EXPERIMENTAL STUDY OF ACOUSTICAL INSULATION OF CEMENT-BASED BOARD PREPARED WITH WASTE COCONUT COIR AND OIL PALM FIBERS

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ABSTRACT

Among the major challenges facing the modern era of technological and industrial advancements are pollution and exponentially growing energy consumption. Pollution continues to be a menace affecting different aspects of life such as health, productivity, and comfort. This paper focuses on the elimination or reduction of sound pollution in buildings using cement-based boards made from pretreated coconut coir and oil palm fibers obtained from agricultural residues. The study includes an account of the preparation of fiber cement boards made from Portland cement Type 1, limestone powder, water, sand, and pretreated coconut coir and oil palm fibers at 5, 10, 15, and 20% by weight of powder materials, respectively, and a high-range water reducer in order to make sure that the natural materials would be spread in an even way throughout the specimens. Sound insulation tests were performed as key indicators of the performance of the fiber cement boards. It was found that an increase in the proportion of natural materials resulted in fiber cement boards with decreased density, compressive strength, and flexural strength. Furthermore, in relation to both physical and mechanical performance, the boards incorporating coconut fibers were superior to those incorporating oil palm fibers. With an increased proportion of natural fibers, sound insulation performance tended to improve. The boards prepared with coconut coir and oil palm fibers in this study yielded acceptable physical and mechanical properties and showed promise in relation to providing insulative protection against sound.

KEYWORDS

sound insulation, fiber cement board, mechanical properties, coconut coir fiber, oil palm fiber

1. INTRODUCTION

Pollution comes in different forms: from soil to water to air with effluents emanating from common or related sources and some from unrelated sources. Sound pollution has become a major form of pollution growing parallel to the increasing usage of devices and machines on

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personal, domestic, and on industrial scales hand-in-hand with the demands and innovations of the modern age. Noise from electrical devices and equipment, mechanical machines and different means of transport, are the major contributors to pollution. Sound pollution is a hazard to health with studies connecting it to strokes, hearing problems, insomnia, high blood pressure and coronary heart disease.

Ensuring a high level of protection against noise in a building is critical to optimizing its use. Because different characteristics and properties of acoustics are required for each area, the area designed without regard to such effects may have resonance or echo, and result in a decrease in hearing efficiency of the users. This research studied and tested wall materials to improve the efficiency of sound insulation. The main material used is cement, which provides strength, combined with natural materials, which provide sound insulation (Fouladi et al., 2010). Natural fibers have unique properties that are useful for thermal and sound insulation; they are lightweight, possess bending resistance and tensile strength, and do not cause toxic substances in their production. The inclusion of natural materials in building projects also reduces the amount of waste incineration, which contributes to air pollution and is the source of diseases in the respiratory system. With an increase in the value of waste natural fibers, agricultural producers could generate income from the sale of agricultural residues to support the production of alternative construction materials. Natural fibers are held in high regard in relation to their ability to dampen sound thereby protecting buildings against an overly high level of sound. Therefore, this research focuses on studying natural fibers as a basis for engineering fiber cement boards suitable for optimizing the performance and use of multiple types of spaces in multiple types of buildings.

Due to the tropical climate in coastal provinces of Thailand, coconut ranks among the plants cultivated on a large scale there both for edible goods and for a multitude of other kinds of manufacturing. It is possible to separate the coconut fiber from the husk manually or through mechanical means, and thanks to the large yield of coconuts, the low cost of production, and the safe quality of the fiber and its mechanical qualities, it is a viable material for inclusion in fiber cement (Asasutjarit et al., 2007). However, waste from the production process of coconut products, when discarded or burned, may cause environmental problems. Two variants of coconut fiber are available in the market and in the producing regions: brown fiber and white fiber. Mature coconuts yield the brown variant of fiber while relatively young coconut yields white fiber. Apart from their color, their physical properties slightly vary. The differences are slight enough to be considered negligible. Mature brown coir contains more lignin while white coir has more cellulose. Brown coir is therefore strong but less flexible; white coir is flexible and smooth but mechanically weak. On average, coconut fiber measures 350 mm by 0.12–0.25 mm and is 1,250 kg/m^3 in terms of density. Coconut fiber is distinguished by its very thick lignin coating—a factor that means it significantly outranks other natural fibers on measurements of strength. In fact, coconut fiber ranks lower than just one other kind of natural fiber, i.e., banana fiber, in relation to mechanical properties. It is also worth noting that coconut fiber is also beneficial in relation to its ability to maintain performance in highly saline conditions and to withstand exposure to microbial processes (Lertwattanaruk and Suntijitto, 2012).

Thailand is the world's third-largest producer of palm oil producing an output of approximately 2 million tons per annum. Eighty-five percent of the plantations and crude palm oil extraction mills are in the south (Arunmas and Wipatayotim, 2018).The market of palm oil continues to expand especially in the European countries, China and the local population. Oil palm plantations are also common in the Southern provinces of Thailand, totaling around 3,250 square kilometers with an approximate production of 750 thousand tons of unprocessed palm oil each year. With the use of this product rising on an ongoing basis, its manufacture has risen accordingly. In general, manufacturing begins by removing the oil from the fruit. After this extraction, 12% is a waste product, which can be put to other industrial uses (Chuanraktam, 2005).The waste fibers, which generally measure 20–100 by 0.2–0.8 mm with a thickness of 1,300–1,450 kg/m^3, are comparable to coconut coir fiber in terms of mechanical properties. Given that they have cell walls that are quite wide, oil palm fibers are able to withstand chemical processes (Ilvessalo-Pfäffli, 1995). For this reason, before mixing with other materials, the fibers should undergo multiple cleaning and refining processes.

In Thailand, natural fibers have been used in the mixture of fiber cement materials to replace asbestos that is toxic to humans and the environment. Fiber cement materials containing natural fibers were developed to yield the properties suitable to be used as a construction material and be effective in energy saving. In this study, the four main constituents in the production of fiber cement materials are Portland cement, natural fibers, water, and high-range water reducer. Properties of cellulose-rich natural fibers can lead to the fiber cement boards produced yielding acceptable mechanical properties, high impact strength, durability, ductility and various applications in construction. The main objective of this study is to identify the natural fiber cement board capable of yielding the strongest sound insulation performance. Prior to testing, the natural fibers were subjected to treatments and then mixed with the cement matrix. These materials convert sound into heat energy (Park, 2000; Vasto et al, 2010), and decrease the volume of noise. As governed by the mass law of acoustics, when the mass increases and the density is constant, the efficiency in reducing the energy level of the sound increases (Harris, 1997) that can be applied to research design and determination of parameters including ratios of natural fibers in the mixtures, density and surface characteristics of fiber cement boards.

