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Sound-Absorbing Material Based Oil Palm Frond Natural Fibres

(Serat Asli Pelepah Kelapa Sawit Berasaskan Bahan Penyerap Bunyi)

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ABSTRACT

Effective noise control is vital for improving living standards, but traditional sound absorbers pose health risks. Natural fibers offer a sustainable alternative, with consistent absorption rates across a broad frequency range. These fibers, widely available in Malaysia, are non-toxic, lightweight, renewable, and eco-friendly, making them an attractive option. The safety benefits of natural fibers further enhance their appeal as sound absorbers, making them an excellent choice for those concerned about environmental impact and personal health. This study will examine the effect of different thicknesses on the acoustic performance of natural fibers from oil palm fronds (OPF). The findings demonstrate that, when material density is 160 kg/m^3, all thicknesses can achieve a good Sound Absorption Coefficient (SAC) of 0.8 or greater within 3600 - 6400 Hz range. However, at 180 kg/m^3 density, only the 10 mm thickness sample has SAC of 0.8 or greater, but for 2800 - 6400 Hz range. It is worth noting that, across 0 - 6400 Hz, 10 mm thick and 180 kg/m^3 density sample has higher SAC than 160 kg/m^3 samples. Nevertheless, for 12 mm, 14 mm, and 16 mm thicknesses, SAC of 160 kg/m^3 is higher than 180 kg/m^3 after an interception point. Before that interception point, SAC of 160 kg/m^3 is lower than 180 kg/m^3. As thickness increases from 12 mm to 16 mm, the interception point decreases from 2100 Hz to 1600 Hz. The research demonstrates that various factors, such as frequency, density, thickness, and fiber structure, impact the acoustic performance of OPF LDF.

Keywords: Density; oil palm frond (OPF); sound absorption coefficient (SAC); thickness

ABSTRAK

Kawalan bunyi yang berkesan adalah penting untuk meningkatkan tahap kehidupan, tetapi penyerap bunyi tradisional mempunyai risiko kesihatan. Serat semula jadi menawarkan alternatif yang mampan dengan kadar penyerapan yang tekal merentasi pelbagai julat frekuensi. Serat ini, yang melimpah di Malaysia, tidak toksik, ringan, boleh diperbaharui dan mesra alam, menjadikannya pilihan yang menarik. Manfaat keselamatan serat semula jadi lebih menambah daya tarikan mereka sebagai penyerap bunyi, menjadikannya pilihan yang sangat baik bagi mereka yang prihatin tentang impak alam sekitar dan kesihatan diri. Penyelidikan ini mengkaji kesan ketebalan yang berbeza pada prestasi akustik serat semula jadi daripada pelepah kelapa sawit (OPF). Hasil kajian menunjukkan bahawa, apabila ketumpatan bahan adalah 160 kg/m^3, semua ketebalan dapat mencapai Koefisien Penyerapan Bunyi (SAC) yang baik iaitu 0.8 atau lebih dalam julat frekuensi 3600 - 6400 Hz. Walau bagaimanapun, pada ketumpatan 180 kg/m^3, hanya sampel ketebalan 10 mm yang mempunyai SAC 0.8 atau lebih, tetapi untuk julat frekuensi 2800 - 6400 Hz. Perlu dicatat bahawa, merentasi julat 0 - 6400 Hz, sampel ketebalan 10 mm dan ketumpatan 180 kg/m^3 mempunyai nilai SAC yang lebih tinggi daripada sampel 160 kg/m^3. Namun begitu, untuk ketebalan 12 mm, 14 mm dan 16 mm, nilai SAC 160 kg/m^3 lebih tinggi daripada 180 kg/m^3 selepas titik intersepsi. Sebelum titik intersepsi itu, nilai SAC 160 kg/m^3 lebih rendah daripada 180 kg/m^3. Apabila ketebalan meningkat daripada 12 mm ke 16 mm, titik intersepsi berkurangan daripada 2100 Hz kepada 1600 Hz. Kajian ini menunjukkan bahawa pelbagai faktor, seperti frekuensi, ketumpatan, ketebalan dan struktur serat, mempengaruhi prestasi akustik OPF LDF.

Kata kunci: Ketebalan; ketumpatan; koefisien penyerapan bunyi (SAC); pelepah kelapa sawit (OPF)

INTRODUCTION

Sound pollution refers to unwanted or excessive levels of noise in an environment. It can have negative effects on human health and well-being, including stress, sleep disturbance, and hearing loss. To reduce the sound pollution, one of the solutions is by introducing sound barriers or sound absorbing materials. This is where oil palm tree waste comes in, it is a sound absorbing material known for its sustainability, cost effectiveness, environmentally friendliness, good acoustic properties, and versatility (Ong et al. 2020).

