ACOUSTIC STUDIES OF OIL PALM TRUNK NATURAL FIBRE: EFFECT OF THICKNESS IN DENSITY OF 120 KG/M$^3$, 140 KG/M$^3$, 160 KG/M$^3$ AND 180 KG/M$^3$

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Abstract

In recent years, oil palm is one of the natural fibre being researched and tested to be used as an acoustic absorber. Experiments have been conducted on different parts of oil palm tree such as Empty Fruit Brunch (EFB), Oil Palm Frond (OPF), Oil Palm Trunk (OPT) and so on. This paper specifically discusses the analysis of the OPT fibre as a function of the sound absorber in densities of 120 kg/m$^3$, 140 kg/m$^3$, 160 kg/m$^3$ and 180 kg/m$^3$ with thicknesses of 10 mm, 14 mm and 18 mm. The OPT natural fibres were fabricated using method of Low-Density Fibreboard (LDF). The results show prominent Sound Absorption Coefficient, SAC (α) values for sample with thickness of 10 mm and 14 mm at frequency range of 3500 Hz to 6400 Hz for all densities except for sample with density of 180 kg/m$^3$. As the thickness and density increases, the resonance peak shifted to lower frequency due to lower perforation exist within the sample which decreases the value of the absorption value. In comparison between the density and thickness, optimum and best result were produced by the sample with thickness and density of 14 mm and 120 kg/m$^3$, respectively, where the SAC (α) value is around 0.93 at wide frequency of 3500 Hz to 5500 Hz. Nevertheless, sample density of 180 kg/m$^3$ also exhibits similar behavior but with lower SAC (α) value and the maximum absorption value of 0.50 over the frequency range of 2500 Hz to 6400 Hz for all the thickness.

Keywords: Oil Palm Trunk, Natural Fibre, Thickness, Density, Sound Absorption Coefficient, SAC (α)
I. Introduction

Numerous studies and investigation on natural fibres for sound absorbing material have been done in recent years. Natural fibres exhibit many advantageous properties, they are a low-density material yielding relatively lightweight composites with high specific properties [XIX]. These fibres also have significant cost advantages and ease of processing along with being a highly renewable resource [VIII]. Recent advances in the use of natural fibres in composites have been reviewed by several authors [VI–XXXII]. Natural fibre composites are likely to be more advanced than glass fibre composites as it has lower environmental impacts, provides good thermal and noise insulation as well as having a higher fibre content for equivalent performance, reducing more polluting base polymer content [XXXIII].

Abdul Latif [II] investigated the ability of oil palm mesocarp fibre in sound absorption as the cost required to acquire Mesocarp Fibre (MF) is small. The test sample was prepared with thicknesses of 10 mm, 20 mm, 30 mm and 40 mm as well as shaped cylindrically with a radius of 14 mm to conceal the measurements of high frequency. The sample was also shaped cylindrically with a radius of 50 mm to conceal the measurements of low frequency [II]. The MF has been found to be a great sound-absorbing material with an ideal Sound Absorption Coefficient, SAC (α) of 0.93 at a frequency of 500 Hz for the test sample thickness of 40 mm. Based on the experience, the SAC (α) increases simultaneously with the increase of the thickness, explicitly at the frequency range of 100 Hz to 1000 Hz. Therefore, it can be strongly concluded that the MF is a porous material [XXXII]. Sound energy with lower frequencies is easier to pass through a porous material in comparison to sound energy with higher frequency [VI] which brings to the fact that acoustic energy, in general, can enter porous material more effectively.

Based on the study by Koizumi [XX], the SAC (α) of bamboo fibre has been identified with different criteria of thickness, air gap, diameter, and apparent density. The SAC (α) of the bamboo fibre increases as the thickness increases in every frequency range. In light of the result, clearly, it can be seen that the variation of thickness influences the peak frequency. Lower peak frequency is produced when the bamboo fibre sample thickness increases and based on the outcomes from the experiment, the frequency for peak absorption also decreases with the increase of the thickness of the sample. Therefore, it can be concluded that the increase of the bamboo fibre sample thickness subsequently increases the efficiency of sound absorption at low and medium frequencies.