1.1 Advantages of natural fiber-cement composites

Natural fiber such as cellulose is not only biodegradable, cheaper, and eco-friendly but also has a low specific weight. They can easily be sourced through sustainable farming practices. Their good electrical insulation properties make them favorable for application even in areas of electrical hazard. Coconut and palm trees absorb carbon dioxide and release oxygen. The fibers, therefore, have a negative carbon footprint on the environment. Good thermal and insulating properties are an added advantage that reduce energy consumption for cooling or heating in areas where they have been installed.

Both acoustic and thermal insulation materials should have other properties such as being fire-resistant. Fire resistance of a material is its ability to withstand the effect of fire. Fire resistance properties of insulation materials can be evaluated by several parameters including temperature increase, mass loss rate, heat release, and smoke production (Asdrubali et al., 2015). Insulation materials produced from conventional materials like recycled glass and rock wool have very good resistance to fire and are classified as non-combustible materials (Asdrubali et al., 2015). But natural fibers are less resistant to fire than mineral fibers. It was found that insulation materials produced from recycled cotton have poor resistance to fire (Innotherm, 2019). The fire resistance properties of natural fibers can be increased by special chemical treatment or by blending natural fibers with synthetic thermoplastic fibers which have a better resistance to fire. However, there are serious side effects of some flame-retardant finishing when applied at a high percentage. One of the adverse effects is that some of the flame-retardant finishes, especially halogenated compounds, are highly toxic (Schindler and Hauser, 2004).

2. EXPERIMENTATION

2.1 Materials

Coconut coir and oil palm fibers measuring in the range of 5–10 mm were prepared. Longer fibers tangle and cling together presenting a challenge during mixing of the material. Fabrics that are tangled together produce a woven fabric effect which is a poor sound insulator in comparison to nonwoven fibers. Nonwovens are ideal methods for producing insulation materials due to their unique fiber orientation and porous structure (Wazna et al., 2018). The length chosen is ideal: not too short to lose the acoustic insulation property. The raw fibers were cleaned with water until a pH of 7 was achieved. ASTM Type 1 Portland cement, limestone powder, sand, water, and natural fibers at the various weight of powder materials proportions are considered herein in relation to their performance as constituents of fiber cement mortars. To ensure even dispersal of the fiber content, we included the ASTM C494 Type G high-range water reducer, and the water-powder materials (w/b) ratio was 0.25, as appropriate for fiber cement. The mix proportions of the mortars considered herein are presented in Table 1. OPC refers to the control cement mortar mixed with Portland cement Type 1, C(X) refers to cement mortars inclusive of coconut coir fiber at X% by weight of powder materials, and P(X) to cement mortars inclusive of oil palm fiber at X% by weight of powder materials. Following the mixing process, the fiber cement mortar was placed in molds before being subjected to the experimentation protocols.

2.2 Natural fiber cement mortars

To establish the differential effects of the two kinds of natural fibers in relation to several fiber-to-cement weight ratios on physical and mechanical performance, the cement mortar mixes specified were subjected to experimentation as provided by ASTM C20 (physical performance) and ASTM C109 (mechanical performance) (ASTM C20, 2016; ASTM C109, 2016). These natural fibers were pretreated with boiling and drying. In the next step, specimens with a fiber-to-cement weight ratio of 5, 10, 15, and 20%, depending on the mortar mixture specified (Table

TABLE 1. Mix proportions of fiber cement mortars.

Mix	Portland Cement (g)	Limestone Powder (g)	Sand (g)	Water (g)	Natural Fiber (g)	Water Reducer (%)
OPC	505	505	1010	252.5	0	1.15
C5	505	505	1010	252.5	50.5	1.15
C10	505	505	1010	252.5	101.0	1.15
C15	505	505	1010	252.5	151.5	1.15
C20	505	505	1010	252.5	202.0	1.15
P5	505	505	1010	252.5	50.5	1.15
P10	505	505	1010	252.5	101.0	1.15
P15	505	505	1010	252.5	151.5	1.15
P20	505	505	1010	252.5	202.0	1.15

1), were created with measurements of 5 × 5 × 5 cm. Next, the bulk density, moisture content, and water absorption of each specimen was measured. That is, the specimens were dried at a temperature of 100°C for a 2-hour period in order to find the dry weight value (D). Next, they were immersed in water for a 12-hour period in order to find the suspended weight value (S). In the last step, a cloth was used to dry the specimens, after which they were measured to find a saturated weight value (W). The results reported in relation to each mix represent the mean results of three samples. In the concluding step, the specimens were placed in water for a period of 28 days after which the compressive strength of each was measured.

The natural fibers were pretreated with boiling and drying. This is a process to improve fiber quality, strength and improve fiber-matrix adhesion. In real-world applications, treatment is necessary to make them applicable and resistant to the elements. Mercerization increases the surface roughness of fiber by removing some important substances like lignin, pectin, and hemicelluloses of the fiber. Although the removal of these substances lowers the acoustic absorption performance of the material, it allows better fiber-binder interface adhesion, fiber fitness, longevity, and antifungus quality and most importantly reduces the diameter of the fibers (Karthikeyan and Balamurugan, 2012).

For this test, then the fibers were subjected to boiling over a 2-hour period. In this way, the fibers' water-soluble chemical content was decreased. Coconut fibers have a thick lignin layer. Lignin being insoluble in water was not removed in the washing process. Lignin accounts for most of the structural strength of coconut fibers. The next step was to dry the fibers in an oven for a period of 24 hours. Following this process, the chemical composition of the fibers, including ash content, hot-water solubility, lignin content, and cellulose content, was studied. Morphological analysis was performed using a scanning electron microscope (SEM).

2.3 Natural fiber cement boards

To establish their effects on the flexural strength and sound insulation of fiber cement boards, both types of natural fibers were included as specified (Table 1) at a ratio of 5%, 10%, 15%, and 20% by weight of powder materials. Placed in a mold, each specimen was cured for 24 hours. After demolding, the specimens were cured continuously at 23.0 ± 2.0 °C and 50.0 ± 5.0% at relative humidity for 28 days. As specified in ASTM C1185 and ASTM C1186 (ASTM C1185, 2016; ASTM C1186, 2016), tests were performed on the 30 × 15 × 0.5 cm specimens to measure the mechanical properties of the respective fiber cement boards.