The oil palm industry is often recognized as the foremost generator of renewable biomass sources, including empty fruit bunches (EFB), mesocarp fiber, palm shell, oil palm fronds (OPF), and oil palm trunks (Loh 2017). Malaysia had 451 operational palm oil mills in 2021, with a collective capacity to process 115.87 million tonnes of fresh fruit bunches (FFB) per year. The majority of these mills (52.50%) were located in Peninsular Malaysia and had a combined capacity of 57.50 million tonnes (Ghulam Kadir et al. 2022). As a result of Malaysia's oil palm industry, a substantial amount of waste is produced, including EFB, OPF, and palm kernel shells. These wastes can cause a number of environmental and social problems if they are not managed properly. If oil palm waste is not properly disposed of, it can release pollutants into the environment, including methane and other greenhouse gases. This can contribute to air pollution and climate change. The accumulation of oil palm waste can also take up valuable landfill space, leading to a shortage of space for the proper disposal of other types of waste. The improper disposal of oil palm waste can harm the environment by polluting soil and water. It can also harm wildlife by destroying their habitats through burning, leading to a decrease in the variety of species, cause social problems such as forced relocation of communities, and loss of jobs (Qaim et al. 2020).

OPF are the large, green leaves of the oil palm tree. They are a natural waste product of the oil palm industry and are often discarded or burned. However, these fronds contain natural fibers that can be extracted and used for a variety of purposes. The fibers are strong and durable, and can be used to make products such as paper, textiles, and building materials. OPF are recognized for their significant content of lignocellulose, which is the intricate mixture of lignin, cellulose, and hemicellulose that composes the plant cell walls. As a byproduct of the oil palm sector, OPF have a high concentration of lignocellulosic material, which presents a potential opportunity for utilizing them as a valuable source of biomass to produce biofuels and various other bioproducts. They can also be used as a bioenergy source. The use of OPF fibers as a resource can help to reduce waste and provide an alternative to using synthetic or non-renewable materials.

OPF fibers have been shown to have good sound absorbing properties and can be used as a natural alternative to synthetic materials in soundproofing applications (Nair & Dasari 2022). The fibers are able to absorb sound waves due to their porous structure, which allows them to effectively trap and dissipate the energy of the sound waves. In addition, the fibers have a high density and are able to absorb a wide range of frequencies, making them effective at reducing noise in a variety of different environments.

There are a number of ways that OPF fibers can be used as a sound absorbing material. They can be incorporated into acoustic panels or ceiling tiles, for example, or used to make insulation for walls and floors. They can also be used to make sound absorbing rugs or carpets. In addition to their sound absorbing properties, OPF fibers are also biodegradable and environmentally friendly, making them a sustainable choice for soundproofing applications.

This research focus on utilizing oil palm fibers for creating composite panels, and studying their properties such as acoustics, mechanics, and water susceptibility (including warm water analysis) to determine their potential for further exploration. The results indicate that the presence of fibers has a positive impact on the acoustic absorption coefficient in the mid-frequency range of 1000-3000 Hz. Additionally, the noise reduction coefficient values for the octave band are more than 50% higher in the presence of fibers compared to traditional refractory boards. The composite panels developed in this research have also shown excellent performance in quasistatic indentation and drop-weight tests (Sihabut & Laemsak 2010). The research found that materials made by combining OPF and EFB with thicknesses of 16 mm and 18 mm had a high sound absorption coefficient (SAC) above 0.8 across the frequency range of 2500 Hz to 6400 Hz (Mageswaran et al. 2019). In addition, the study tested wood fiber boards with varying densities from 200 to 800 kg/m^3 for their SAC at multiple frequencies from 125 Hz to 4000 Hz. The findings indicated that the sound absorption qualities of the lower-density fiber board were comparable to those of acoustic panels available on the market, such as wood wool building slabs/boards and low-density particle boards (Nandanwar, Kiran &

Varadarajulu 2017). A research investigation into the sound-absorbing capabilities of various combinations of OPF and EFB in four thicknesses shows that the SAC value rises as the frequency increases for all samples analyzed. Positive SAC results were obtained for both mixing ratios tested. It is worth noting that SAC values for both ratios increased with greater thickness, likely due to the influence of tortuosity. Additionally, SAC values of all samples attained unity (~0.96) at different frequency ranges. Furthermore, the research found that increasing the content of OPF expanded the frequency range in which the SAC was 0.8 or higher, from 4500 - 6400 Hz to 3500 - 6400 Hz (Mageswaran et al. 2021). A separate study discovered that 100% OPF did not attain a SAC of 0.9 within the frequency range of 0-6400 Hz. The absorption coefficient (SAC) of a material indicates how much of the sound energy is absorbed, reflected, or transmitted. A material with a high absorption coefficient across a wide range of frequencies is preferred for reducing overall noise levels because it absorbs a greater proportion of the sound energy across the frequency spectrum. In contrast, materials that only absorb sound at certain frequencies can create resonance, where certain frequencies become amplified instead of reduced, because the material absorbs sound at some frequencies but reflects or transmits it at others. Therefore, it is important to use materials that can absorb sound effectively over wide range of frequencies to reduce noise levels without amplifying specific frequencies.