Research on arengapinnatafibre was conducted systematically by Ismail [XIV] and presented the scientific data of the SAC (α) in a precise manner. Each sample is prepared in different thicknesses of 10 mm, 20 mm, 30 mm and 40 mm individually. It can be very well seen that the arengapinnata shows a very promising result of SAC (α). It is also proven that when the thickness of the arengapinnatafibre increases, the SAC (α) will also increase simultaneously. The thickness increase causes the space available that is the cross-section area of the material is big that makes more sound energy to be absorbed [I]. The outcome of this experiment shows that the sample
thickness of 40 mm has its best SAC ($\alpha$) value where the optimum SAC ($\alpha$) occurred at high frequency is 0.88.

Work carried out by Lim [XXII] on properties of sound absorption on the Kenaf Fibre (KF) has resulted that it has an enormous potential to be utilized as an acoustic panel material. To acquire the SAC ($\alpha$) of the KF fibre, with a sample thickness of 10 mm, 20 mm and 30 mm, the Impedance Tube Method (ITM) has been utilized. The KF fibre sample with a thickness of 10 mm shows that the SAC ($\alpha$) value is greater than 0.5 when the frequency is over 3500 Hz. On the other hand, the KF fibre sample with a thickness of 30 mm also shows that the SAC ($\alpha$) value is greater than 0.5 but with a frequency level of over 1000 Hz. This sample also exhibits SAC ($\alpha$) which is near equivalent to unity at the frequency level of about 2000 Hz. It is more prominent than the increase of thickness of the KF fibre sample influences the SAC ($\alpha$) level to be greater based on the experiment results obtained on lower frequencies.

The availability of Oil Palm Trunk (OPT) is abundant throughout Malaysia and it is also known to be the less expensive raw material that can be used to supply and produce potential value-added products [XXIX]. Some of the examples of the potential value-added products are particleboard, laminated board, fibreboard and plywood [XXIX]. Most natural fibre contains cellulose which provides high specific properties such as impact resistance, flexibility and modulus that make it useful material [I – XXX]. Researchers and studies about sound absorbers or insulation are rapidly developing to achieve the maximum effect of sound attenuation. The abundance, weightless, and biodegradable makes natural fibres an attractive material to be considered for sound absorbers. In addition, no research has been found that studied about the potential of OPT on sound absorbing material. Therefore, this research focused on producing acoustic absorber using OPT and the effect of different thickness in density of 120 kg/m$^3$, 140 kg/m$^3$, 160 kg/m$^3$ and 180 kg/m$^3$.

II. Methodology

The OPT Fibreboard were prepared using the method of fabrication of Low-Density Fibreboard (LDP) as shown in Fig 1. The fabrication involves chipping process, refining process, glue blending process, mat forming process, pre-pressing process and hot-pressing process [XVIII – XVII]. To test and measure the moisture content of the fibre, Mettler Toledo HB 43 Halogen was utilized.

1. Chipping Process – OPT were cut and chipped into small pieces using Laboratory Maier Chipper. Then it was dried up to 100 °C in an oven to reach 10 % of the moisture content [XVIII – XVII].

2. Refining Process – Chipped OPT were converted to cottonized fibre using Sprout-Bauer (ANDRITZ) refiner. Then it was dried up until the moisture content reached 4 % – 5 %.

3. Glue Blending Process – Cottonized fibre were mixed with UF glue based on calculated proportions for homogeneous mixing.

4. Mat Forming Process – Samples were formed into three different thicknesses of 10 mm, 14 mm and 18 mm with four different density of 120 kg/m$^3$, 140 kg/m$^3$, 160 kg/m$^3$ and 180 kg/m$^3$. 

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160 kg/m$^3$ and 180 kg/m$^3$, using a wooden former with the dimension of 300 mm × 300 mm.

5. Pre-Pressed Process – The mixture was manually shaken and formed to ensure sufficient compactness and evenness distribution of OPT fibre inside the wooden former.

6. Hot Pressed Process – Pressure machine was heated up to a temperature of 200 °C. Once the desired temperature is reached, the mat was consolidated at 160 kg/cm$^2$ for 300 seconds.

The SAC (α), is a dimensionless number between zero (0.0) and one (1.0), used to characterize the quality of the absorption level of a surface as well as to evaluate the proportion of incident sound energy which is not returning to the room in the form of a reflection [XIV]. For example, a marble with SAC (α) of 0.25, reflects 75 % of the sound energy impinging upon it and only 25 % is absorbed or transmitted through the absorbing material [XIII]. OPTFibreboard were tested using impedance tube method as shown in Fig 2. The samples were cut into 30 mm diameters and placed within the B&K tube from the frequency range of 0 Hz to 6400 Hz.

