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Effect of density and surface finishing on sound absorption of oil palm frond

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Abstract

In this study, worthless discarded oil palm fronds were used to produce environmentally-friendly sound absorbing material to replace harmful man-made inorganic fibers. To quantify the properties of sound absorption, oil palm frond fiberboards in various densities, i.e., 0.17, 0.21, 0.26 and 0.30 g cm^{-3}, were produced by traditional soft board production and tested for their sound absorption coefficients at 250, 500, 1000 and 4000 Hertz using a standing wave apparatus assembled following ASTM C-384. The boards with the best sound absorption capacity were selected to cover their surfaces using the nonperforated and 5% perforated wood veneers, and the effects of surface finishing on their sound absorption capacity were rechecked. Results showed that the lower density fiberboards showed better sound absorption at high frequencies. Among these, 0.17 g cm^{-3} fiberboards displayed the highest sound absorption capacity. Once these boards were finished with the nonperforated wood veneers, the sound absorption coefficients at high frequencies sharply decreased. However, when perforating the veneer sheets, the coefficients of fiberboards increased and were comparable to the ones without any finishing. Therefore, the optimum density of fiberboard and opening surface can enhance the sound absorption capacity of fibers.

Keywords: oil palm frond, sound absorption, natural fibers, noise, fiberboard

1. Introduction

Owing to the rapid growth of new technologies without proper management, various types of pollution have arisen in Thailand. Among these, noise has been ranked as one of the top three problems complained about the most [1]. To alleviate the problem, sound absorbers, especially inorganic materials, are popular to control noise pathways. However, much research has indicated that some materials made of inorganic substances can cause adverse health effects. For example, Drent [2] indicated that vulnerable populations exposed to man-made mineral fibers such as glass wool and rock wool may be at a higher risk to develop sarcoid-like granulomas. International agency for research on cancer (IARC) [3] reported that mineral wool fibers can cause skin irritation and reach the lung alveoli. Therefore, green materials, especially agricultural fibers such as cotton, flax, jute, hemp, bamboo and coconut, have been offered as alternatives as they have no known impact on human health. Moreover, most natural materials generally have less impact on the environment and require less embodied energy than human-made inorganic materials [4 & 5]. Among these, oil palm (*Elaeis guineensis*) fronds are of interest as approximately 2.7 million tons per year of oil palm fronds are needlessly discarded in Thailand alone [6 & 7]. Additionally, our previous work transforming fronds to uncompressed acoustic mats without finishing confirmed their promising sound absorption property [8]. Therefore, the flattened surface acoustic boards in various densities were continually tested to evaluate their sound absorption capacity and the effect of surface treatment on sound absorption was also explored.

2. Methodology

2.1 Fiberboard production

This study employed traditional fiberboard production including cooking, refining, forming and surface finishing processes to produce oil palm frond acoustic boards. For the cooking process, three hundred-gram batches (dry weight) of frond chips were weighed and soaked in water for 36-48 hours before steaming at a temperature of 163±2°C for 21 minutes. At completion of this process, the fibers were mixed to be homogeneous and refined twice by a refiner set at a disk clearance of 0.5 mm. Then various densities of fiberboard, i.e., 0.17, 0.21, 0.26 and 0.30 g cm^{-3}, were produced by a round-shaped former. Each newly wet formed fiberboard was pressed to make 12 mm thick boards and left exposed to the sunlight until dry. Finally, they were left inside a laboratory room for one week to let the moisture content achieve a state of equilibrium before being checked for their density, thickness, and moisture content. At each density, a set of three fiberboards were produced to check for production quality control. To determine their sound absorption coefficient (SAC), representative specimens of each board were prepared by cutting 7.2 cm diameter and 2.75 cm diameter round-shaped samples. In total, three large specimens and three small specimens were prepared from a set of fiberboards with the same density. The fiberboards with the highest sound absorption capacity were selected to be finished with a non-perforated wood veneer and 5% perforated wood veneer. To study the effect of finishing on sound absorption without interference of the intrinsic characteristics of the wood's texture, the same wood veneer was used to finish each specimen. Consequently, the non-perforated veneer was firstly used to cover a specimen without using any adhesive before being perforated and rechecked for the SAC. The experimental process is summarized in Figure 1.