However, it has been found that jute has the potential to improve its acoustic performance over a broader range of frequencies (Nasir et al. 2021). Jute fibers contain numerous small openings or gaps between fibers that allows sound to penetrate and become trapped within. Thus, it is able to lower the amount of sound reflected back into a room. Jute fiber, which is rich in cellulose, has a naturally occurring organic substance and strong sound-absorbing abilities to convert sound energy into heat energy. These traits make jute an excellent material for soundproofing and enhancing acoustics (Shen, Li & Yan 2021). The porous structure and high cellulose content of jute fibers make it effective in reducing unwanted noise and echo, thereby improving the sound quality and overall acoustic performance of a space. Whereas, the composition of oil palm fiber, which may include substances that can impact its ability to absorb sound, such as oils or resins, may reduce its sound-absorbing properties. These elements in the chemical composition of the fiber can decrease its capability to absorb sound waves. In addition, the oil palm fiber may be thicker than other natural fibers, which can negatively impact its effectiveness in trapping and absorbing sound waves. Oil palm frond natural fibers are equipped with inherent physical structures such as microfibrils, lumens, cell walls, pores, and fiber length, which provide mechanical strength, structural support, enable sound wave dissipation, allow for air to pass through and increase the surface area of interaction with sound waves, all of which enhance their sound absorption ability (Abdul et al. 2012). The study investigated the sound absorption performance of particleboards made from oil palm frond (OPF) fibers and urea-formaldehyde adhesive. The results showed that when the bulk density of the OPF composite particleboards ranged between 0.3-0.4 g/cm3 and the particle size varied between medium to coarse, the absorption coefficient of normal incidence sound exceeded 0.45 at 1000 Hz and could reach 0.95 above 3.3 kHz. Additionally, the absorption frequency and degree of absorption significantly increased as the bulk density decreased. Based on these findings, OPF fibers can be utilized to create sound-absorbing composite particleboards (Istana et al. 2023).

The connection between density, frequency, and SAC in natural fibers can be intricated and may be affected by other factors such as material composition and thickness. To delve deeper and gain a more comprehensive understanding of the properties and characteristics of this fiber, further research and experimentation is needed. Moreover, no previous research has been conducted on this topic, therefore this research holds a significant value. Hence, the study on acoustic performance of 100% OPF natural fibers at varying thicknesses and densities can gain a more thorough insight into this natural fiber.

MATERIALS AND METHODS

The low density fibreboards (LDF) was fabricated at the Research Station MPOB located in Pekan Bangi Lama, Kajang. This study created 8 low density fibreboards (LDF) from OPF natural fibers with varying densities (160 kg/m^3 and 180 kg/m^3) and thicknesses (10 mm, 12 mm, 14 mm and 16 mm) as shown in Figure 1.

The fibers were blended together using E1 grade Urea Formaldehyde adhesive. E1 grade UF glue provides a range of advantages, including its low formaldehyde emission, strong bonding, cost-effectiveness, versatility, and ease of use. It offers a safe and environmentally

FIGURE 1. Final product left to cool down at room temperature

friendly adhesive option for indoor use, while providing a durable bond between materials. The mass and moisture content of the natural fibers were determined through the use of a pre-set excel sheet developed by Malaysian Palm Oil Board (MPOB), in order to attain the intended mixing ratio, density, and thickness.

The OPF natural fibers were chipped into smaller pieces using the Maier Chipper Machine and oven-dried at 100 °C for five days to achieve a moisture content of 10%. The OPF chips were then refined using the Sprout-Bauer (ANDRITZ) machine, subjected to preheating time and precise pressure to obtain high-quality conttonized fiber. The pressure of 6 bar of steam and heating time of 5 min were set to ensure consistency among all fiberboards. After the refining process, the OPF natural fibers were oven-dried to achieve a moisture content of 4% to 5% and then mixed with UF glue to achieve the desired density and thickness. The UF glue used was E1 type, which has an emission discharge level of less than 0.01 ppm. The mixture was blended in a mechanical blender to achieve a perfect mix ratio. The mixture was placed into a wooden mold box with dimensions of 30 cm × 30 cm to achieve the desired density and thickness. A fork-like tool was used to remove the stack layered and shape the fiberboard by hand. The fiberboard mixture was then compressed even further using a metal plate flattener to avoid destroying the fiber during the pre-press process. The wooden box was removed after the pre-press process. The fiberboards were then placed in a hot press machine with a temperature set to 200 °C. A metal plate was placed on top and bottom of the fiber to avoid burning, and the fibres were amalgamated at the desired density (160 kg/m^3 and 180 kg/m^3) for 5 min. The fiber panels were pressurized until they reached the desired thickness of 10 mm, 12 mm, 14 mm, and 16 mm. Finally, the fiberboards were cooled down at room temperature once removed from the hot press machine as illustrated in the flowchart shown in Figure 2.

The sound-absorbing capabilities were assessed by measuring the SAC through the use of the Impedance Tube Method (ITM) (B & K Tube Type 4206). ITM is a well-established and widely adopted testing technique that utilizes an acoustic impedance tube to evaluate the acoustic characteristics of materials. The B & K Tube Type 4206 is a popular impedance tube that conforms to multiple industry standards, including ISO 10534-2 and ASTM E2611. To enhance the precision and reliability of the collected data, two LDFs measuring 30 mm each have been cut and evaluated for their acoustic performance using the Impedance Tube Method, for every density and thickness combination.