![Fig. 1: Oil palm trunk sample preparation [XIII – XIV]](image-url)
III. Result and Discussion

From Fig 3 (a), it can be seen that apart from sample with density of 180 kg/m³, all samples have a very consistent trend of SAC (α) value throughout the frequency. The acoustic absorption rate almost increases in a persistent way as the frequency increases from 0 Hz to 6400 Hz. It is noteworthy that, the maximum SAC (α) values of 0.91, 0.90 and 0.89 have been found for samples with density of 120 kg/m³, 140 kg/m³ and 160 kg/m³ at wide frequency range of 3500 Hz to 6400 Hz. On the other hand, the SAC (α) values are found higher than 0.8 for all samples except for sample with density of 180 kg/m³ at frequency range of 3500 Hz to 6400 Hz. Nevertheless, sample with density of 180 kg/m³ exhibits similar behavior but with a lower SAC (α) value. A drastic hike in the absorption level from 0.54 to 0.70 over the frequency range of 3000 Hz to 3500 Hz for sample with density of 180 kg/m³. Even so, the SAC (α) value is found to decrease after 3500 Hz to 0.62 and increase again at a slow pace. At 6400 Hz, this sample reaches absorption value of 0.64. As density increase, the amount of fibre used in the sample also increases. This causes improper dissipation of sound through the fibre[VII –XXIV].

![Fig. 3(a): SAC (α) value vs. applied frequency (Hz) in four different density with thickness of 10 mm](image_url)
Similar behavior can be seen for sample with thickness of 12 mm and density of 180 kg/m$^3$ as shown in Fig 3 (b) where all samples show the SAC ($\alpha$) value above 0.8 at wide frequency range of 3500 Hz to 6400 Hz except for sample with density of 180 kg/m$^3$. Sample with density of 140 kg/m$^3$ and 160 kg/m$^3$ show a good correlation level between the sound absorption level and frequency applied. On the other hand, samples with density of 180 kg/m$^3$ shows an irregular rising in the absorption rate. For example, sample with density of 180 kg/m$^3$ shows the most changes of ups and downs in the trend of the graph at the frequency of 1500 Hz, 2000 Hz, and 2500 Hz respectively. It can also be seen that the absorption level of the OPT Fibreboard result at mid-frequency range from 1500 Hz to 3000 Hz is still lacking. However, the sample is able to exhibit a good and constant SAC ($\alpha$) at high-frequency range.

Fig. 3(b): SAC ($\alpha$) value vs. applied frequency (Hz) in four different density with thickness of 14 mm

Based on Fig 3 (c) all the samples have identical inclination throughout the SAC testing. Samples with density of 120 kg/m$^3$, 140 kg/m$^3$ and 160 kg/m$^3$ have a specific drop at frequency of 1500 Hz. However, they decreased somewhat at this frequency of 1500 Hz and increased again with the rise of the frequency. These three samples reached the peak frequency of 6400 Hz at almost same SAC ($\alpha$) value of $\alpha = 0.86$, $\alpha = 0.83$ and $\alpha = 0.83$, respectively. Yet, sample with density of 180 kg/m$^3$ has a different point of inflexion correlated to the other samples with thickness of 18 mm.

Fig. 3(c): SAC ($\alpha$) value vs. applied frequency (Hz) in four different density with thickness of 18 mm
Based on Fig 3 (a) to (c), it can be concluded that sample with thickness of 10 mm possesses the optimum SAC value in comparison to others. Almost all sample has a consistent trend throughout the applied frequency apart from the sample with density of 180 kg/m$^3$. The acoustic absorption rate increases in a persistent way as the frequency increases from 0 Hz to 6400 Hz. However, sample with density of 180 kg/m$^3$ fluctuate the most throughout the frequency range in thickness of 10 mm, 14 mm and 18 mm. Theoretically, the increase of density causing a decrease in SAC ($\alpha$) value due to the more compactness of the fibre during sample preparation. Different thickness sample would result in different tortuosity within the sample and therefore impacts the sound absorption level. Moreover, the sample thickness decreases during the cooling process attributed to the fibre rebound effects [XXVI]. Decrease in thickness will cause a decrease in absorption rate and follow by reducing the tortuous path [XXXI]. This proves that thickness has a significant influence on the topological characteristics of the pore structure of the OPT sample.

