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Sound Insulation Properties of Malaysian Biomass Waste Fibre UF Composites

Ida Norfaslia Nasidi[1], Lokman Hakim Ismail[1], Emedya Murniawaty Samsudin[1*]

[1]Faculty of Civil and Built Environment,
Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, MALAYSIA

*Corresponding Author

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Abstract: Natural fibre has a good capacity as acoustic insulation materials because of its characteristics, and therefore it is widely used in many applications. This research aims to explore biomass waste from the palm oil mill and coconut production as insulation materials. Fibre wastes used for this study included the empty fruit bunch (EFB), mesocarp fibre (MF) and coconut coir fibre (CF), which were treated using sodium hydroxide (NaOH) to eliminate excess oil and fibre surface impurities. The effect of the treatment was also considered to observe the effect towards the sound transmission loss (STL) performance of natural fibre. Three varying concentrations of NaOH (1%, 2% and 3%) were used to treat the fibre. The STL of EFB, MF and CF were measured using the impedance tube method with four microphones at frequencies from 160 Hz to 5,000 Hz. Pretreatment on EFB, MF and CF showed a decrement on the fibre diameter and changes on the fibre surface morphologies after examining using the scanning electron microscopy (SEM) analysis. The results showed that EFB, MF and CF treated fibre had higher STL performances than untreated fibre. The STL performances were increased by increasing the tested frequency from 160 Hz to 5,000 Hz. Changes in fibre morphology following the fibre pretreatment affected the STL performances of EFB, MF and CF. Additionally, treated MF using 2% of NaOH concentrations obtained the highest STL amongst all the test samples.

Keywords: Sound transmission loss, biomass waste, sodium hydroxide

1. Introduction

Research and development in the field of acoustics have intensively grown with the introduction of several newly developed natural materials as a sound insulator. The sound insulation materials are necessary to prevent any excessive sound from affecting humans and creating annoyance, which may cause sleep disturbance and hearing loss, which could lead to mental health symptoms [1]. Consequently, the use of acoustic insulation materials to create an interior acoustic environment has been a normal practice since then. Many fibrous materials primarily from natural fibre had started to be commercialized in various industries, including the building industries, especially for sound insulation materials. Natural fibres were used to reduce the dependencies on synthetic insulation materials, including mineral wool, glass wool, polyester and polyurethane. These materials are believed to be a risk to humans' health and the environment and are also expensive to manufacture [2]. Therefore, researchers have been turning their interests towards natural fibre including kenaf, hemp, bamboo, corn husk, pineapple-leaf, kapok and jute [3].

Malaysia has been blessed with fertile land and tropical weather, and it is well-known for its agricultural byproducts, such as palm oil and coconut, which are planted on agricultural land. However, this agricultural product produces biomass waste from its production. Empty fruit bunch (EFB) and mesocarp fibre (MF) are two types of fibres from palm oil

*Corresponding author: emedya@uthm.edu.my

processing mill. EFB is the fibrous mass left over from the separation of the oil fruits caused by the sterilisation process. On the other hand, MF, or also known as palm-pressed fibre originated from loose fruits from the fresh fruit bunch (FFB), which were formed after the digestion process [4]. Coir fibre (CF), which is obtained from coconut husk, is widely used as rope, mat or turns as bio composite material. This abundant residue is classified as fibrous materials and provides a great opportunity to convert the waste into alternative raw materials to become value-added products.

When a sound waves travels and hits into materials, some of the sound wave will be absorbed through the heat dissipation process, transmitted or reflected back as echo [5]. Generally, sound absorption and sound transmission are two different acoustical concepts. Sound absorption occurs due to sound energy losses caused by viscous friction and thermal effects within the materials, while sound transmission is the prevention of the transmission of sound waves through the materials [6]. There were two methods to determine the sound insulation performances of materials, which include the reverberation room and the standing wave impedance tube method. The reverberation room method provides a closer result to the actual working conditions [7], however, it has several drawbacks, which are time consuming, expensive and requires a large sample size [8]. Therefore, the impedance tube method becomes a favourable measurement because it is a convenient device, requires only small sample sizes and more cost-effective.