2.4 Sound insulation property

Sound transmission loss (STL) refers to a measure of the sound insulation value of a panel, in decibels (dB) which the intensity of sound is reduced in the transmission through the panel. Other researchers also used STL to study sound insulation property, and reported that natural fiber panels can deliver high STL (Tan et al., 2016). Natural fibers have been known for its good acoustic damping properties (Mamtaz et al., 2016; Arenas et al., 2020). In recent years, researchers started working on the fabrication of fiber composites, and the incorporation of fibers increase the flow resistivity of the composite material, which has a significant effect in enhancing low frequency acoustic absorption (Arinas and Croker, 2010; Mamtaz et al, 2016; Pickering. 2016). The increase of airflow resistivity in the fibers causes loss of sound energy through the friction of sound waves with air molecules and thus improves low-frequency sound absorption (Fouladi et al., 2010). Friction between the air molecules set in motion by sound waves and the fibers produces heat. The mechanical energy of sound waves is thus converted to heat and dissipated into the environment. This mechanism is however possible where the fibers are free to move. Fibers infused into composites may not experience significant movement limiting this mechanism of sound dissipation. STL is based on the decibel (dB) decrease in sound pressure that takes place as sound encounters the barrier. However, when a given space is smaller than the volume needed for a diffuse field, noise reduction (NR) can be used instead of STL in standard tests (Praščević et al., 2012). In this study, testing of the sound insulation property of the fiber cement boards was designed, and performed in a 4 m wide ×12 m long × 4 m high room (Hansen, 1993; Papanikolaou and Trochides, 1988; ASTM E90, 2016; ISO140-4, 1998). The test room was set up with test equipment as shown in Figure1 including the following:

1. Four Class-2 sound level meters.
2. Three tripod stands for sound level measurement.
3. A computer for controlling the 1/3 octave band sound signal.
4. 1/3 octave band signal generator with frequencies from 100 to 10,000 Hz.
5. 1.00 × 1.00 × 1.00 m soundproof test box with 50 × 50 cm opening on the box top for installation of fiber cement board sample.
6. 8-in 500-Watt loudspeaker.
7. Sound amplification device.

In the test, the sound level was measured at the receiver positions of 1.50, 2.00 and 2.80 m. away from the test box, and the heights from the floor of 0.9, 1.10 and 1.40 m, respectively, as shown in Figure 2. The average sound level (L) for three positions was calculated using Eq. 1.

$$L = 10\text{Log}\left[\frac{10^{L_1/10} + 10^{L_2/10} + \ldots\ 10^{L_n/10}}{n}\right] \tag{1}$$

where L is the average sound level when measuring different positions (decibels)

L_n is the sound level at n different measurement positions.

FIGURE 1. Equipment used for the measurement of sound insulation property.

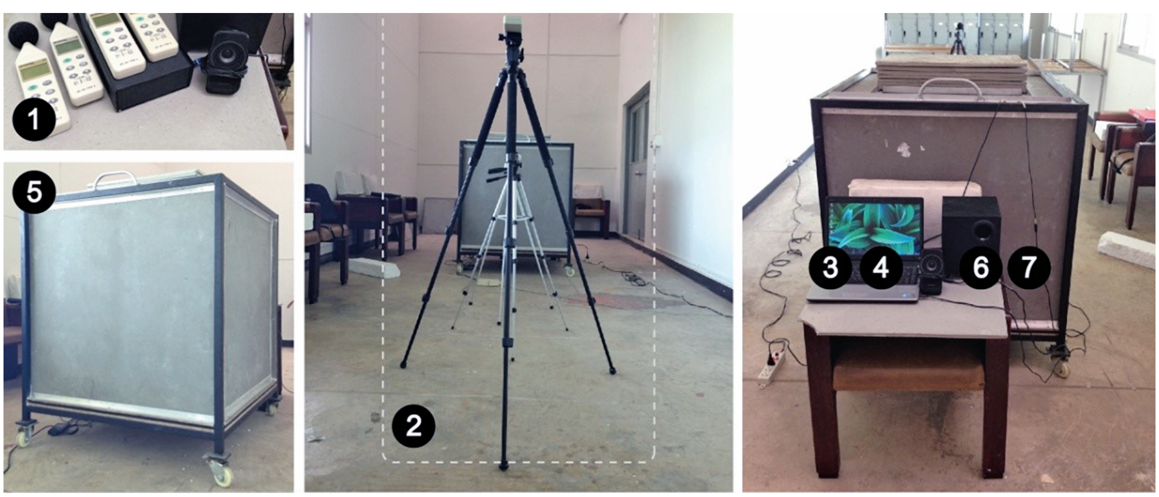
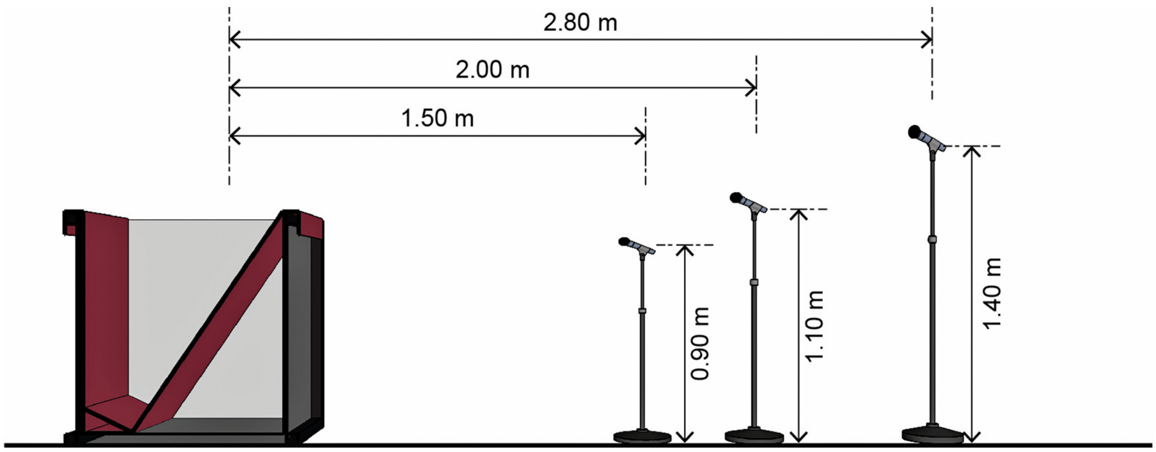


FIGURE 2. Positions of sound level measurement.



