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Sound Absorption Performance of Oil Palm Empty Fruit Bunch Fibreboards using different Fibre Lengths

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Abstract: Solid biomass wastes from oil palm industry has lots of benefits economically. Natural fibre wastes such as Oil Palm Empty Fruit Bunch (OPEFB) is suitable to use as sound absorber material in producing cement board since it contains chemical composition such as Holocellulose, Alpha cellulose, Pentosans, water, ash, and lignin that can improve the acoustic efficiency of the material compared to synthetic fibres. EFB was chose as the main material since the increase in waste output creates environmental sustainability problems in terms of waste management and greenhouse gas emissions from solid biomass and POME. This study aims to utilize OPEFB as a raw fibre in cement board production and measure sound absorption coefficient (SAC) using different fiber lengths retained sieve (1mm, 3mm and 5 mm). and Raw fibers will undergo sodium hydroxide pretreatment to removed excessive oil content, unwanted dirt, lignin, and hemicellulose since it's a cement retarded. The sound absorption coefficients (SAC) of OPEFB fiberboard determined using impedance tube test by Transfer-Function Method according to BS EN ISO 10534-2: 2001. Further analysis has been done to the SAC values at 5-centre 1/3 octave frequencies to determine the Noise Reduction Coefficient (NRC). Relationship between fibre length and sound absorption performance of OPEFB fiberboard established using correlations between the two parameters (fibre length and NRC). The finding is that the long fibre retained sieve 5mm are suitable to be used as it obtained optimum SAC value at 1000Hz and NRC value of 0.62 because long fibres would not fill the gaps or pores between the fibres such as dust particles and effect the sound absorption coefficient value. Thus, EFB can be used as a green technology product for revolutionary absorption for its promising future.

Keywords: Oil Palm Empty Fruit Bunch (OPEFB) , Sound Absorption Coefficient (SAC), Noise Reduction Coefficient (NRC), Fibre Length

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1. Introduction

Malaysia is one of the largest producer and exporter of oil palm in the world [1]. Malaysia is a South-East Asian nation with a tropical climate combined with constant high humidity and temperature where oil palm plantation will thrive in. Almost 4.49 million hectares of land are planted in Malaysia and 17.73 million tons of palm oil and 2.13 tons of palm kernel oil are produced each year [2]. A total of approximately 75.61 million tonnes per annum was produced in the palm oil industry, while the waste created in the palm oil mills (POME) amounted to 65.35% annually. The waste of palm oil and POME was expected to hit between 85 and 110 million tonnes, and between 70 and 110 million tonnes per annum by 2020 [3]. In Nigeria, one of the most plentiful agricultural waste is the biomass waste from palm manufacturing plants which is oil palm empty fruit bunch (OPEFB) which removed from an empty fruit bunch by a retting process. Fibre can also be converted to valuable items such as fuel, fertiliser and mulching materials and at the same time can cause pollution problems if used as gasoline. Natural fibre cement composites have been used widely in building materials and processes such as insulation, cladding, noise barriers and house construction. Most farm waste comes from green sources and is low-cost, lightweight, biodegradable and environmentally sustainable [4]. Natural fibres have more benefits compare to using synthetic fibres as sound insulation materials like those days because these materials can cause harm to human health.

Noise today has been one of the main factors that affected by the development of the industrial economy and transportation networks for human wellbeing and the environment. The need for efficient noise-reduction methods has therefore become a major concern, with the most recent use of waste material and natural fibers as a sound absorber. This is because the use of these materials not only has the ability to minimize noise, it can also address air emission issues. For example, several researchers have been able to develop agricultural waste to produce sound absorption panels [1]. Therefore, this study is to identify the sound absorption coefficient (SAC) and evaluate noise reduction coefficients (NRC) and signifies the relationship between fibre length and sound absorption performance of OPEFB fibreboard. According to the past research, the suitable fibre length in absorbing sound has not been studied by other researchers in wide. So, from this study, it helps to identify optimum length of fibre that can absorb maximum sound when used in cement board.

2. Literature Review

Fibreboards is an engineered wood wallboard made from raw materials such as wood chips, plant fibres, softwood flakes, sawdust and other recycled materials which have been cut into small particles and removed impurities using magnet then blended with wax and synthetic resin and hot pressed under high temperature and pressure into rigid sheets thus really suitable as sound proofing panel [5]. Moreover, fibre board is known as high density particle board and produced using method close to a particle board. For its sound proofing qualities, fibre boards are used in both industrial and residential areas.

Different boards have different type of material on it and different value of densities used to evaluate the mechanical properties. Flexural test has been studied as its appropriate for composite components. Flexural test is the ability of the material to withstand the bending force perpendicular to its longitudinal axis. Other than density, covered surface of fibre bonding, composites porosity, void and fibre structural interfacial bonding are the factors play role in water absorption characteristics of a material. Hydrophilicity is the main factor affecting water absorption rate and mechanical failure during an application. This is because the contents of hydroxyl and other oxygen containing groups on the plant cell wall in most of natural fibres boost absorption of water through hydrogen bonding [6].