The main consideration in the study of natural fibre is that natural fibre are cellulosic materials that is hydrophilic in nature [9]. The major drawback of natural fibre is their tendency to absorb moisture and poor adhesion between the fibre and matrix. Therefore, alkali treatment using sodium hydroxide (NaOH) is the most convenient and favourable method to improve the natural fibre incompatibilities by removing impurities which are lignin, pectin, waxy substances and natural oil covering the fibre's surface [9]. This also includes silica bodies, which are micro-metric compound commonly found at the surface of oil palm fibre and coconut fibre [10]. By removing this substance, it thereby increases the fibre's surface roughness and increased the bonding between the fibre and binder, which was primarily used in this study, known as urea formaldehyde (UF). The effect of fibre surface treatment was observed on EFB, MF and CF as insulation materials and the sound transmission loss (STL) measurement was measured using the impedance tube method.

2. Materials and Method

2.1 Material

The EFB, MF and CF used in this research were in the form of long fibre, except for MF. The EFB and CF fibre strands were cut into shorter length ranging from 2 cm to 5 cm to facilitate the processes in the fabrication stage. The MF appeared in the form of short fibre, which underwent a sieve process to separate the leftover kernel and dust on the fibre. The NaOH used in this research was prepared with 1%, 2% and 3% of concentrations. The preparation of the treatment chemical involved the dilution of NaOH pallets in the water at a ratio of 1: 20 (fibre: solution) [11]. The fibre were then immersed in NaOH solution for two hours and washed with running water to eliminate any excess NaOH. Thereafter, the wet fibre were sun-dried for several days to reduce the oven-dry duration. To control the moisture content of the fibre, oven-drying process was done at an elevated temperature of 110°C ± 5°C for 30 minutes. During fabrication, the dried fibre were mixed with 15% of UF to form a rounded sample for acoustic testing [12]. Samples were then fabricated at 45 mm thickness with a constant target density of 0.4 g/cm^3 [13]. Spraying technique was used to ensure that the UF uniformly covered the fibre during mixing. The wet fibre were then fitted into a round-shaped steel mould with a diameter of 100 mm and 28 mm, respectively, and a hot compression technique at 180°C was applied to the fibre for 15 minutes.

2.2 Physical Characterization

Physical characterization of the treated and untreated EFB, MF and CF were performed through the fibre diameter measurement and scanning electron microscopy (SEM) analysis. The Digital Microscope Image Analyser was used to measure the fibre diameter. Hundreds of single fibre strands were randomly picked from the untreated fibre, and from each percentage of the treated fibre. Due to the irregular shape of the fibre strands, three points were used (top, middle and bottom sections) on the fibre to measure the strands diameter. Average diameters were used to represent the fibre diameter according to their treatments. Changes on the surface morphological were observed using SEM analysis. To ensure the visual outputs from the SEM were clear and constant, an accelerating voltage of 15 kV was set to 63.0 uA emission at 200 magnifications. All the fibre strands were cut to ±10 mm length and gold-coated three times before performing the SEM analysis.

2.3 Sound Transmission Loss (STL) Measurement

Sound transmission loss (STL) measurement was done following BS EN ISO 10534 Part 2-transfer function method. This measurement was made based on the four-microphone as shown in Fig. 1. The schematic diagram of the impedance tube setup for STL measurement is illustrated in Fig. 2. The sound source and the anechoic termination are mounted on the left and right end of the impedance tube respectively. One set of microphones consisted of mic-1 and mic-2 were fixed to the upstream tube and another set of microphone, mic-3 and mic-4 are fixed on the downstream tube. The test sample is placed in between the two sets of microphones allowing the sound to transmit in perpendicular direction from the source. A distance of four microphones from the front surface of sample are denoted as x1, x2, x3 and x4 respectively.

A single frequency sound was generated from the sound sources, and it was passes through the sample in between the two sets of microphones. 'A' and 'B' indicated the incident and reflected sound component in the upstream tube, while 'C' and 'D' indicated the transmitted and reflected sound in downstream tube. STL is measure as the differences between the incident sound power waves and the transmitted sound power waves as calculated using Eq. (1) [14].\

$$STL = 10\log\frac{Wi}{Wt} \quad (1)$$

where *Wt* is transmitted sound pressure and *Wi* is the incident sound pressure.