The sound insulation performance of the fiber cement boards was assessed in a 4 × 12 × 4 m test room. The 50 × 50 cm fiber cement board samples with a thickness of 8, 12 and 16 mm were used to test the sound insulation property. The parameters studied include the ratio of natural fibers in relation to the weight of powder materials and the density of fiber cement boards. The experimental procedure was as follows:

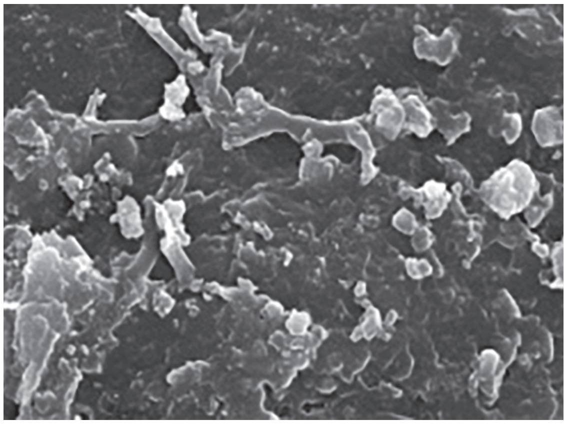
1. Set up the sound level meters at three receiver positions of 1.50, 2.00 and 2.80 m away from the edge of the opening on the test box top with the heights from the floor of 0.9, 1.10 and 1.40 m, respectively, as shown in Figure 2.
2. Install the sound source loudspeaker inside the test box. Turn on the sound signal by using the 100 Hz frequency, and then at the opening on the top of the box determine the sound pressure as a reference.
3. Perform a sound level measurement, and record the results from the three-receiver positions. Repeat a measurement three times, and average the results as described in Eq. (1).
4. Change the frequency of the sound to 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, 5000, 6300, 8000 and 10000 Hz, respectively, and measure the sound levels.
5. Install the natural fiber cement board on the top of the box as a sound barrier, and then repeat the sound measurement procedure as described above. The noise reduction value (NR) for each frequency is then calculated by comparing the sound pressure level with and without the installation of the fiber cement board.

3. RESULTS AND ANALYSIS

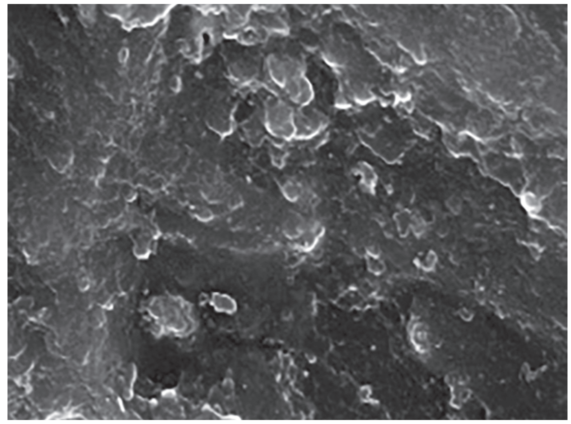
3.1 Properties of coconut coir and oil palm fibers

The test results pertaining to the physical properties of the natural fibers after pretreatment showed that coconut coir fiber had a diameter-to-length ratio of 0.01–0.03, water absorption of 257.1% and dry density of 163.3 kg/m^3. Oil palm fiber had a diameter-to-length ratio of 0.02–0.08, water absorption of 353.7% and dry density of 175.0 kg/m^3.

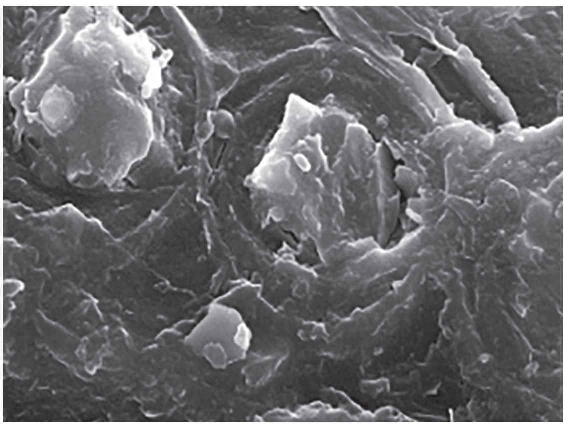
FIGURE 3. SEM micrograph coconut coir fiber and oil palm fiber (2500×)



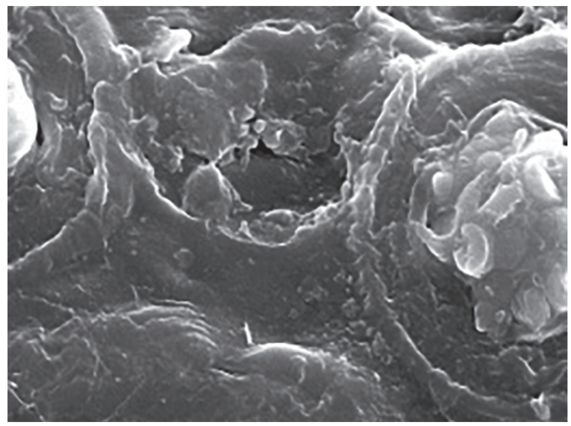
(a) Coconut coir fiber before pretreatment



(b) Coconut coir fiber after pretreatment



(c) Oil palm fibers before pretreatment



(d) Oil palm fibers after pretreatment

A scanning electron microscopy (SEM) was used to explore the morphological and structural characteristics of the fibers, those subjected to pretreatment and those not subject to pretreatment, as shown in Figure 3. Before pretreatment, the oil palm fibers characteristically displayed a non-uniform surface marked by irregular strips and nodes that, in turn, attracted various kinds of contaminants. On the other hand, coconut coir fiber has a characteristically more consistent surface and, therefore, shows evidence of less contamination. Washing and boiling each gave rise to an altered shape in the specimens subjected to these processes. Specifically, these processes have the effect of taking low-molecular-weight compounds, especially lignin, out of the fiber's structure. These kinds of compounds, especially lignin, are found between the outer cell walls of the fibers, which act as the main structure. Therefore, under washing and boiling conditions, the outer cell walls decompose easily (Saheb and Jog, 1999). This produces a relatively rough surface, greater uniformity, and a high number of voids (Asasutjarit et al., 2009; ASTM C1185, 2016). Therefore, in comparison with the unpretreated fibers, the pretreated fibers have an incrementally larger surface, are not as dense, and are capable of incorporating larger quantities of water, which results in a better reaction with Portland cement (Park, 2000).

The constituents of coconut coir fiber and oil palm fiber both prior to and following pretreatment can be found in Table 2. Natural fibers are not consistent in regard to chemical composition thanks to differences in all kinds of environmental factors, whether soil, air quality, or water, as well as in relation to the processes through which the plants from which the fibers were harvested were grown (Lewin and Goldstein, 1999). When subjected to the pretreatment process whereby the fibers from both kinds of plants were cleaned with water up to the point of achieving a pH of 7 and then subsequently boiled, the fibers underwent changes in terms of chemical composition that rendered them more appropriate for use in the manufacture of fiber cement boards (Asasutjarit et al., 2009). As a result of the pretreatment, the fiber specimens showed decreases in relation to ash, alcohol-benzene solubility, and 1% NaOH solubility in accord with the extent to which the impurities present decreased. The fibers thus treated were, therefore, stronger and more consistent in character than in their original state (Sun et al., 2004). At temperatures above 70° C, lignin begins to dissolve and thereby causes the cellulose fibers to become bonded to each other (Yang et al., 2007). In comparison with the unpretreated fibers, those subjected to pretreatment show greater amounts of lignin, holocellulose, and alpha-cellulose. For this reason, pretreated fibers are less flexible and stronger. Given that holocellulose and alpha-cellulose are insoluble, they are more robust than the other constituents comprising the natural fibers (Bousri, 2001). Based on its membrane characteristics, cellulose plays a key role in the ability of fiber cement to absorb noise (Neithalath et al., 2004; Rangsiraksa, 2008).