Table 1: Sound absorption class [7]

Sound absorption class	Absorption Coefficient, α
A	0.90 – 1.00
B	0.80 – 0.85
C	0.60 – 0.75
D	0.30 – 0.55
E	0.15 – 0.25

According to Nasidi *et al.*, (2018) they focused on how different fibre lengths effect sound absorption performance of OPEFB. In this study, fibre length were decided by the sieving process of fibre. The retained fibre in sieve size 15 mm, 12 mm, 5 mm, 2 mm & <2 mm were used as fibre lengths. Theoretically, small particles of fibre that filled an empty space between the fibre will cause the decrease in porosity value of the sample and effect the SAC value and caused sound transmitted on it cannot be changed into heat energy. So, the fibre between the length 2 mm to 5 mm obtained optimum SAC.

Sound is known as a change in the air pressure, which oscillates around the atmospheric pressure. The surface of the material will be impacted by the incident wave. This can reflect some of wave energy and sending the rest into the material. The percentages of sound wave that were not reflected is taken as sound absorption coefficient. The higher absorption indicates better absorption and less is reflecting [9]. The standard way to identify the effectiveness of a sound absorption coefficient of a material is through the range from 0 to 1.0, where 0 being perfectly non-absorbent and 1.0 being 100 percent absorbent [10]. A part of sound energy also converted to heat energy during this process. The heat is being transferred as there are differences in temperature between fibers causing the sound energy to dissipate. Materials that tend to absorb sound highly dependent on their porosity. Sound transmitted by frictional force so that sound wave can enter the porous material. Hence, there should be sufficient pores on the surface itself for the wave pass through and dampened [11].

Noise Reduction Coefficient (NRC) is a single value calculation used to measure the scalar of sound energy absorbed once it is striking the surface of the board [7]. The NRC value will be determined at the octave band of 250 Hz, 500 Hz, 1000 Hz and 2000 Hz by averaging the SAC value (α) of materials and rounded off the value to the nearest 0.05. The NRC value can be calculate using Equation 1 below.

$$NRC = \frac{\propto_{250\text{ Hz}} + \propto_{500\text{ Hz}} + \propto_{1000\text{ Hz}} + \propto_{2000\text{ Hz}}}{4} \qquad Eq.\ 1$$

There are three frequency ranges that have identified as main concerns in building acoustic studies which in range from 50 Hz to 200 Hz (low frequency sector), 250 Hz to 1000 Hz (medium frequency sector), and 1250 Hz to 5000 Hz (high frequency sector) (high frequency sector) [12].

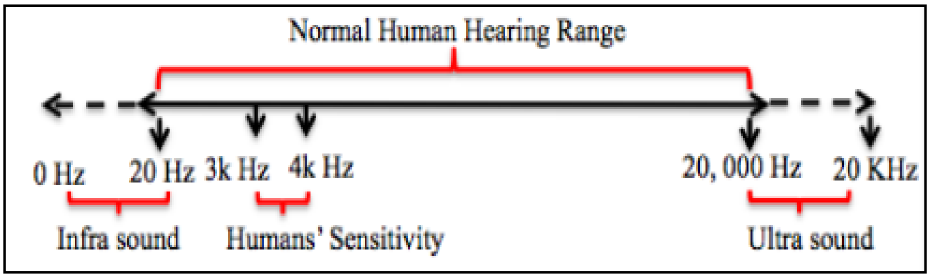

Figure 1: Human Hearing Range [12]

3. Materials and Methods

All the material preparation, board processing, and testing involved were conducted at the Wood Fabrication Laboratory, and Noise and Vibration lab in Mechanical Laboratory. Oil Palm's Waste which is Empty Fruit Bunch (EFB) was used in producing fibre board to determine the sound absorption capability of the board. Three different lengths of fibre that are retained from three different sieves were used (5mm, 3mm, and 1mm) in preparing three different boards. A detailed overview of the project including fibre processing, EFB fibre treatment, manufacturing process, and testing to measure the sound absorption performance of the fibre board are discussed. Figure 2 shows the flow chart of the experiment which is divided into several stages.

3.1 Materials and Equipment

The main raw materials which is Oil Palm Empty Fruit Bunch (OPEFB), water, Ordinary Portland Cement and sodium Hydroxide (NaOH) were prepared for fabrication of cement-fibre board. The fabrication process takes place by using equipment's such as hammer mill, sieve (7mesh,14 mesh & 30mesh), mixer machine, steel mold, wooden mold, plywood plate, polypropylene sheet, wire mesh and hydraulic compressor.