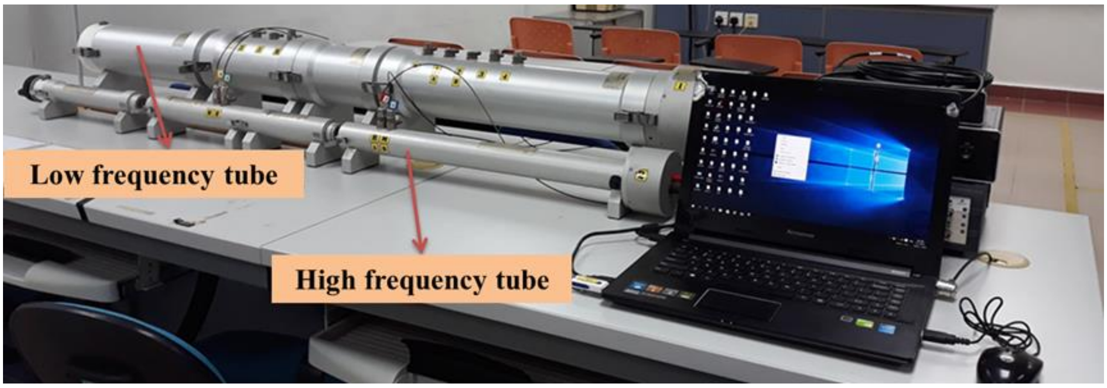

Fig. 1 - Sound transmission loss set-up

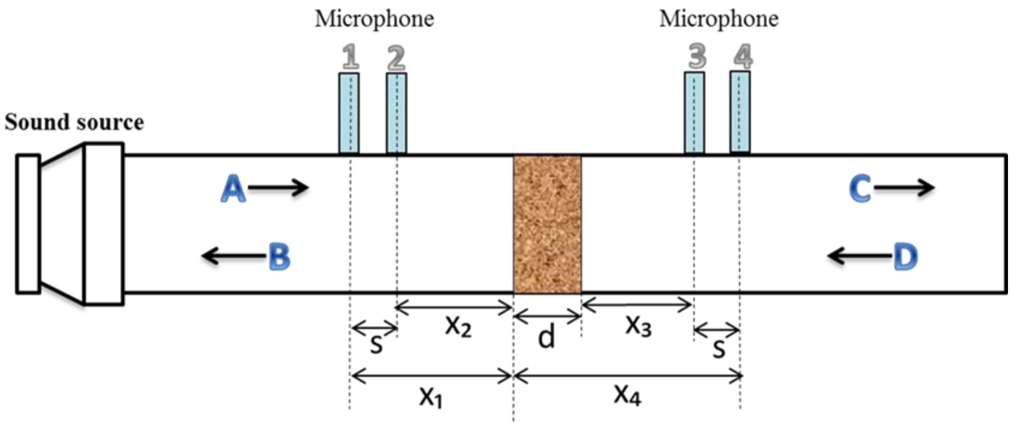

Fig. 2 - Schematic of impedance tube for STL measurement

3. Results and Discussion

3.1 Fiber Diameter

The results of EFB, MF and CF fibre diameters changed after adding various NaOH concentrations as presented in Fig. 3. The MF showed a larger fibre diameter, followed by EFB and CF. When the NaOH concentrations increased, significant decrement of fibre diameter had been observed for all the three fibre. Earlier, the untreated EFB was recorded at 153.5µm, then it reduced to 151.7µm, 149.4µm and 148.1µm when being treated with 1% to 3% of NaOH concentrations. The percentage of reduction was observed at 3.5%. While, for MF, the untreated fibre diameter was at 167.3µm, reduced by 6.5% after being treated with 3% of NaOH concentrations. The MF diameter was recorded at 157.4µm diameter after being treated with 1% of NaOH concentrations, 156.5µm diameter after being treated with 2% of NaOH concentrations and became 156.4µm after being diluted with 3% of NaOH concentrations. As for the CF, percentage of decrement was at 14.8% from the untreated fibre at a diameter of 124.3µm, reduced to 105.9µm after being treated with 3% of NaOH concentrations. It was recorded that 1% and 2% of NaOH concentrations used in the treatment of CF resulted in the fibre diameter to be at 123.9µm and 105.9µm, respectively. Generally, the natural fibre strands consist of a layer of impurities, lignin and hemicellulose that have been removed due to the NaOH pretreatment [15]. Therefore, higher NaOH concentrations caused the removal of more fibre layers and led to a higher reduction of fibre diameter. For instance, a study by Ren et al. [16] also found that the decrement of fibre diameter was due to the removal of pectin, wax and other impurities from the fibre's surface. Furthermore, the removal of the outer surface fibre layers could be verified through observations using SEM analysis.