The test results pertaining to the physical properties of the natural fibers after pretreatment showed that coconut coir fiber had a diameter-to-length ratio of 0.01–0.03, water absorption of 257.1% and dry density of 163.3 kg/m^3. Oil palm fiber had a diameter-to-length ratio of 0.02–0.08, water absorption of 353.7% and dry density of 175.0 kg/m^3. Diameter is a key property that dictates the insulation performance of a material. Fiber diameter is the most important physical geometrical parameter for enhancing the sound absorption performance of any fibrous material. The decrease in fiber diameter leads to an increase in the value of the sound absorption coefficient. This is because more fibers are required to reach the same volume density at the same density of the sample material. This results in a more tortuous path and higher airflow resistance. As a result, the acoustical performance of the sample material increases due to the viscous friction through air vibration (Koizumi et al., 2002).

TABLE 2. Chemical composition of coconut coir fiber and oil palm fiber.

Chemical composition	Before pretreatment		After pretreatment	
	Coconut coir fiber	Oil palm fiber	Coconut coir fiber	Oil palm fiber
Ash content (%)	2.64 ± 0.24	6.98 ± 0.42	0.79 ± 0.05	4.52 ± 0.27
Alcohol-benzene solubility (%)	9.34 ± 0.53	11.0 ± 0.61	1.75 ± 0.22	6.88 ± 0.84
Hot-water solubility (%)	9.33 ± 0.88	8.20 ± 0.70	0.75 ± 0.24	2.42 ± 0.46
1.0% NaOH solubility (%)	38.4 ± 1.06	44.1 ± 1.88	26.2 ± 0.83	26.2 ± 0.33
Lignin (%)	29.7 ± 1.21	24.4 ± 1.14	32.1 ± 1.06	32.2 ± 1.11
Holocellulose (%)	56.7 ± 3.55	47.6 ± 3.12	70.8 ± 3.51	63.7 ± 3.76
Alpha-cellulose (%)	34.8 ± 2.31	32.5 ± 2.10	53.8 ± 2.27	52.0 ± 2.78
Pentosan (%)	14.3 ± 0.98	16.4 ± 1.04	15.13 ± 1.01	20.8 ± 1.20

The accession of thinner fibers due to the reduction of fiber diameter results in a high specific surface area and more micropores in equal volume density of the sample material. This increases the value of the sound absorption coefficient due to more friction of air molecules with a larger surface area (Khan et al., 2012). Furthermore, thin fiber moves more easily than thick fiber in sound waves, which causes vibration in the air, and this enhances absorption by means of more viscous losses due to air vibration.

3.2 Physical properties of fiber cement mortar

The bulk density, moisture content and water absorption of the fiber cement mortar specimens tested in this study are shown in Figures 4–6. For each kind of fiber in fiber cement mortars,

FIGURE 4. Density of fiber cement mortars.

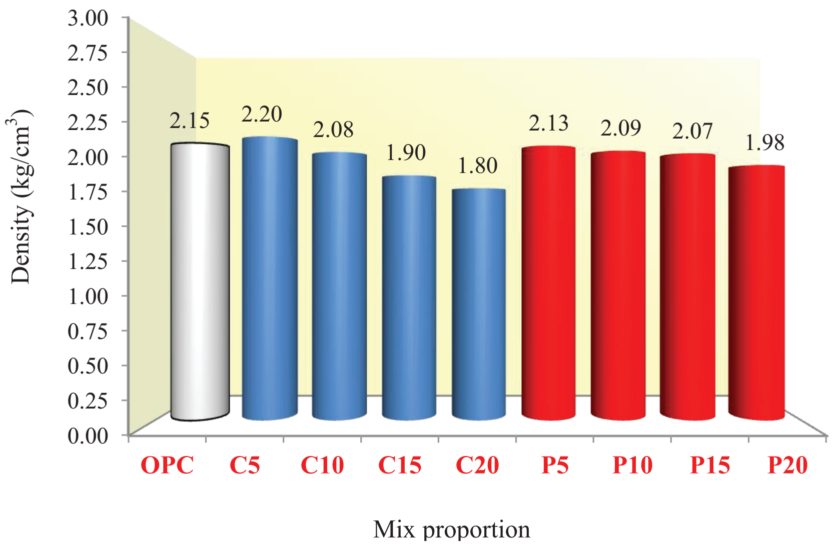


FIGURE 5. Moisture content of fiber cement mortars.

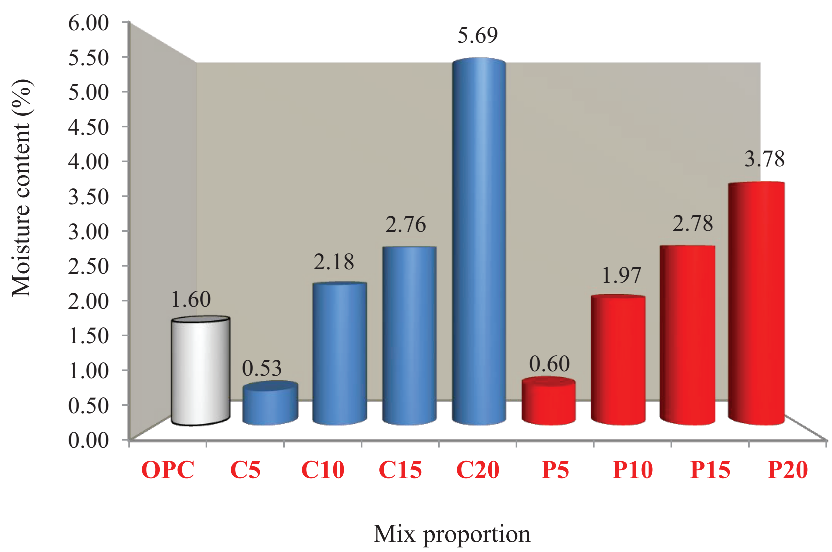
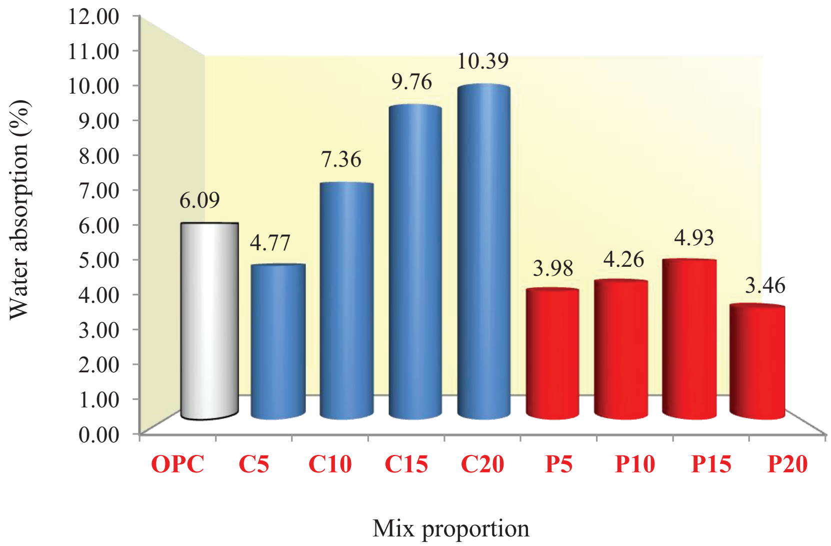


