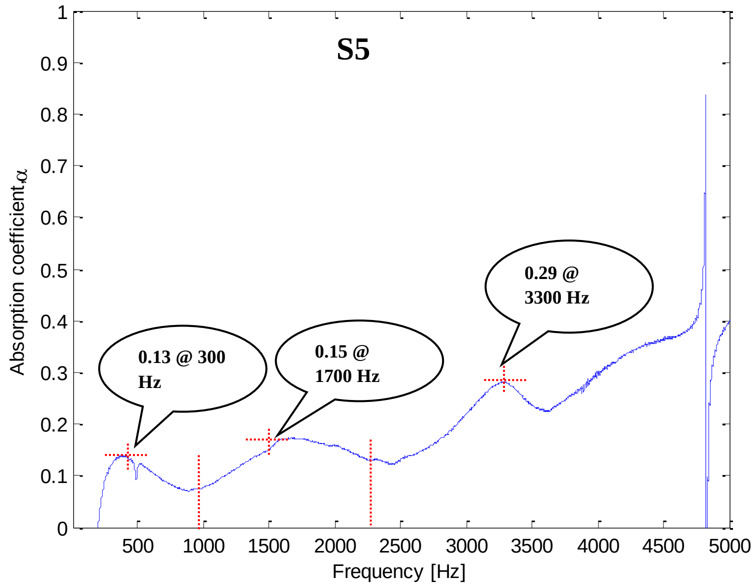


Fig. 20. The graph of absorption coefficient against frequency of S5.

Furthermore, the absorption coefficient of S5 is increased when the percent of the open porosity is increased as suggested by authors [4]. Although the S5 have 3 mm perforation on the sample, however by comparing with the results in Figure 15 and 20, the absorption coefficient of the S3 and S5 samples are almost the same. Both samples have lower absorption coefficient value which is below than 0.5 at low, medium, and high frequency.

3.6 Sample 6

Figure 21 shows the sample of CSM coconut fiber filled with PU with 6mm perforated or holes. The distance between holes is constant which is 10 mm. The thickness of the sample is about 6.5 mm. Since the 3 mm perforation of CSM coconut fiber is not effective to be used as an acoustic panel. Thus, the 6 mm perforation of the acoustic panel has been tested. The results obtained from the impedance tube the testing as shown in Figure 22.

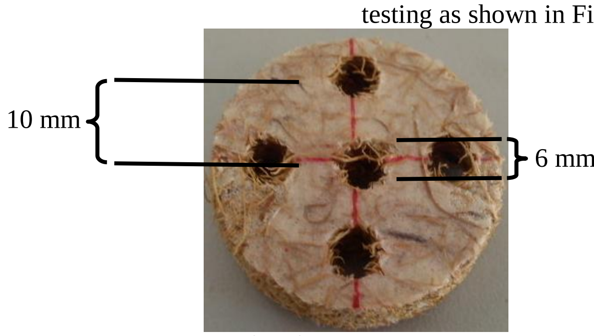


Fig. 21. CSM coconut fiber filled with polyurethane (with hole 6 mm).

Based on Figure 22, the absorption coefficient between 4500 Hz to 5000 Hz is 0.52. Moreover, the absorption coefficient increases progressively starting from 500 Hz until 5000 Hz which is 0.14 at low frequency, 0.27 at medium frequency until 0.52 at high frequency. This shows that the absorption of the sample is relatively low at low and medium frequency.

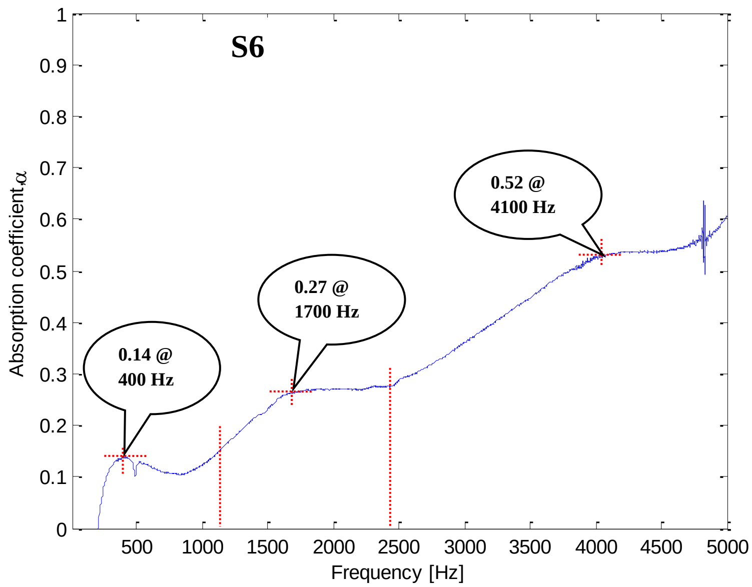


Fig. 22. The graph of absorption coefficient against frequency of S6.

However, the experiment in the research of authors [11] stated that, the porous layer backing can enhance the noise absorption coefficient at low and high frequencies with significant increasing. In addition, by comparing with results of S4 in Figure 18, the absorption coefficient of the S6 shows better absorption potential. This is due to the difference in perforation size of the sample. As a result, the 6 mm perforation size is more effective compared to 3 mm perforation size.