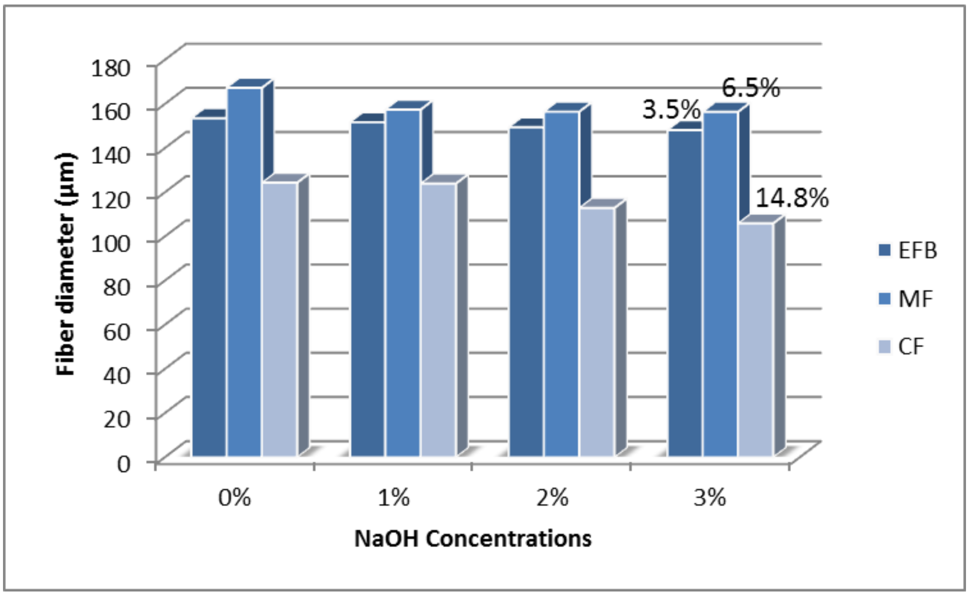

Fig. 3 - Fiber diameter

3.2 Fiber Surface Morphology

Morphological changes that occurred on the surfaces of the fibre after NaOH treatments are shown in Fig. 4. At 0% concentration, the untreated EFB, MF and CF showed the attachment of impurities and waxes on the fibre surfaces, which was due to the handling and mill processing activities.