FIGURE 6. Water absorption of fiber cement mortars.



a higher fiber ratio resulted in lower density, higher moisture content, and higher moisture absorbency as compared to Ordinary Portland cement mortar, which is consistent with other studies (Cook et al., 1978; Khedari et al., 2001; Asasutjarit, 2009). This is because the dispersion of fibers in cement mortar led to increases in the number of voids and in the extent of the specimen's porosity. Hence, the mortar incorporating a higher ratio of natural fiber gives rise to more voids and reduced density. Accordingly, the results indicate that the incorporation of coconut coir fiber into cement mortar results in a mortar that is less dense than when oil palm fiber is incorporated. However, the moisture content and water absorption are higher because coconut coir fiber had a lower density and a smaller diameter than oil palm fiber.

3.3 Mechanical properties of fiber cement materials

The test results indicating the compressive strength values of the specimens (Figure 7) are reported as follows: Fiber cement mortars incorporating both kinds of natural fibers had comparable compressive strength: 41.7, 37.8, 35.5 and 31.9 MPa for coconut coir fiber, and 37.0, 34.5, 28.3 and 25.8 MPa for oil palm fiber, with a fiber ratio of 5, 10, 15, and 20% by weight of powder materials, respectively. The cement mortars mixed with coconut coir fiber showed compressive strength slightly above that of the mixed oil palm fiber because coconut fiber has a higher cellulose content and because there was a very little divergence between the two kinds of fibers in relation to physical properties (Seung and Dae, 2004). In accord with results reported in several previous studies, the cement mortars incorporating both kinds of natural fibers showed decreased compressive strength with an increase in the natural fiber ratio (Khedari et al., 2001; Khedari et al., 2004).

The respective flexural strength measurements of the fiber cement boards incorporating 5, 10, 15, and 20% of coconut coir and oil palm fibers by weight of powder materials are shown in Figure 8. It was found that increasing the natural fiber ratio in the fiber cement board resulted in a reduction in flexural strength (Agopyan et al., 2005; Kriker et al., 2005; Odera et al., 2011). According to the test results, the fiber cement boards with a fiber ratio of 20% were all above 4 MPa on the flexural strength measurement, which means that they are suitable for such use in

FIGURE 7. Compressive strength of fiber cement mortars.

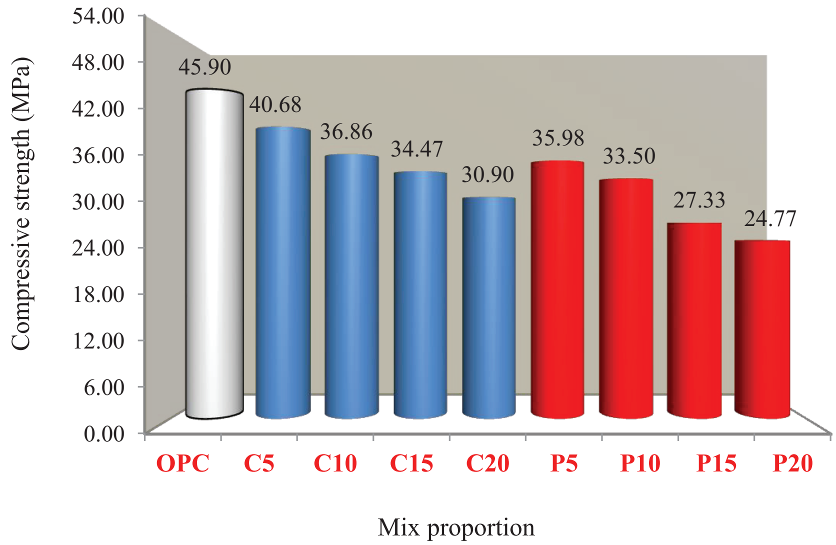
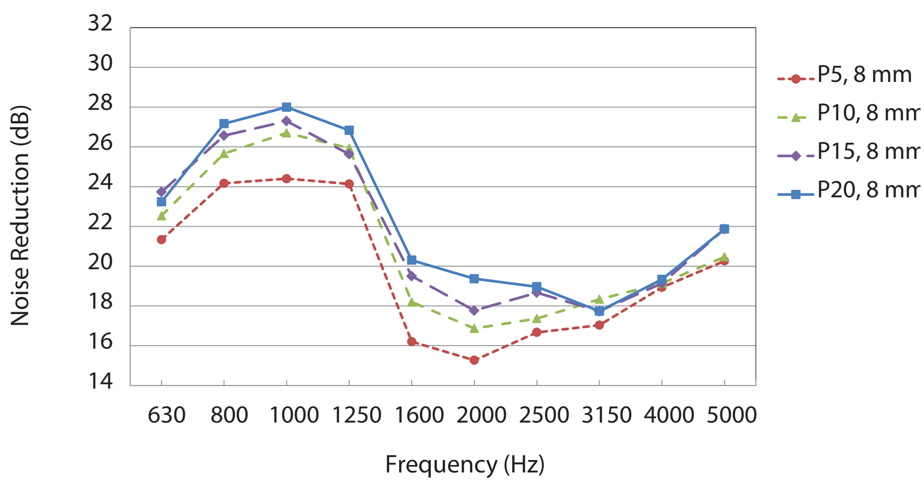


FIGURE 8. Flexural strength of fiber cement boards.



line with ASTM C1186 [18]. The reduction in flexural strength with increasing fiber content is attributed to the poor dispersion in the matrix as excessive loading of fiber tend to aggregate in the composite.