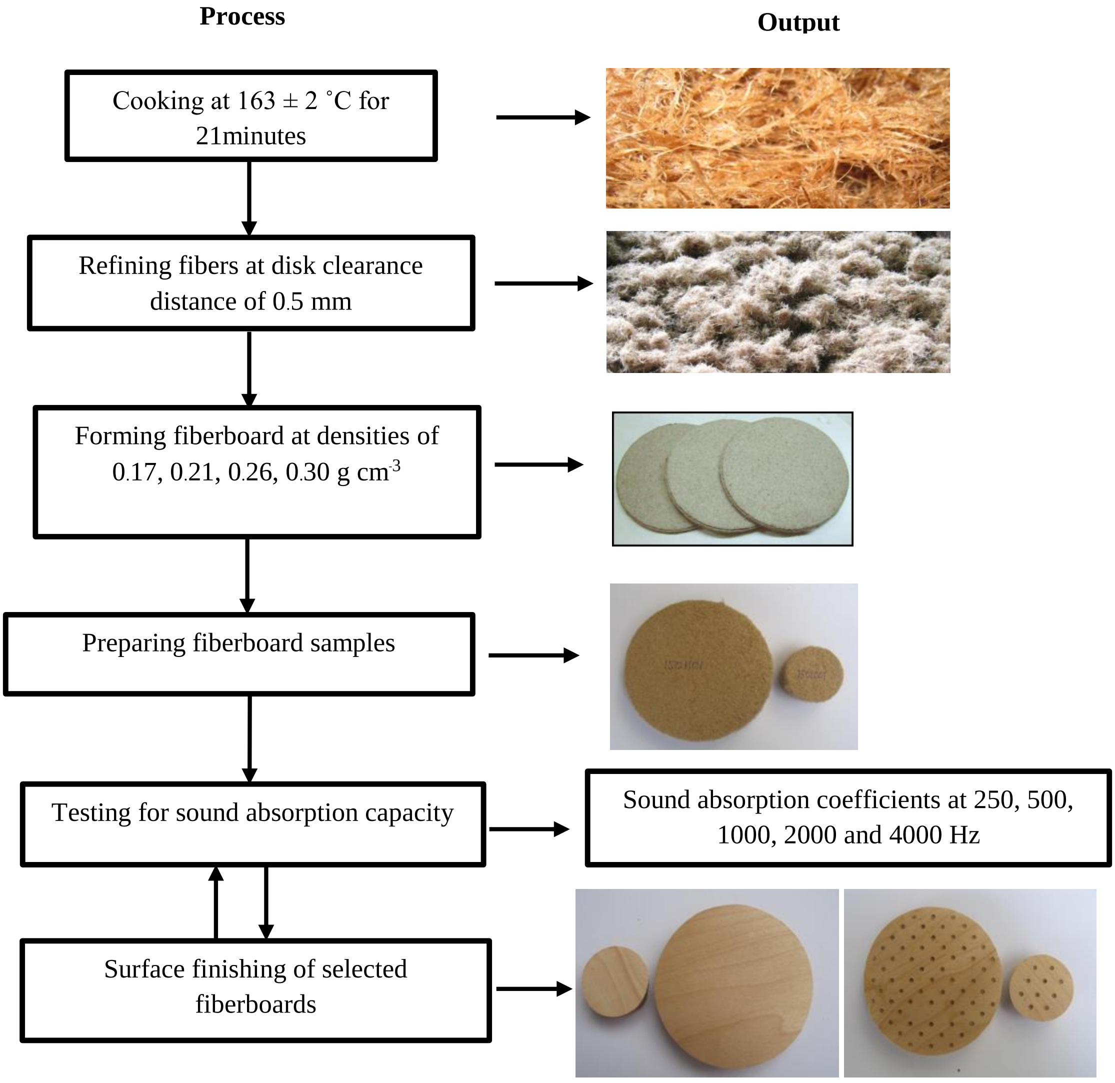

Figure 1 Flowchart of experimental design

2.2 Sound measurement

A standing wave apparatus was assembled following ASTM C 384-2004 to test the material's sound absorption (Figure 2). This equipment was selected to be used in this study as it required a small sample, provided a high level of precision, and was easy to assemble and use. For theses aforementioned reasons, the standing wave apparatus was suitable for prototype acoustic material for which the optimum density was still unknown. Although currently no material can be used to test the bias of this method as indicated in the ASTM C 384-2004, the equipment efficiency of arranging materials in order was proven before testing our materials.

In sum, PVC tubes with diameters of 7.2cm and 2.75 cm were prepared. The 7.2cm tube was designed to measure the sound absorption coefficients at 250, 500, 1000 Hz, while the 2.75cm PVC tube was used to measure the sound absorption at 2000 and 4000 Hz. To measure the sound absorption coefficient at the determined frequency, a loudspeaker was installed and connected to an audio generator to generate the signal at the ends of the selected PVC tube, while the other end was installed with a sample holder. Then a condenser microphone, connected to the pre-amplifier and the oscilloscope, was moved inside a PVC tube to search for the highest (A+B) and lowest amplitude (A-B). These values were used to calculate the sound absorption coefficient as shown in the following equations:

$$SWR = \frac{|A+B|}{|A-B|} \quad (1)$$

$$R = \frac{|B|}{|A|} = \frac{SWR-1}{SWR+1} \quad (2)$$

$$\propto_0 = 1 - R^2 = 1 - \left(\frac{SWR-1}{SWR+1}\right)^2 = \frac{4}{SWR + \left(\frac{1}{SWR}\right) + 2} \quad (3)$$

where SWR is the standing wave ratio; R is the reflection coefficient and α_0 is the normal sound absorption coefficient.

Three repetitive measurements were conducted for each specimen. Totally, nine values from a set of three specimens were calculated as the sound absorption coefficient at each frequency.