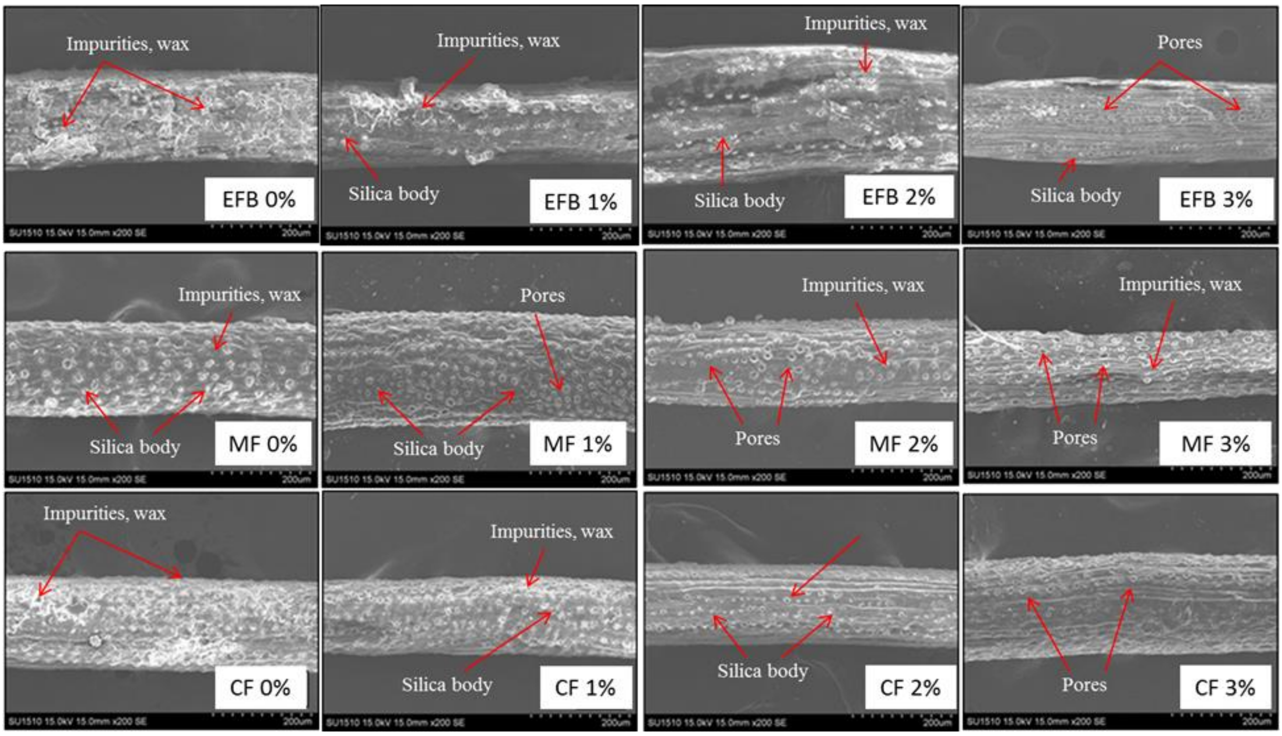

Fig. 4 - Fiber surface morphology of EFB, MF and CF

The EFB sample showed the presence of uneven embedded silica bodies after being treated with 1% of NaOH concentrations. At this stage, the fibre surface was rough, and several impurities were found attached on it. When the NaOH concentrations increased to 2%, a number of silica bodies attached on the strands reduced, resulting on pores being created on the strand surfaces. By increasing the treatment concentrations to 3%, the fibre surfaces became cleaner with more open pores distributed all over the strands. Therefore, increasing the NaOH concentrations caused more pores to appear on the fibre surface [16].

Overall, higher silica bodies were found attached on the MF strands compared to EFB and CF. Fibre pre-treatment using 1% of NaOH concentrations was unable to remove the impurities and silica bodies on the MF surface. Some of the wax and slightly more silica bodies were removed using 2% and 3% of NaOH concentrations on the MF. Moreover, higher treatment concentration had created more pores due to the detachment of the silica bodies, thus increased the interlocking adhesion between the fibre and matrix [17].

The untreated CF surface was greatly covered by impurities including wax, pectin, and grease [18]. Further treatment caused the CF surfaces to be slightly coarser with their silica bodies partially removed. It was observed that the pores created on the coir surfaces due to the pre-treatment were smaller compared to the pores sizes created on EFB and MF strands. Furthermore, 3% of NaOH concentrations used in the pre-treatment produced cleaner fibre, which indicated that NaOH had successfully cleansed the surface of the CF from all impurities. The SEM analysis done on all three fibres indicated the changes on the fibre surface morphology. The removal of impurities, wax, lignin, and pectin layers on the fibre caused the fibre diameter to reduce after the NaOH pre-treatment.

3.2 Sound Transmission Loss (STL)

The sound transmission loss (STL) measured for EFB, MF and CF using the impedance tube method are shown in Fig. 5, Fig. 6, and Fig. 7, respectively. The measurement was taken at a frequency from 160 Hz to 5,000 Hz. The STL for EFB, MF and CF were observed around 5 dB to 18 dB. The STL values are increasing from lower frequency range to the high frequency range for all fibers. At high frequency range, the wavelength of the sound waves less than the thickness of the materials, hence tend to attenuate the energy of incident sound wave [20]. Below 1000 Hz, the STL values were fluctuated but steadily increased toward the end of the tested frequency (5000 Hz). Several other researchers also observed similar trend of the fluctuation graph at lower frequency range [21]-[22]. According to Rajadurai et al, [23], fluctuation is observed on STL graph at lower frequency range due to vibrations, external noises, electric noises and other environmental noises.

The result for EFB showed that using 1% of NaOH concentrations, could achieve higher STL values. However, compared to 2% and 3% of NaOH treated fibre, the untreated fibre surprisingly showed better STL performance. Previously in the diameter measurement and surface morphology analysis, treatment using higher NaOH concentrations caused the fibre outer layers to be diminished and caused the strand diameter to decrease. At a diameter less than 150µm, more porosity had been created on the sample allowing for the sound to pass through the sample, which led to a higher transmission.