3.4 Sound insulation performance of fiber cement boards

The sound insulation performance of fiber cement board specimens each incorporating one of the natural fibers measuring 8 mm thick is shown in Figures 9 and 10. It was found that the fiber cement boards all yielded a similar level of noise reduction in the 15–28 dB range for each ratio of fiber content from 5 to 20% by weight of powder materials. This is because coconut coir fiber and oil palm fiber had similar amounts of lignin and cellulose resulting in the sound insulation performance at a comparable level (Koizumi et al., 2002). When both kinds of natural fibers are included at 5, 10, 15, and 20% by weight of the powder materials, increasing the ratio of the natural fiber resulted in reduced sound due to the amount of fiber affecting the density, stiffness, and sound insulation properties of the fiber cement board (Koizumi et al., 2002). The fiber cement boards incorporating coconut coir fiber and oil palm fiber at 20 % by weight of powder materials yielded the best sound reduction performance compared to those of 5%, 10% and 15% of fiber (Cook et al., 1978). Fiber cement board with a higher ratio of fiber tends to have higher surface density acting together with sound absorption property of natural fiber leading to better sound insulation performance. It was also found that noise reduction performance can be improved for sound insulation applications by increasing the mass of the natural fibers. For various frequency ranges and at high frequencies (1,600 Hz and 5,000 Hz),

FIGURE 9. Noise reduction of 8-mm fiber cement boards incorporating coconut coir fiber.

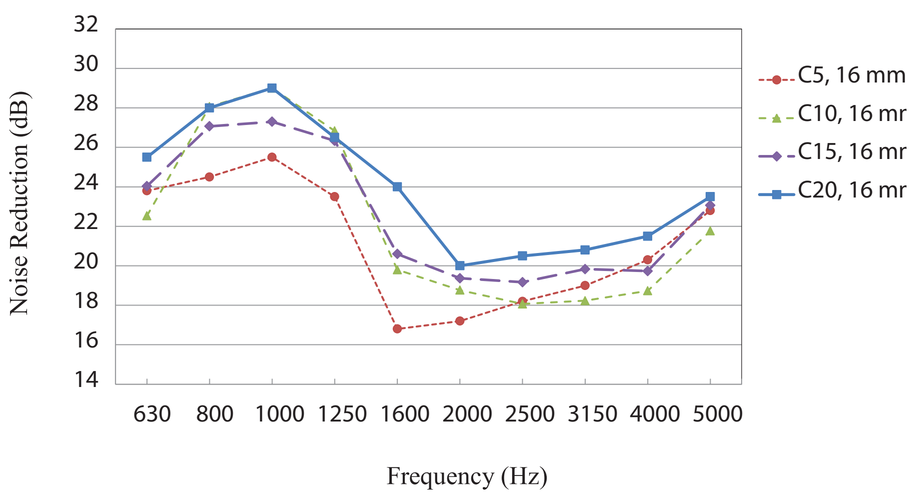
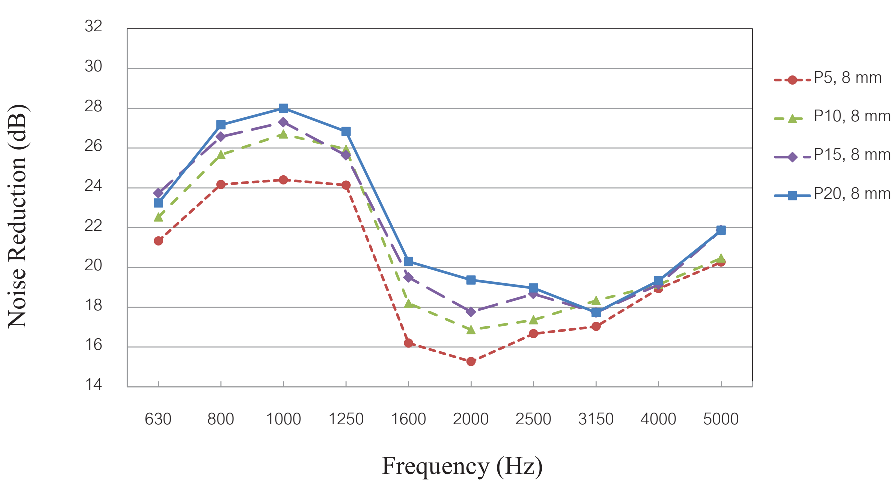


FIGURE 10. Noise reduction of 8-mm fiber cement boards incorporating oil palm fiber.



the fiber cement boards have lower noise reduction compared with those at mid frequencies (800 Hz to 1,250 Hz). The reason for this phenomenon is that low-frequency sound waves are more easily transmitted than high-frequency sound waves (Wan et al., 2016).

The sound insulation performance of fiber cement boards into which natural fibers with a 16 mm thickness have been incorporated is shown in Figures 11 and 12. Incorporating the highest amount of natural fibers at 20% by weight of powder materials yielded compressive and flexural strength measurements that meet the industrial standards applied to fiber cement flat sheet for building applications (ASTM C1186, 2016). Increasing the density of fiber-cement board tends to improve the sound insulation performance. This is because the density is an important factor in increasing the efficiency of a noise reduction level of fiber cement board. Test results were consistent with other research works of the fiber cement board containing natural

FIGURE 11. Noise reduction of 16-mm fiber cement boards incorporating coconut coir fiber.

