Enhancement of Acoustic Performance of Oil Palm Frond Natural Fibers by Substitution of Jute Fiber

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ABSTRACT
Noise is defined as an unpleasant or loud sound, which may cause disturbance to others. It can damage an inner ear and even cause noise-induced hearing loss, threatening health and well-being. Researchers have successfully studied and invented many different types, shapes, and sizes of sound absorbers to absorb/control unwanted noises. A simple method used to control noise is by controlling the noise source using acoustic absorption panels, reducing noise along the transmission path, and protecting the noise at the receiving end before it reaches the receiver. Presently, the market or in most developed countries uses synthetic materials for buildings to absorb sound. The commonly used synthetic materials are glass or mineral fibers as they can be produced chemically in the factory very quickly. However, materials such as foam, rock wool, and glass wool made from minerals are recognized for their poisonous and polluting effects, which are harmful to human health and the environment. This paper reported the effect of substitution of Jute on the acoustic performance of Oil Palm Frond (OPF) natural fibers (150 kg/m³) with a thickness of 19 mm. Jute is suitable for insulating, antistatic, and low thermal conductivity. It also has a promising result of sound absorption coefficient (SAC) at lower frequency range (50 - 1000 Hz), and on the contrary for OPF, the SAC is only promising at higher frequency range (2000 Hz - 6400 Hz). Thus, it will be very remarkable to study these two blending fibers’ acoustic performance. The commonly used synthetic materials are glass or mineral fibers as they can be produced chemically in the factory very quickly. However, materials such as foam, rock wool, and glass wool made from minerals are recognized for their poisonous and polluting effects, which are harmful to human health and the environment. This paper reported the effect of substitution of Jute on the acoustic performance of Oil Palm Frond (OPF) natural fibers (150 kg/m³) with a thickness of 19 mm. Jute is suitable for insulating, antistatic, and low thermal conductivity. It also has a promising result of sound absorption coefficient (SAC) at lower frequency range (50 - 1000 Hz), and on the contrary for OPF, the SAC is only promising at higher frequency range (2000 Hz - 6400 Hz). Thus, it will be very remarkable to study these two blending fibers’ acoustic performance. The findings show the substitution of Jute to broaden the frequency range of SAC above 0.8. For 20 % of jute substitution, SAC's frequency range above 0.8 is 1600 – 6400 Hz. Whereas for both 40 % and 60 % of jute substitution, the frequency range is marginally widened to 1400 – 6400 Hz. For 80 % of jute substitution, the frequency range of SAC above 0.8 has been increased to 1000 – 6400 Hz. An impressive result has been observed, where 100 % OPF unable to reach the SAC of 0.9 throughout the frequency range of 0 – 6400 Hz. Jute has proved its ability to improve its acoustic performance at a more comprehensive frequency range.

Keywords:
Oil Palm Frond (OPF); jute fiber; noise; Sound Absorption Coefficient (SAC); impedance tube method

1. Introduction

Noise is defined as unwanted sound or audible acoustic energy that is detrimental. In other words, there's a situation in which a person playing loud music on the radio hears no noise, but it is audible for others. It can cause damage to the ears, sleep disturbance, stress, and high blood pressure.

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under constant exposure [1]. National Institute of Occupational Safety and Health (NIOSH) protects the working community against the adverse effects of it by reinforcing the existing laws. These laws ensure that the executives will improve work environment security and facilitate its repercussion circumspectly [2]. NIOSH suggests the safe exposure limit is 85 dB for eight hours per day [3].

The noise issues can be eliminated by introducing a sound absorption or sound reflection. Often times, the insulation material is used as a sound absorber. Soundproof or sound-insulated materials are mostly used in studios, industrial worksite, movie theatres, offices, home depot, and automotive industry [4].

Recently, synthetic material could be used as sound absorber such as fiberglass, mineral wool, and so on [5]. Despite its versatility, these materials are detrimental to human health, such as causing lung infection and irritation to skin, eyes, and throat, leading to breathing difficulties [6][7]. Furthermore, synthetic material is non-biodegradable. These substances will have severe repercussions to climate as it can induce oil-based plastics to release poisonous toxins. They start to soften and produce hazardous gases into the air at high temperature through a cycle known as out-gassing [8].