The 30 mm diameter impedance tube offers advantages in capturing and reproducing higher frequencies with improved clarity and focused sound

FIGURE 2. The flowchart of samples' procedure

projection. It minimizes interference and enhances audio quality within the range of 500 Hz to 6.4 kHz. However, it is limited in handling low-frequency signals. On the other hand, the 100 mm diameter impedance tube excels in accurately measuring and analyzing low-frequency signals, reducing reflections and improving impedance matching. It is specifically designed for the lower frequency range but may not provide the same level of fidelity for higher frequencies. This research focuses on measuring acoustic performance in the higher frequency range using a 30 mm diameter impedance tube. This choice is driven by the direct relevance of these frequencies, which typically range from 500 Hz to 6.4 kHz, to human hearing. These frequencies encompass vital sounds such as speech, music, and various environmental sounds that play a significant role in our perception and communication abilities.

The sample, which was cut to a diameter of 30 mm dimensions, was tested using a two-microphone transfer function method based on the ASTM E1050-2 for sound absorption coefficient. The amplitude of the incident and reflected energy waves were measured by a microphone probe at the end of the setup, which allowed for the determination of nodes and antinodes amplitude pressure. The B&K Tube Type 4206 apparatus was used as it is equipped with a piston backplate that can be withdrawn to produce an air gap, which is known to increase the acoustic performance of materials. The apparatus is designed to measure normal incidence parameters, making it a fast and accurate tool for measuring sound absorption coefficients, and can cover a large frequency range achieved using tubes of various diameters and microphone spacings. The setup of the B&K Tube Type 4206 apparatus and the properties of measurement using this apparatus are shown in Figure 3. Only a small portion of the OPF samples with a diameter of 30 mm are required for sound absorption testing. To achieve this, all OPF fibreboards were cut to the same diameter using a mold. The results and data were accurately recorded in Microsoft Excel to facilitate further analysis.

RESULTS AND DISCUSSION

Natural fibers have gained attention for their potential as sound-absorbing materials in recent years, as they are viewed as cost-effective and environmentally friendly options. One type of natural fiber, which has garnered interest, is OPF fibers as they demonstrate potential for sound absorption. In this section, we will present the results of our study, which explores the SAC of OPF fibers at varying densities and thicknesses through experimental methods.

Figure 4 illustrates the acoustic performance of OPF natural fibers at various densities and thicknesses, namely 160 kg/m^3 and thicknesses of 10 mm, 12 mm, 14 mm, and 16 mm. In general, the SAC displays an increasing pattern as the frequency range goes up from 500 to 6400 Hz. The SAC value at 0 Hz is assumed to be zero since sound wave oscillation is absent at this frequency. By including this reference point, a more comprehensive understanding of the material's absorption characteristics can be obtained, further reinforcing the notion that sound absorption is negligible or non-existent at 0 Hz. This reference point serves to highlight the lack of meaningful sound waves and their subsequent absorption, allowing for a more thorough analysis of the material's behavior across the frequency spectrum.