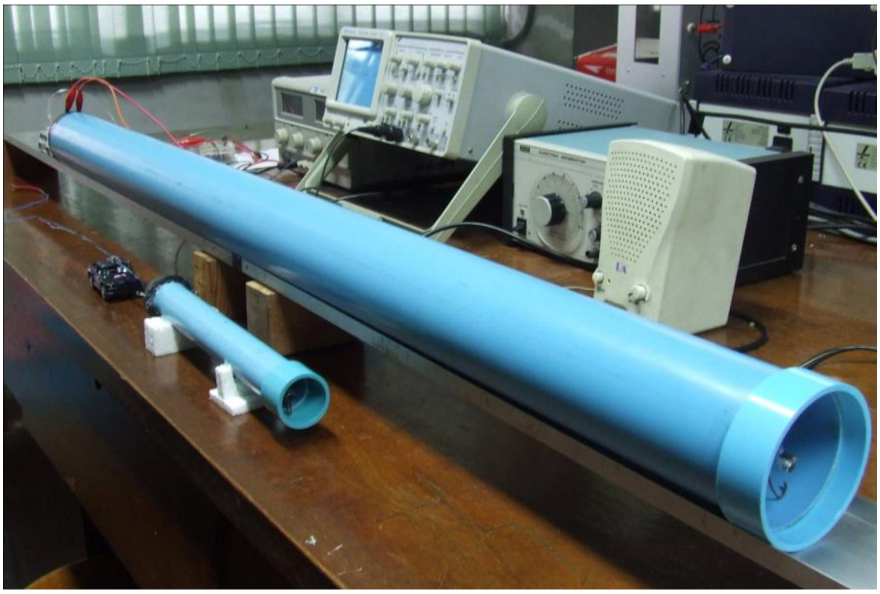

Figure 2 Assembled standing wave apparatus in this experiment

3. Results

3.1 Fiberboard production

In this study, the thermomechanical pulping method was chosen to defiberize frond chips because of its ability to yield massive amounts of fibers [6-8]. Once formed, treated fibers bind by hydrogen bonding [9]. Therefore, although no adhesive was added to the process, fibers can strongly intertwine to form fiberboard. Visually, the fiberboard surfaces were smooth and firm, differing from our previous work in 2010 [7] due to the pressing process added in this study (Figure 3). Fiberboard properties including density, thickness and moisture content are presented in Table 1. It can be noted that we could only produce fiberboard with a density range of 0.17-0.30 g cm^{-3} in this study because of the thickness limitation. Forming fiberboard with a density less than

0.17 g cm^{-3} resulted in the board collapsing due to low amounts of fiber; fiberboard with a density 0.30 g cm^{-3} could not be pressed to the desired thickness because of the opposite reason. The percentages of fiberboard moisture content were approximately 5-6%, the range recommended by JIS A 5905-2003: *Insulation Fiberboards* (5-13%). Once fiberboards were finished with wood veneer as shown in Figure 1, their appearance was significantly improved. However, the decorated material was rather brittle. Therefore, careful drilling of the surface area was required.

(3A) (3B)

Figure 3 Surface of fiberboard: this study (3A), previous study (3B)

3.2 Sound absorption capacity

Table 1 presents sound absorption coefficients at 250, 500, 1000, 2000 and 4000 Hz of oil palm fiberboard with various densities and Figure 4 shows their sound absorption characteristics. The sound absorption coefficients for the set of fiberboards with densities of 0.17, 0.21, 0.27 and 0.30 g cm^{-3} ranged 0.3022-0.7913, 0.3530-0.6748, 0.3825-0.5943, and 0.3996-0.6031, respectively. Among these, 0.17 g cm^{-3} fiberboards presented a superb sound absorption capacity at many frequencies, particularly high frequencies. Notably, the sound absorption characteristics were divided in two forms. While the lower density boards (0.17 and 0.21 g cm^{-3}) presented better sound absorption capacity at higher frequencies, the higher density boards 0.26 and 0.30 g cm^{-3}) showed lower sound absorption capacity at these frequencies. When the 0.17 g cm^{-3} materials were covered with wood veneer, the sound absorption of the materials at high frequencies dramatically decreased (Figure 5). Once 5% of the veneer's surface area was perforated, the sound absorption property of all measured frequency ranges of the material was considerably improved. Comparing our fiberboards with a 5% perforated surface to the commercialized fiberboards made from mineral wools (Figure 6), the sound absorption property of the boards was close to or even better than commercially available products at many frequencies.

Table 1 Physical characteristics and sound absorption coefficients at different frequencies of oil palm frond fiberboard with various densities

Density (g cm^{-3})	Thickness (mm)	MC (%)	Sound absorption coefficient 250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
0.17 (0.00)	12.24 (0.07)	5.69 (0.28)	0.3022 (0.0224)	0.5648 (0.0193)	0.6211 (0.0118)	0.7913 (0.0420)	0.7537 (0.0258)
0.21 (0.00)	12.73 (0.20)	5.32 (0.11)	0.3530 (0.0471)	0.5125 (0.0983)	0.5479 (0.0140)	0.6748 (0.1117)	0.6281 (0.0773)
0.27 (0.00)	12.77 (0.07)	5.18 (0.15)	0.3825 (0.0183)	0.5943 (0.0670)	0.4817 (0.0131)	0.3916 (0.0268)	0.4768 (0.0740)
0.30 (0.00)	13.48 (0.12)	5.71 (0.52)	0.3996 (0.0078)	0.6031 (0.0457)	0.3918 (0.0405)	0.3835 (0.0452)	0.4833 (0.0966)