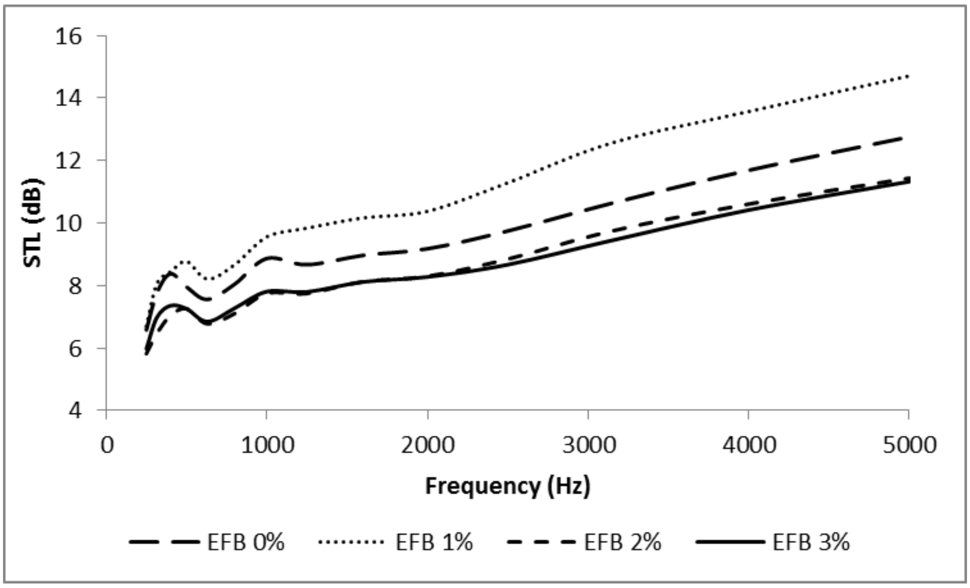

Fig. 5 - STL for EFB

For MF, the 2% NaOH used in the treatment leads to highest STL values obtained from 2200 Hz onwards. Between 1000 Hz to 2200 Hz, MF 1% sample documented STL value more than 9dB, higher than MF 2% before reduced when entering 2200 Hz. However, increasing the treatment concentration to 3% causing the STL performance drop below the untreated fibre performance.

A different result was shown by the untreated CF, whereby this fibre was observed to have the lowest STL for the entire frequency compared to the treated CF. Therefore, using 2% of NaOH concentrations enabled the improvement of the STL performance for CF to the highest STL values. The STL performance obtained by CF treated using 2% of NaOH concentrations was found to be better compared to the results obtained by the same fibre conducted by Kesharwani et al. [20].