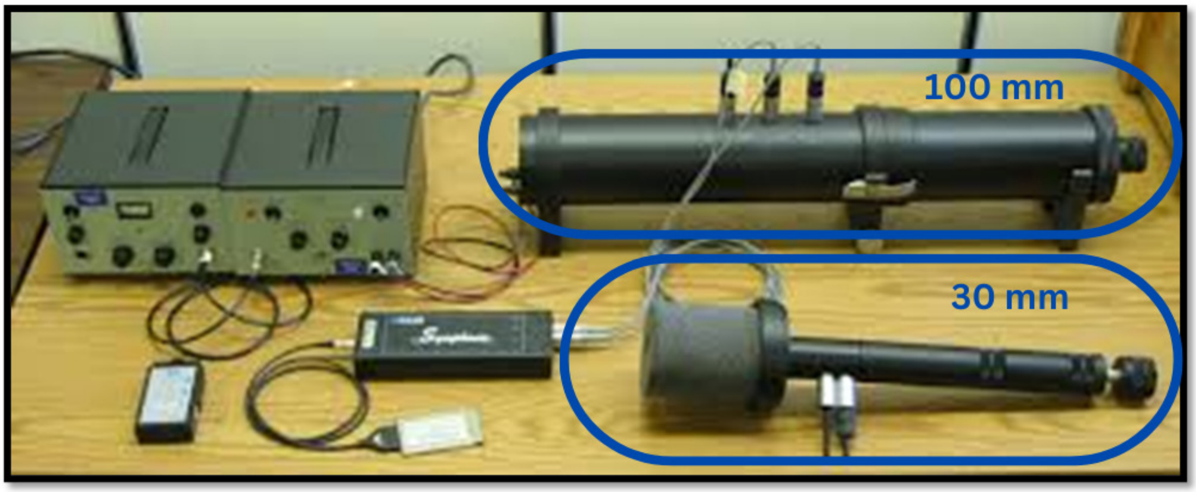


FIGURE 3. Setup of B&K Tube Type 4206

With the exception of the 10 mm thickness sample, all samples exhibited favorable acoustic behavior (SAC > 0.8) between the frequency range of 2400 - 6400 Hz. The thickness of the material was found to have an impact on acoustic performance. By examining Figure 2, it is evident that the SAC increases with decreasing thickness, with the exception of the 10 mm sample. Interestingly, the acoustic performance is found to be opposite for frequencies below 3000 Hz, where the SAC values increase with increasing thickness in general. Similar results can be seen in a new type of wool absorption board, where increasing the board's thickness led to a rise in SAC at low frequencies, with fluctuations at high frequencies. Initially, increasing the board's density had a negligible impact on the SAC, but these coefficients improved at higher frequencies (Hua & Yang 2018). A subtle decrease in acoustic performance can be observed for samples with thicknesses of 12 mm, 14 mm, and 16 mm within the frequency range of 3000 - 6400 Hz. However, the SAC for the sample with a thickness of 10 mm continues to increase and reaches a maximum value of 0.93 at 6400 Hz. According to the sound absorption class calculated in compliance with BS EN ISO 11654:1997, all of the samples demonstrated acoustic performance (SAC > 0.8) above 3600 Hz and were rated as A and B materials referring to the diagram in Figure 5.

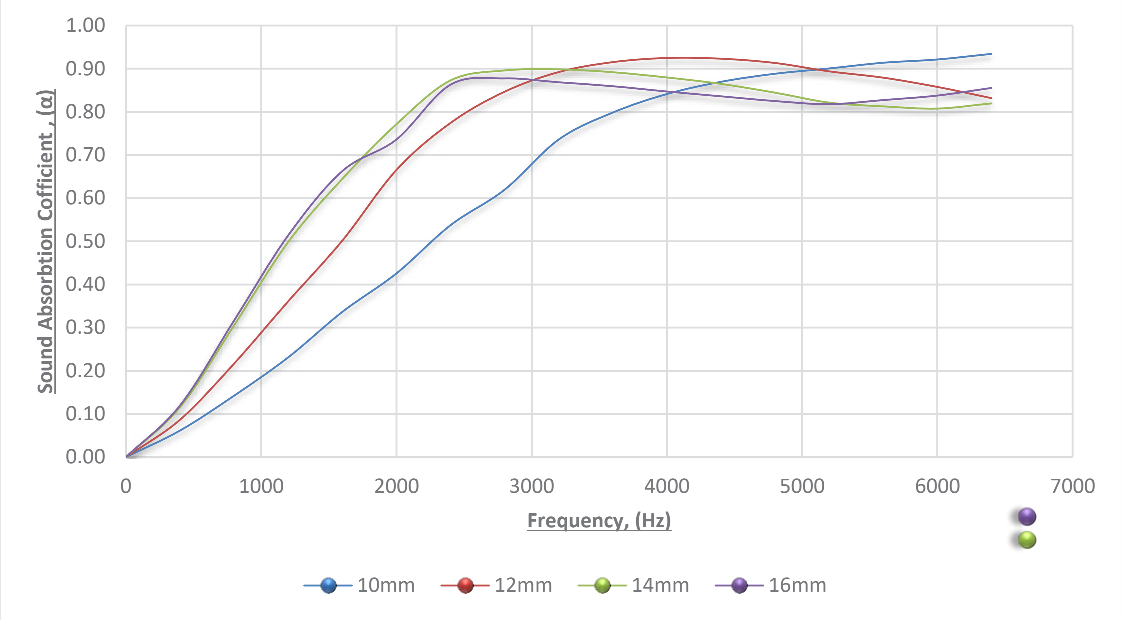


FIGURE 4. SAC, α values versus frequency (Hz) at 160 kg/m³ in different thickness

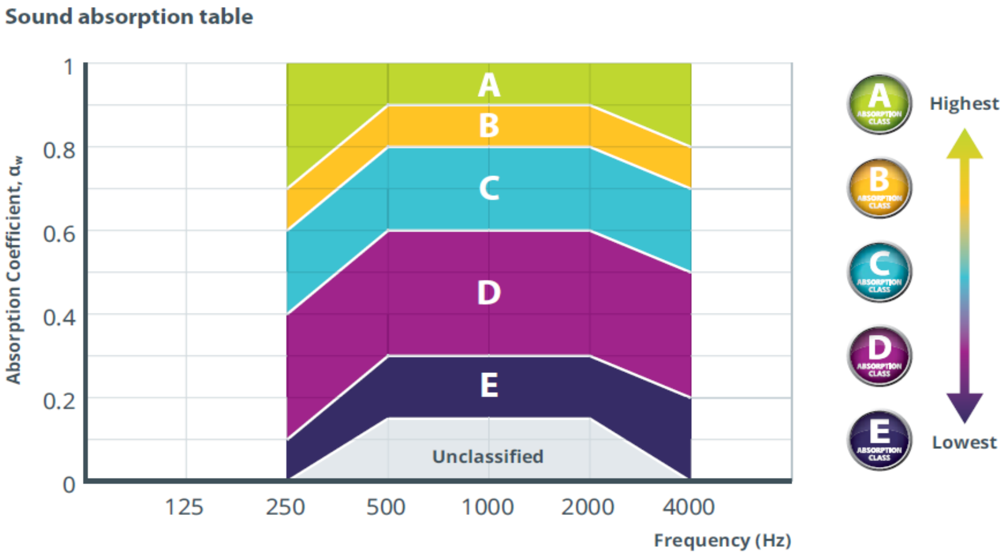


FIGURE 5. Sound absorption table – BS EN ISO 11654:1997 (Acoustic Comfort n.d.)