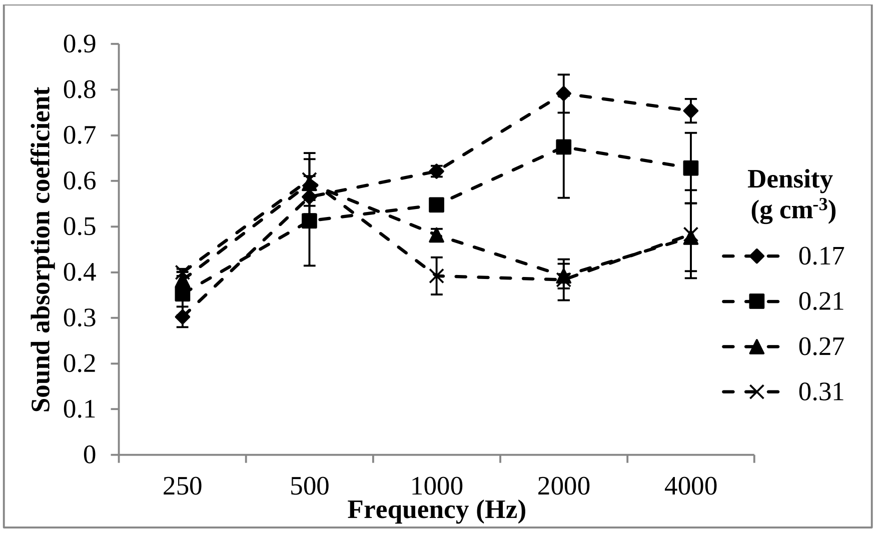

Figure 4 Comparative sound absorption of oil palm frond fiberboard with different densities

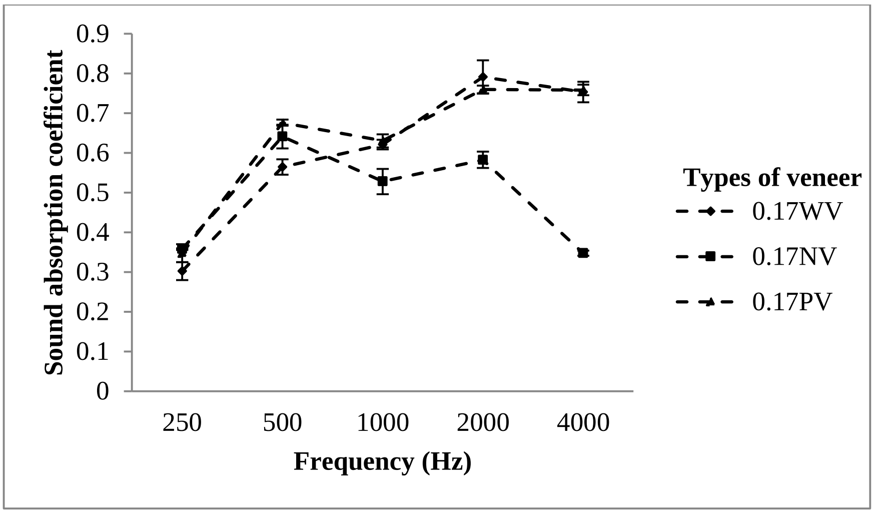

Figure 5 Comparison of sound absorption properties of oil palm frond fiberboard with different finishing surfaces: oil palm frond fiberboard without a veneer (WV); with a nonperforated veneer (NV); with a 5% perforated veneer (PV)