3.7 Sample 7

The sample (S7) used is PU foam with 6 mm perforation and holes. The distance between the holes are constant which is 10 mm. The thickness of the sample is about 6.5 mm.

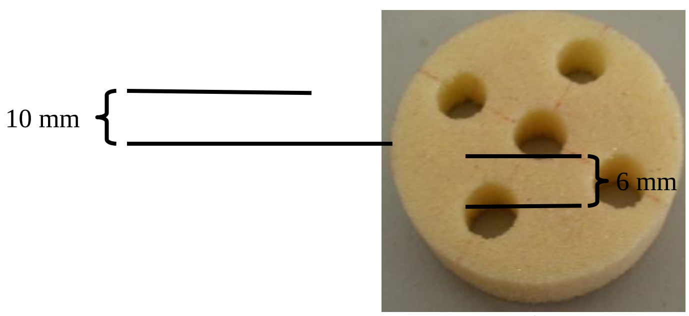


Fig. 23. Polyurethane foam (with hole 6mm).

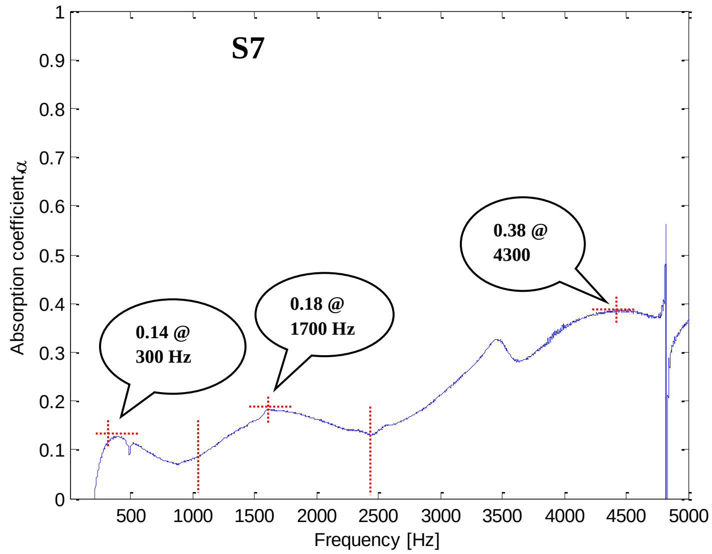


Fig. 24. The graph of absorption coefficient against frequency of S7.

Figure 24 shows the simulation values of sound absorption coefficient when the sample is placed inside of the impedance tube. The absorption coefficient between 4500 Hz to 5000 Hz is 0.57. However, the absorption is not stable due to the rapid decrease of the absorption coefficient at this frequency range. Moreover, the absorption coefficient increases gradually starting from 0.10 to 0.38 at frequency 500 Hz until 4500 Hz. This shows that S7 is not effective to be used as an acoustic panel at low, medium and high frequency.

4.0 CONCLUSION

The present study was designed to determine the sound absorption properties of coconut fiber with and without holes reinforced PU for acoustic applications. The following points emerged from the present investigation:

- S1 have low absorption coefficient at low, medium and high frequency. Meanwhile, the absorption coefficient is less than 0.15 at low frequency which is below 1000 Hz.
- The highest absorption coefficient of S2 is 0.40 which is between 2400 Hz to 5000 Hz. The absorption coefficient at medium and low frequency is slightly low which is 0.20 at medium and 0.10 at low frequency.
- The absorption coefficient between the frequencies of 500 to 2400 Hz is below than 0.42. However, the absorption coefficient is higher at 3900 Hz which is 0.75. Thus, the results shows that S3 have little absorption coefficient at low and medium frequency but have good absorption coefficient at high frequency.
- The absorption coefficient of S4 is 0.49 at range 3500 Hz to 4000 Hz of the frequency. The absorption coefficient is below 0.23 at medium and low frequency.
- The absorption coefficient of S5 is increased when the percent of the open porosity is increased.
- The absorption coefficient of the S6 shows better absorption potential compared to S4. This is due to the difference in perforation size of the sample. 6 mm perforation size is more effective compare to 3 mm perforation size.
- The absorption coefficient of S7 is increase gradually starting from 0.10 until 0.38 at frequency 500 Hz until 4500 Hz. This shows that S7 is not effective to be used as an acoustic panel at low, medium and high frequency.

The evidence from this study suggests that the most suitable sample that can be used as an acoustic panel is S3 which is the CSM coconut fiber filled with PU sample which have 0.75 of the absorption coefficient value between the frequencies of 3500 to 4000 Hz. The findings of this study also suggest that the absorption coefficient of CSM coconut fiber filled with PU without holes shows better perfomance compared to CSM coconut fiber filled with PU with holes 3 mm or 6 mm. This research has thrown up many questions in need of further investigation. Further work need to be done to establish whether the effect of arrangement of the sandwich structure of coconut fiber towards acoustical performance.

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