Figure 6 presents the SAC of OPF natural fibers at various thicknesses (10 mm, 12 mm, 14 mm and 16 mm) under a density of 180 kg/m^3. The SAC values are observed to rise as the thickness increases over the range of frequencies from 500 to 2000 Hz, but they decrease as the thickness increases for frequencies above 2400 Hz. In the range of frequencies between 2400 to 3200 Hz, there is a point where the change in sac values with respect to thickness intersects. Only the sample that is 10 mm thick is capable of achieving a sac value of 0.8 or greater. The fact that only the 10 mm thick sample can reach a sac value of 0.8 or higher indicates the possibility of an ideal thickness for the material that can optimize its sound absorption characteristics. The increase in SAC values with thicker material at lower frequencies (500-2000 Hz) implies better sound absorption of lower frequency sounds for thicker materials, which may be attributed to the ability of thicker materials to dissipate sound wave energy, thereby reducing sound reflection. In contrast, the decrease in sac values with increasing thickness at higher frequencies (>2400 Hz) suggests that thinner materials are better at absorbing higher frequency sounds. This could be due to the fact that higher frequency sounds have shorter wavelengths and are more easily scattered by the smaller thickness of the material, which leads to greater sound energy absorption. The efficiency of sound absorption is influenced by several factors such as the material's mass density, thickness, and pore features. An increase in the mass density of a porous material can enhance sound absorption for low frequency sound, but it can decrease efficiency for high frequency sound. On the other hand, an increase in the material's thickness can improve absorption for low frequency sound, but has little effect on high frequency sound. The number and size of pores in a material also impact its sound absorption efficiency, with smaller pores increasing the effect and larger pores having a weaker effect (Li & Ren 2011).

Furthermore, the 'mass law' in acoustics states that sound absorption is proportional to the surface area and mass of a material. A thicker board with more fibers can absorb more sound energy by reducing the amplitude of