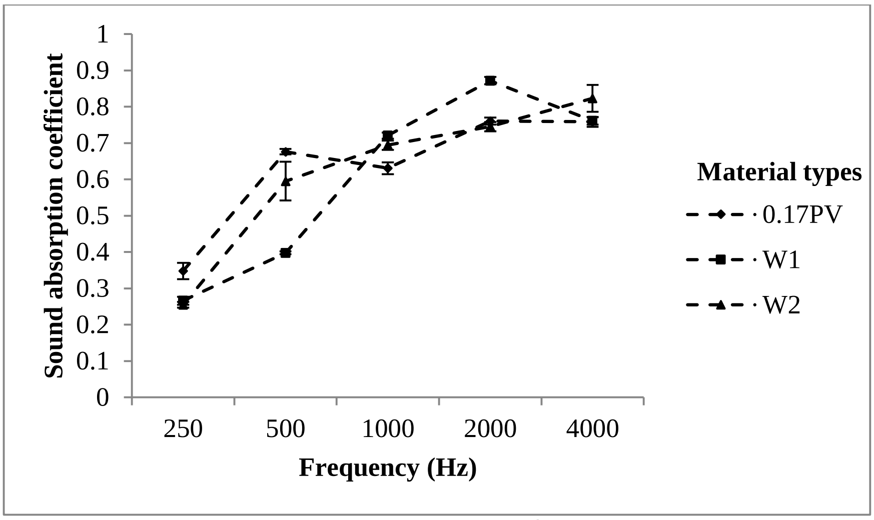

Figure 6 Comparison of sound absorption properties of 0.17 g cm^{-3} oil palm frond fiberboard with a 5% perforated veneer (PV) and mineral wool fiberboards with densities of 0.31 (W1) and 0.39 g cm^{-3} (W2)

4. Discussion

It has been known that acoustical fibrous material can reduce incident sound energy by converting sound energy to other forms such as heat by vibrating the small fibers of porous materials and producing friction and vicious loss of sound as a result of the sound travelling inside the material. For each species and production method, there is an optimum density of material to achieve the best sound absorption capacity. For example, oil palm fibers treated with PVA required a higher density than that of coir fibers treated with latex for better sound absorption [10 & 11]. Koizumi [12] showed that bamboo fibers required a higher density than glass wool to obtain a similar sound absorption coefficient. In this study, 0.17 g cm^{-3} was the optimum density and can be partly explained by the voids inside of this fiberboard. Because the lower density boards posed higher voids inside, the friction and vicious loss resulting from the sound travelling inside the material was greater. As a result, conversion of sound energy was higher. In contrast, the higher density boards were rather tight due to using greater amounts of fiber but limiting the thickness of the fiberboard. Therefore, the sound conversion was lower and incident sound energy was mostly reflected from the material's surface, like hardboard.

Like other porous materials such as Betung bamboo [13], low density oil palm fiberboard showed better sound absorption at high frequencies. In theory, maximum sound absorption occurs when material thickness is about ¼ of the lowest frequencies. Consequently, the higher the frequencies, the better the sound absorption coefficients of fiberboards.

When the surface of material was closed by veneer sheets, the sound absorption capacity was sharply decreased at high frequencies because of reflection from the finishing material. However, at low frequencies, their sound absorption was slightly better than the unfinished boards. This might be explained by additional loss of incident sound energy due to internal damping of the veneer sheet. Once the veneer sheet was perforated, the sound absorption was higher because the opening hole was large enough to let incident sound energy dissipate inside the materials in accordance with Borelli [14].

Comparing our study to the work of Netmali [15] who tested the sound absorption capacity of oil palm empty fruit bunch fiberboard by using the same standing wave apparatus, it was found that empty fruit bunch showed approximately 5-20 percent more sound absorption capacity than 0.17 g cm^{-3} frond fiberboard at high frequencies. This was a result of much lower density empty fruit bunch fiberboards could be produced and were not pressed in production process. Therefore, the voids inside must be higher than our work. However, without pressing in forming process, the surface material was rough; thus being difficult to finish the surface.

To be commercialized, this material needs to be further tested by ASTM C423 and improved for other qualities of fiberboard such as fire retardants and prevention of insect-infested wood by adding the preservative chemicals required. In addition, other fiberboard properties such as strength, flame spread index, water absorption and linear expansion require investigation.

5. Conclusion

Different fibers and species have their own optimum densities to absorb sound energy at differing frequencies. For oil palm frond fiberboards produced by this method, 0.17 g cm^{-3} proved to be the optimum density at many frequencies, particularly at high frequencies. However, to produce commercial fiberboard, appearance needs to be considered. As in the case of veneer sheet, surface perforation is important to increase the sound absorption performance.

6. Acknowledgements

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