Withal, increased thickness improves the sound absorption according to the absorption phenomena within a porous material. This is due to a long dissipative process of viscosity and thermal conduction between the air and absorbing material inside the composite improves the absorption [XXV]. Doubling the sample layer of thickness encompasses a significant effect in improving the sound absorption of the porous material at the low-frequency region, while there is an immaterial impact at the higher frequency range [XII]. In this way, progressively stable sound energies are devoured during the process of being changed over into heat and improving sound absorption properties [II – XV] as the density increases.

The flow resistance within the samples becomes more robust and the inner voids begin to be smaller as the sound waves are being absorbed in the low and mid-range frequencies. Nonetheless, with more prominent density and lesser pores within the sample, a huge division of the sound wave was reflected which likewise prompts a lack of sound absorption [XXVIII]. High-frequency acoustic waves are easily absorbed on the surface of the sample. Hence increase in density weakens the ability of the sound absorption properties at high frequencies.

Generally, denser structure gave lower SAC ($\alpha$) value from mid to high-frequency range but tends to increase at the low frequency. At the same time, all samples display healthier quality of acoustic properties at higher frequencies [XXIII –XXIII]. The expansion in density broadens the way of the sound waves taken to travel from within the sample as it accelerated the friction [XVIII]. This is because when density increase, the percentage of porosity decreases and therefore it shows a lesser sound absorption rate. Excessive usage of material attributable to a more compacted test specimen. This reduces the ability of acoustic absorption in the sample.
Fig. 4: SAC ($\alpha$) value vs. applied frequency (Hz) in three different thickness with density of 120 kg/m$^3$.

Fig 4 shows the samples with density of 120 kg/m$^3$ in thickness of 10 mm, 14 mm and 18 mm. This density shows the most absorption rate in comparison to others. Based on Fig 4, all the samples show a resonance peak between frequencies of 1500 Hz to 3500 Hz. It has been found that decreasing in thickness may shift the resonance peak to higher frequency. This is because more perforation exists within the sample which improves the absorption coefficient [XXIII].

The sample with thickness of 14 mm possess the highest SAC ($\alpha$) value of 0.93 at the frequency range of 3500 Hz to 6500 Hz, followed by sample with thickness of 10 mm with SAC ($\alpha$) value of 0.91 and sample with thickness of 18 mm with SAC ($\alpha$) value of 0.86. All the OPT samples possess similar characteristics at low frequency beginning from 0 Hz to 1500 Hz where the acoustic absorption increases with increase in frequency.

On the other hand, the graph exhibits a different trend in the high-frequency range with few highs and lows [III]. Each sample has some dip between the mid-range frequency bands. For example, the sample of 18 mm thickness have a dip at the frequency of 2500 Hz and 1500 Hz, respectively. The root cause of this dip is due to sample irregularity which may have occurred during the preparation of the OPT Fibreboard. Overall, all the OPT sample shows significant absorption behavior where the SAC values are found above 0.7 at wide frequency range of 2500 – 6400 Hz.

Density impacts the acoustic impedance due to the impedance that defines the reflection of materials [V]. For low density, the tortuosity effects can enhance the absorption value. Whereas for high density, tortuosity effects will cause more reflection in the sound wave if compare to absorption. A high-density material has a bigger surface area per unit volume as well as it is efficient in absorbing sound engrossing partner with fibre that consists of porous material [XXI]. The bigger the surface is with the increase of fibre, the more energy loss because of high friction within the fibre resulting in a higher number of incident waves being changed over to heat energy [XXVII].
V. Conclusion

This paper has proven that Oil Palm Trunk (OPT) is a very effective natural fibre that can be used as a substitute material for fiberglass board and mineral glass wool in the market. Particularly, the sample with density of 120 kg/m$^3$ in thickness of 10 mm has almost directly proportional rate of change SAC $\alpha$ value with the frequency range. The highest SAC $\alpha$ value of 0.93 was achieved at frequency range of 3500 Hz to 6400 Hz by the sample with density of 120 kg/m$^3$ in thickness of 14 mm. This value represents that 93% of the sound energy absorbed by the OPT Fibreboard sample and only 7% of the sound energy were reflected back. This shows that the OPT sample can be categorized as class A material as the absorption rate are above 0.8 [IV].

Withal, the increased thickness may improve the sound absorption according to the absorption phenomena inside a permeable material. This is because a long dissipative phase of viscosity and thermal conduction between the air and absorbing material from inside the composite strengthened the absorption [XXV]. In a nutshell, OPT can be proposed to be an alternative material of the synthetic made fiberglass for the betterment of future.

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