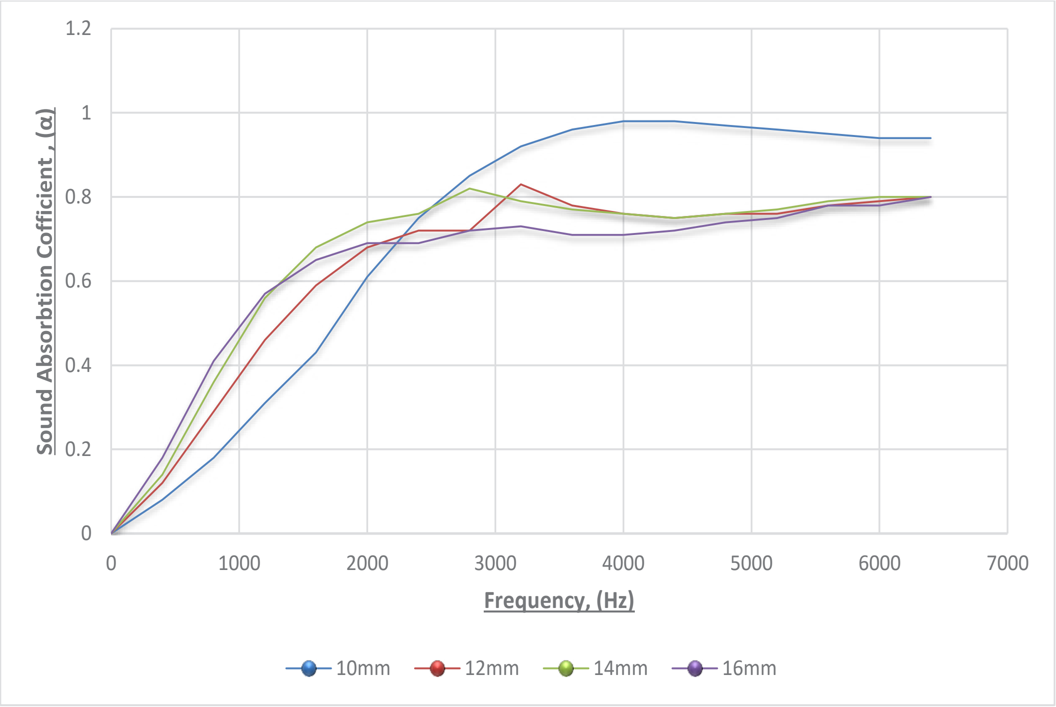
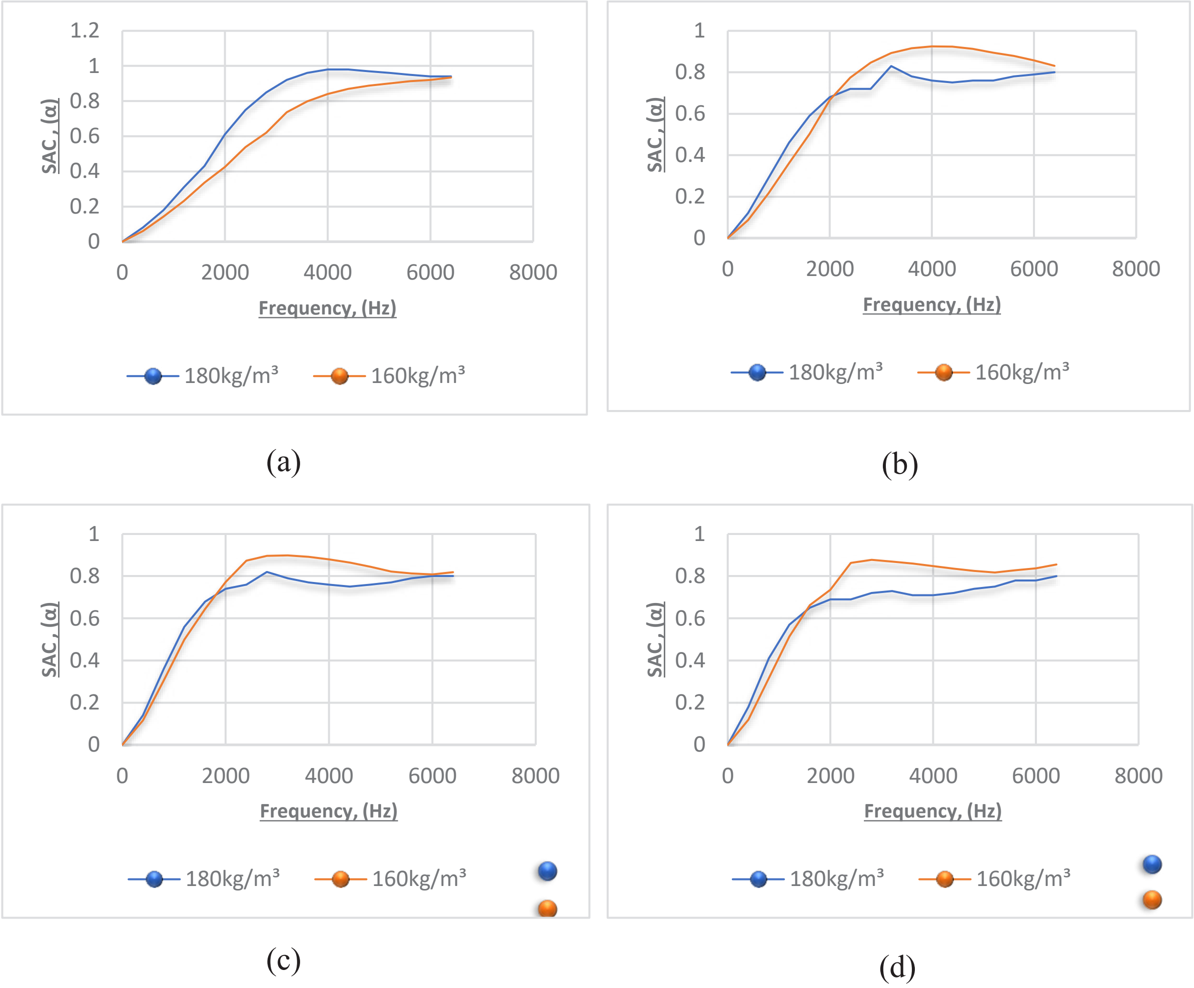


FIGURE 6. SAC, α values versus frequency (Hz) at 180 kg/m³ in different thickness

sound waves passing through the material. This type of board also provides more surface area for sound waves to interact with, leading to better sound absorption performance. Additionally, at low frequencies, sound waves can penetrate deeper into the material before being absorbed or reflected, allowing for more efficient sound energy dissipation.

Sound absorption in materials is a complicated process involving several mechanisms such as viscous friction, thermal conductivity, resonant absorption, scattering, and diffraction. The efficiency of sound absorption depends on factors like density, thickness, tortuosity, physical and chemical properties of the material (Hoda 2009). In general, low frequency sounds can be absorbed more effectively by thick materials, while high frequency sounds can be absorbed better by thin materials. The ideal thickness for achieving the best possible sound absorption depends on the material and the range of frequencies involved.