Thus, this research paper is looking forward to supporting green technology by using sustainable material (natural fibers) to replace synthetic material. There are three types of natural fibers, which are animal fibers, vegetable fibers and mineral fibers [9]. Jute and Oil Palm Frond (OPF) are excellent sound absorbent with good acoustic properties from previous research. According to YANG Wei Dong, et al., 2012, jute fiber has the best sound absorption property with SAC values from 0.8 to 0.95 at a frequency range of 750 - 2000 Hz [10]. Untreated Jute fibers showed an increasing trend of SAC from 0.38 to 0.95 with increasing in fiber length (5 mm to 20 mm) [11]. In addition, according to R. Mageswaran, et al., [12], a combination of EFB and OPF showed promising SAC value from 0.81- 0.98 with a frequency range of 4000 - 6400 Hz [12].

The study from Mathan Sambu et al., [13] showed OPF has a good absorption at low and high frequency. The SAC value can reach 0.8 at 1000 Hz and almost reach unity 0.99 at a frequency range of 3500 to 4000 Hz. However, the result might be due to the density, porosity and tortuosity [13]. A. R. Mohanty et al., [14] reported the highest SAC value of Jute is 0.93 at a frequency of 1500 - 2000 Hz. At a low frequency of 250 - 500 Hz, the SAC trend is dipping from 0.5 to 0.3, however it tends to increase where at 1000 Hz its already reach SAC 0.7. At a frequency of 2000 - 4000 Hz, SAC value for Jute is decreased from 0.93 to 0.85 [14].

These two materials have its own advantages in which Jute fiber has a good absorption at lower frequency whereby the OPF has a good absorption at a higher frequency. Not only that, they are found in abundance in Malaysia. The research in 2015 disclosed the solid biomass waste generated in the palm oil industry in Malaysia was rated about 75.61 million tons per annum while the palm oil mill effluent (POME) waste generated amounts to 65.35 million tons per year [15]. Jute is an annual crop taking about 120 days (April/May-July/August) to grow [16]. However, it is imported from India or Bangladesh and mainly used in clothes, automotive, handcraft, etc. By using the waste of Jute and OPF, the production cost for this material will be minimal. To get more insight into these two natural fibers’ acoustic performance, substitution of Jute into OPF low-density fiberboard (150 kg/m$^3$) in different blending ratio with a thickness of 19 mm has been investigated.

2. Methodology
2.1 Samples Fabrication and Characterization

The panels were prepared with low-density fiberboard (LDF) ($\rho = 150$ kg/m$^3$) dry method process. The flowchart of dry method process that used to fabricate panels with blending ratio of 80% Jute –
20% OPF, 60% Jute – 40% OPF, 40% Jute – 60% OPF, 20% Jute – 80% OPF and 100% OPF with a thickness of 19 mm has been shown in Figure 1. The dry method process comprises refining, drying, weighing, blending, mat-forming, pre-pressing and hot-pressing.

The Maier chipper machine was used to cut the jute and OPF fibers into smaller pieces before oven-dried and well-kept at 100 °C for several days until the chips' moisture content reached 10%. Followed by, the jute and OPF chips were refined using Sprout-Bauer (ANDRITZ) to turn the chips into cottonized fibers. After pre-computed of the mass of fibers and resin (where polymeric methyl diphenyl diisocyanate (PMDI) used as resin) by pre-programme excel sheet based on the desired blending ratio, thickness and density. The refined fibers and resin have been blended using a mechanical blender. The mixed fibers were then spread uniformly within the wooden mould and pressed under the pre-press machine, which will then be hot-pressed at 180 °C.