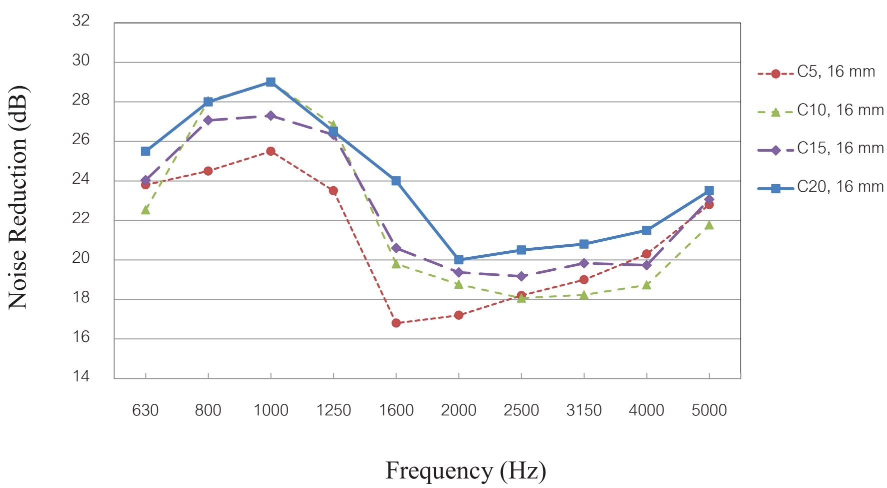
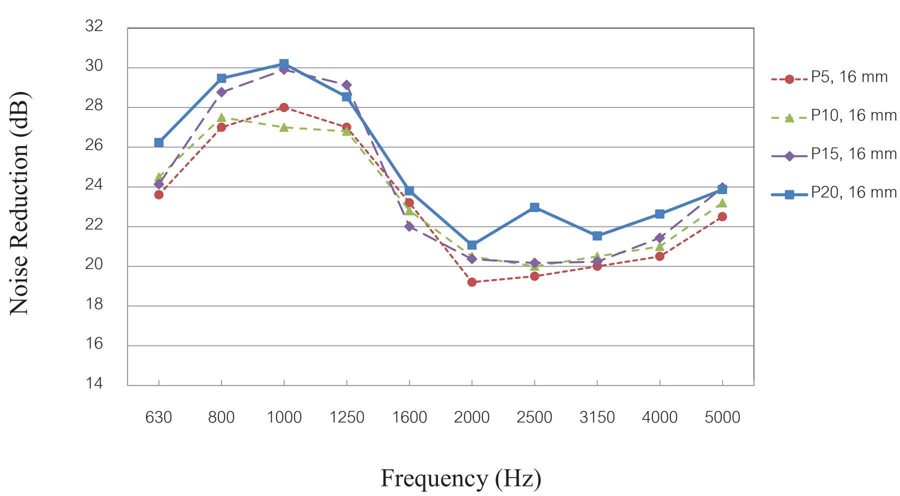


FIGURE 12. Noise reduction of 16-mm fiber cement boards incorporating oil palm fiber.



fibers such as pineapple fiber and bagasse (Ng and Zheng, 1997), and synthetic fibers such as polyester fiber (Narang, 1995). Moreover, the sound level was greatly reduced in the frequency range of 100–5,000 Hz, which is in the range of low-to-medium frequency. In addition, the loss of sound transmission also depends on the mass and hardness of the material (Miller and Montone, 1978).

For the 16-mm thick fiber cement boards, the two kinds of fibers yielded very similar sound insulation performance with noise reduction in the 17–30 dB range, which is about 2 dB better than the 8-mm thick fiber cement boards. By incorporating the natural fibers at 20% by weight of powder materials, which was the largest fiber proportion, the fiber cement board mixed with both fibers achieved a higher overall noise reduction performance compared to those of lower amounts of natural fibers in the mixture. The fiber cement boards containing oil palm fibers provided a little more noise reduction than did those with coconut coir fiber (Communities, 2006). This is because the density of oil palm fiber was slightly higher than coconut coir fiber, and yielded a higher density fiber cement board as well. Oil palm fiber is about 1.88 kg/cm^3 dense, which is higher than that of coconut fiber, for which the measurement is 1.70 kg/ cm^3. Because of the higher density of oil palm fiber, the fiber cement boards have a denser surface layer, rendering them more effective in regard to impeding sound energy, thereby retarding the extent to which noise is transmitted (Egan, 1972; Miller and Montone, 1978; Communities, 2006).

An increase in natural fiber content in fiber cement boards should also improve the sound insulation property by distributing more fiber particles in the cement paste matrix. Figures 9–12 illustrate how increasing natural fiber content possesses a better sound insulation effect. When the soundwaves reached the fiber cement board surface, the sound wave transmission will undergo certain behaviors including reflection, dispersion, refraction, and diffraction. For each fiber cement board, there are apparent differences between the cement matrix and natural fiber in density, elastic modulus, heat transfer, and acoustic transmission. Thus, the incorporation of natural fibers into a cement matrix yields more diffraction and greater spreading of sound waves, which has the result of leading to a reduction in the effect of sound waves. Natural fibers also act as barriers to sound waves; therefore, the sound waves have to detour and the transmission becomes diffraction. Consequently, the extended transmission pathways give rise to greater wave energy consumption, which has the effect of enhancing sound insulation (Zhao et al., 2010).

4. CONCLUSIONS

Natural fibers used in cement boards constitute an option that goes beyond the standard choices, among which are asbestos and synthetic fibers. The use of natural fibers in the applications discussed could lead to the demand for these materials in the marketplace and thereby present a sustainable solution to what is currently an environmental problem regarding the disposal of what is almost entirely waste products. The study shows that the two kinds of natural fiber cement boards, i.e., those with cement mortar into which coconut coir fiber was incorporated and those with cement mortar into which oil palm fiber was incorporated, were similar in reference to performance pertaining to physical, mechanical, and sound insulation. In this study, an account of the extent to which different natural fibers incorporated into fiber cement boards with a consideration of density and thickness was presented. Based on the results, we offer several inferences:

- To fulfill the goal of improving sound insulation performance, cement boards into which natural fibers are incorporated would include either coconut coir fiber or oil palm fiber at up to 20% by weight of powder materials. Prior to adding the natural fibers to the cement mixture, it is necessary to put them through a process to eliminate multiple chemicals, including inorganic compounds, which have the potential to undermine the performance of the cement over time.
- The fiber cement boards incorporating coconut coir and oil palm fiber showed a decrease in bulk density. The increased amount of fibers added to the mix proportions resulted in a lower compressive and flexural strength of fiber cement products. Yet, the resulting performance is still in accordance with ASTM specifications for fiber cement flat sheet designed for use in construction projects.
- The use of both of the natural fibers improved the sound insulation performance of fiber cement boards. An increase in natural fiber content in the fiber cement board will also improve the acoustic insulation. The fiber cement boards incorporating both of the natural fibers at 20% by weight of powder materials yielded the best sound reduction performance compared to those at 5, 10, or 15% of natural fiber.
- Increasing the thickness of the fiber cement board and increasing the replacement ratio of natural fibers resulted in better sound insulation performance. The 8-mm thick fiber cement boards incorporating coconut coir fiber and oil palm fiber yielded similar noise reduction in the 15–28 dB range. For the 16-mm thick fiber cement boards, the noise reduction of both natural fiber cement boards was in the range of 17–30dB.
- For the comparison of the sound insulation performance of the 16-mm thick fiber cement boards, it was found that the fiber cement board containing oil palm fiber had the ability to reduce the sound level slightly better than that containing coconut coir fiber. The density of oil palm fiber is about 1.88 kg/cm^3, which is a little higher than 1.70 kg/cm^3 of the coconut fiber. Overall, fiber cement boards that include high-density fibers will render greater sound insulation than will those including low-density fibers.

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