Figure 7 exhibits a comparison between the SAC values of 10 mm, 12 mm, 14 mm, and 16 mm thicknesses with densities of 160 kg/m^3 and 180 kg/m^3. In Figure 7(a), it can be observed that the sac values across all frequency ranges are greater for a density of 180 kg/m^3 compared to 160 kg/m^3. One possible explanation for why 180 kg/m^3 has greater SAC values than 160 kg/m^3 is that 180 kg/m^3 tends to have a denser and more uniform structure with fewer empty spaces or gaps if compared to 160 kg/m^3. Sound waves able to travel through a more resistant and frictional medium, causing greater



(a) (b)

(c) (d)

FIGURE 7. Comparison of SAC, α values versus frequency (Hz) of OPF natural fibres in different density for (a) 10 mm (b) 12 mm (c) 14 mm and (d) 16 mm

absorption. Conversely, 160 kg/m^3 may contain more pores or voids, which allow sound waves to pass through more easily, resulting in lower SAC values. The SAC value of 0.8 is achieved at a frequency of 2800 Hz for 180 kg/m^3, while the material with density of 160 kg/m^3 reaches the same SAC value only at a higher frequency, which is at 3600 Hz.

When examining samples with thickness of 12 mm (as shown in Figure 7(b)), the SAC values of the material with a density of 180 kg/m^3 are higher than those of the material with a density of 160 kg/m^3 across the frequency range of 500 - 2000 Hz. However, for the frequency range of 2000 - 6400 Hz, the SAC values of 160 kg/m^3 are higher than 180 kg/m^3. The findings were comparable for samples of both 14 mm and 16 mm thickness (Figures 7(a) and 7(d)). In both cases, the material with a density of 180 kg/m^3 exhibited higher SAC values compared to the material with a density of 160 kg/m^3 at the outset. However, the SAC values of 160 kg/m^3 surpassed the SAC values of 180 kg/m^3 afterwards. Notwithstanding, the intersection points where the SAC values of the two materials intersect are different for each thickness, occurring at 1800 Hz and 1600 Hz, respectively. The ability of a material to absorb sound waves can be influenced by its density and the frequency of the sound. When sound waves with lower frequencies encounter a material, they have more time to travel through it and interact with the natural fibers, which can result in higher SAC for materials with higher densities (180 kg/m^3) compared to those with lower densities (160 kg/m^3).

The acoustic analysis of cigarette butts yielded similar results, indicating that increasing density and thickness of samples made from used cigarette butts led to improved absorption at medium frequencies. The maximum absorption coefficient shifted towards lower frequencies as the density increased, but its value decreased. In general, the absorption levels in the 500 - 5000 Hz octave bands increased with increasing density within the studied range (110 to 160 kg/m^3) (Gómez Escobar, Moreno González & Rey Gozalo 2021).

Sound waves have longer wavelengths and more time to penetrate the material and interact with its fibers. This interaction is dependent on the density of the material, as denser materials have more fibers for the sound waves to interact with, which can result in higher SAC values. Conversely, when sound waves have higher frequencies and shorter wavelength, they have less time to penetrate the material and interact with its fibers, leading to higher SAC values for materials with lower densities (160 kg/m^3) compared to those with higher densities (180 kg/m^3). In conjuction with, lower density materials have larger pores between fibers, which can provide more opportunities for the sound waves to enter the material and be absorbed too.

As a result, materials with lower densities may have a higher SAC value than those with higher densities at higher frequency region. In summary, the density of a material can impact its ability to absorb sound, and this effect can vary depending on the frequency of the sound waves. The density and frequency of the sound can impact this interaction and ultimately affect the material's SAC value.

CONCLUSION

The comprehensive outcomes of this research as shown in Table 1. In scrutinizing the samples with a density of 160 kg/m^3, increasing their thickness from 10 mm to 16 mm causes the frequency range of SAC > 0.8 to expand from 3600 - 6400 Hz to 2200 - 6400 Hz. However, samples with a density of 180 kg/m^3 generally do not achieve SAC > 0.8, except for the 10 mm sample at the frequency range of 2800 - 6400 Hz. Samples with a thickness of 12 mm and 14 mm show a narrow frequency range where SAC > 0.8 can be observed, which are 3200 - 3600 Hz and 2800 - 3200 Hz, respectively. Regarding the interception frequency point, both the 160 kg/m^3 and 180 kg/m^3 densities exhibit a subside as the thickness increases.

SAC values of LDF based OPF are influenced by various factors, including their density, frequency and fiber structure. These factors are significant in determining the fibers' capacity to absorb unwanted sound waves. Although materials with higher density may absorb more sound, it may not be true for all frequencies. Furthermore, the fiber structure and contents can affect its sound absorption ability at various frequencies. The OPF fibers' unique structure, comprising porous walls and hollow tubes, contributes to their excellent sound absorption capabilities, as it creates a large surface area for sound wave interaction. To optimize the sound absorption ability of the fibers, it is essential to control relevant factors such as fiber structure, thickness and density.

TABLE 1. Frequency range of SAC > 0.8 and the interception frequency point for all samples

Density(kg/m^3)	Thickness (mm)	Frequency range of SAC > 0.8	Interception frequecy (Hz)
160	10	3600 - 6400	-
	12	2800 - 6400	2400
	14	2100 - 6400	1800
	16	2200 - 6400	1400
180	10	2800 - 6400	-
	12	3200 - 3600	2400
	14	2800 - 3200	1800
	16	-	1400

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