**Fig. 1.** Flowchart of the dry method process to fabricate low-density fiberboard (LDF)

Acoustic measurement has been performed by measuring sound absorption coefficient (SAC) using Impedance tube method type 4206, which is connected to an analyzer, as shown in Figure 2. This acoustic testing using two microphones transfer function method following international standards of ASTM E1050-2. SAC was computed spontaneously from a frequency range of 0 – 6400 Hz by Labview software following the ISO Standard ISO10534-2 where the SAC is defined as the ratio of absorbed energy to incident energy.
3. Results and Discussion

Figure 3 illustrates the measured SAC data of five different blending ratio of Jute and OPF fibers (hybrid composites) with a thickness of 19 mm at frequency range 0 – 6400 Hz. As a whole, the SAC for all the blending ratios is found to increase linearly from 0 – 1400 Hz. From 2200 – 6400 Hz, the SAC for all samples stays amidst 0.8 to 1. In average, the SAC for all blending ratios is found to increase with increasing in Jute content from 0 to 1400 Hz. The similar trend can be seen at high-frequency range (4800 to 6400 Hz) too. However, the SAC for all samples between 0.8 and 1 at frequency range of 2200 – 4800 Hz has no profound effect on sound absorption with increasing in Jute fibers.
The ability to absorb unwanted sound is highly dependent on frequency, composition, thickness, density, etc. The samples fabricated in this research were set at 19 mm thickness and 150 kg/m³ density. Hence, the absorption rate will be entirely dependent on frequency and composition—both OPF and Jute fibers composed of cellulose, hemicellulose and lignin. OPF fiber has numerous sizes of vascular bundles. They are broadly implanted in thin-walled parenchymatous ground tissue made up of a fibrous sheath, vessels, fibers, phloem, and parenchymatous tissues, albeit Jute fiber is a multicellular fiber made up of many single fibers. The diameter of raw Jute fiber was around 61 µm) [17], whereas the fiber diameter for OPF was 11 – 19.7 µm [18]. The maximum SAC for 100% of OPF content is unable to exceed 0.9, as can be observed in Figure 3. However, the addition of Jute fibers can shift the SAC values to 0.9 and above. The hybrid composites between these two natural fibers of different diameter might enhance sound absorption effect. Materials with good sound absorption coefficient are customarily porous, which according to Jawaid et al. [19]. Jute plus OPF fibers appear to be promising materials due to higher tensile strength after combining both properties.

Table 1 displays the frequency range of hybrid composites in different blending ratio of Jute (J) and OPF (O) fibers where the SAC values are 0.8 and above. It is worth mentioning that the frequency range has been broadened from 2400 – 6400 Hz to 1000 – 6400 Hz with the Jute contents. Chemical composition of OPF fibers is lower in cellulose content as compared to Jute fibers [18]. The increase of Jute contents can retain the strength of the hybrid composites and hence more sound energy that collided with them may be absorbed instead of being reflected back to the environment. Acoustic absorption is a process in which the penetrating sound energy is dissipated and transformed into heat during the collision with the fibers.

SAC is the ratio of sound energy absorbed by a material to incident sound energy striking them that range between zero to one [20]. Zero indicates that there is a total reflection of the sound energy and one indicates full absorption. Materials with SAC greater than 0.50 are generally considered sound-absorbent materials while for SAC, less than 0.20 are considered sound-reflective materials. Notably, the only sample with 80% of Jute content (J80-O20) exhibits the highest SAC values (> 0.95) from a frequency range of 5400 – 6400 Hz. Where the highest SAC, α = 0.98 almost reached unity at a frequency of 5800 Hz. Therefore, the hybrid composite between Jute and OPF fibers shows promising results.

### Table 1

| Different Blending Ratio | SAC Value | Frequency Range |
|--------------------------|-----------|-----------------|
| J80-O20                  | > 0.8     | 1400 – 6400     |
| J60-O40                  | > 0.8     | 1600 – 6400     |
| J40-O60                  | > 0.8     | 2400 – 6400     |
| J20-O80                  | > 0.8     | 2000 – 6400     |
| J0-O100                  | > 0.8     | 2000 – 6400     |
4. Conclusions

In summary, our findings showed that the substitution of Jute fibers from 0% to 80% was able to broaden the frequency range of SAC above 0.8 from 1600 – 6400 Hz to 1000 – 6400 Hz. Meanwhile, the results from the 100% OPF content is unable to reach the SAC of 0.9 and above throughout the frequency range of 0 – 6400 Hz. With the substitution of Jute fibers, the SAC values are able to reach 0.9 and above at different frequencies. Jute has been proven that it has the ability to improve its acoustic performance at a more comprehensive frequency range. Thus, this research paper is looking forward to supporting green technology by using sustainable material (natural fibers) to replace synthetic material.

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