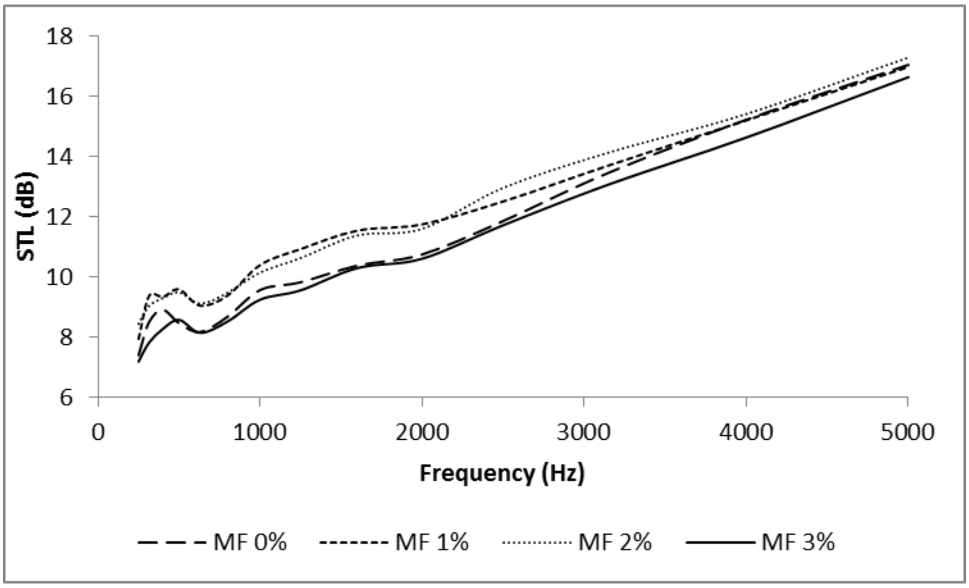

Fig. 6 - STL for MF

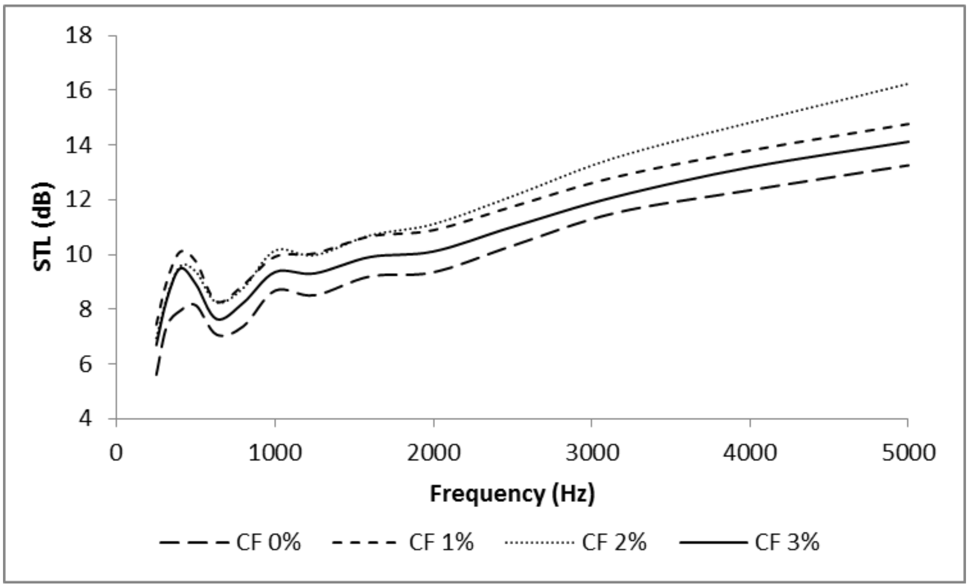

Fig. 7 - STL for CF

Overall, MF treated with 2% of NaOH concentrations performed better transmission loss compared to 1% of NaOH concentrations for EFB and 2% of NaOH concentrations for CF. At 5,000 Hz, 2% of NaOH concentrations for MF gained STL values of 17.27 dB, while 1% of NaOH concentrations for EFB and 2% of NaOH concentrations for CF gained STL values of 14.71 dB and 16.24 dB, respectively. All fibres had satisfactory results for STL measurements, however, extended studies for improvement on STL values to compete with commercial insulation materials are still required. The pores created on the fibre surfaces contributed to the effectiveness of EFB, MF and CF to transmit the sound waves. Higher number of pores on the fibre surfaces of EFB and MF treated with 3% of NaOH concentrations reduced the STL values compared to a few pores with only 2% of NaOH concentrations. Similarly, observations found by Setyowati et al. [24], showed that kenaf fibre tend to have larger pores with channels appearing frequently on its surface than hemp fibre, which resulted in lower STL values for kenaf fibre than hemp fibre. EFB and MF treated with 3% of NaOH concentrations tend to have lower STL values than untreated fibre. The reduction of fibre diameter resulted in several micropores in equal volume density of the sample material [25]. This created the fibre to have larger porosity value and decreased the STL value, as the sound wave was easily transmitted on the porous structure of the sample.

4. Conclusion

This paper aims to explore the potential of the Malaysian biomass waste, namely empty fruit bunch (EFB), mesocarp fibre (MF) and coconut coir fibre (CF) to be used as raw fibre for sound insulation materials. NaOH was used in this research as the primary pretreatment to remove excessive oil and impurities, which were attached on the fibre, and also as a method to modify the fibre diameter and surface morphology. The influence of different NaOH concentrations in the pretreatment of the fibre towards the STL performances was observed in the impedance tube testing. It could be concluded that EFB, MF and CF diameters decreased as the NaOH concentrations used in the pretreatment increased. Therefore, significant changes on the surface morphology were observed. Several pores were created on the fibre surfaces due to the removal of silica bodies, as well as other substances on the fibre. In most cases, transmission loss performances of treated fibre exhibited better results compared to the untreated fibre. Overall, MF had shown the highest transmission loss performance followed by CF and EFB. Based on the diameter and surface morphology analysis, MF had thicker diameter and more pores compared to the other two fibres. These characteristics were found to have significant effects in the STL values. Therefore, it could be concluded that the Malaysian biomass materials have good potential to be utilised as sound insulation materials. However, further studies and some improvements are still needed to maximise their potentials to enable those fibre to compete with the well-established synthetic sound insulation materials that are available in the market.

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