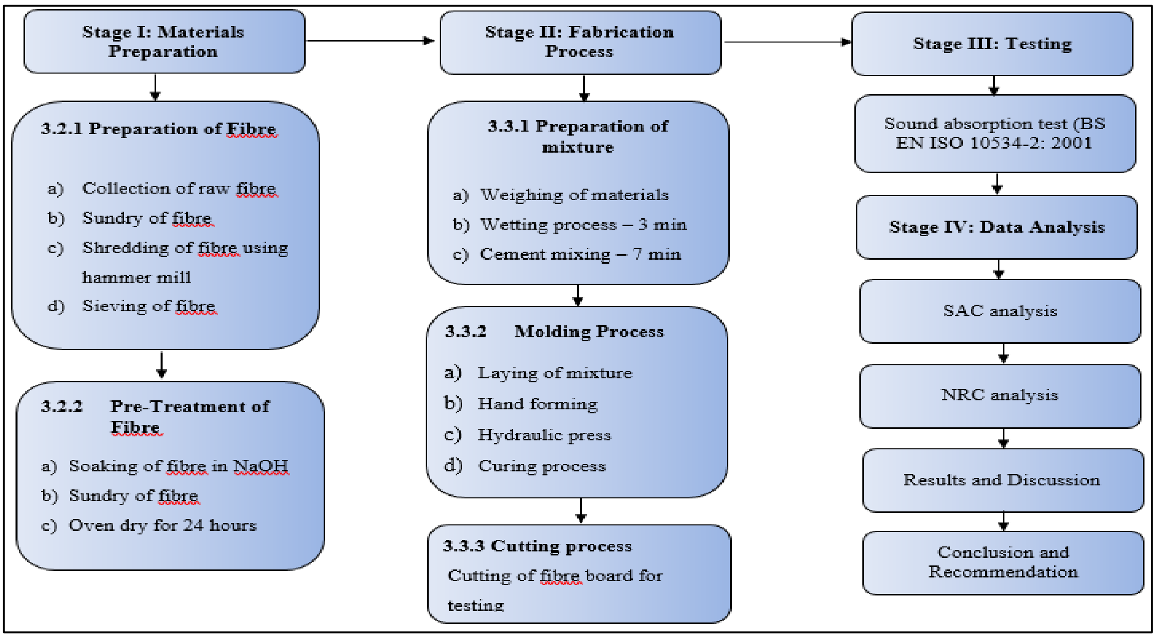

Figure 2: Flowchart of research

3.2 Fabrication steps

As the first step in the manufacturing of the fibre board, raw material should be prepared. A ton of raw fibres were collected from Oil Palm Mill and dried under the hot sunlight to reduce the moisture content until reaches around (10% -15%). Then, the dried fibre was crushed using a hammer mill and sieved for 2 minutes to remove the dust and separate it according to lengths 5mm, 3mm and 1mm. The fibre was pre-treated for 24 hours by soaking it in 0.4% of sodium hydroxide (NaOH) from the total weight of the water used to soak the fibre to remove unwanted dirt, lignin, and hemicellulose since it's a cement retarded [16]. After 24 hours, the fibre was washed using tap water and sundried till it partially dry and oven-dried for 24 hours under 100°C till it reaches moisture content around 5%. The fibre board samples using the different lengths of fibres of targeted density 1300 kg/m^3 were prepared for a total of 3 samples. The dried EFB fibre was mixed with the water and cement gradually in the mixer for total of 10 minutes until all the surfaces of fibre were covered with cement. For this study, the cement-fibre ratio is 3:1 with water content of 40% [17]. After done with the mixing, the mixture was poured into the mould size of 350mm x 350mm x 12mm and used hand forming method to form the cement-fibre board. To make it easier for demolding afterward, a polypropylene sheet was put on both sides of the mold to prevent the sample from forming an irregular surface and to make demolding smoother. Once the mixture is added to the mold, it is compressed until it reaches the desired thickness. After that, the samples were dried at ambient temperature for 28 days. Upon completion, the sample is cut into several circle specimens for testing procedures. Sound absorption coefficient (SAC) testing procedure conducted using Impedance Tubes following Transfer-Function Method: BS EN ISO 10534-2: 2001. The impedance tube was connected with VA-Lab4 software, an amplifier, two microphones, a loudspeaker and one signal analyser.

Table 2: Number of samples produced according to the sizes

Sample	No of Sample Produced	Length of Fibre Used	Ratio
1	1	R7M – Retained sieve 5mm	3 : 1
2	1	R14M – Retained sieve 3mm	3 : 1
3	1	R30M – Retained sieve 1mm	3 : 1

4. Results and Discussion

The results focus on the sound absorption coefficient (SAC) and noise reduction coefficient (NRC) of empty fruit bunch cement board (EFBCB). As mentioned previously, the suitable fibre length in absorbing sound has not been studied by other researchers in wide but it is proven that the fibre length will affect the sound absorption rate. Three fibre length has been compared by producing cement-fibre board in order to find which fibre tend to absorb optimum sound.

4.1 Sound Absorption Coefficient (SAC) Analysis

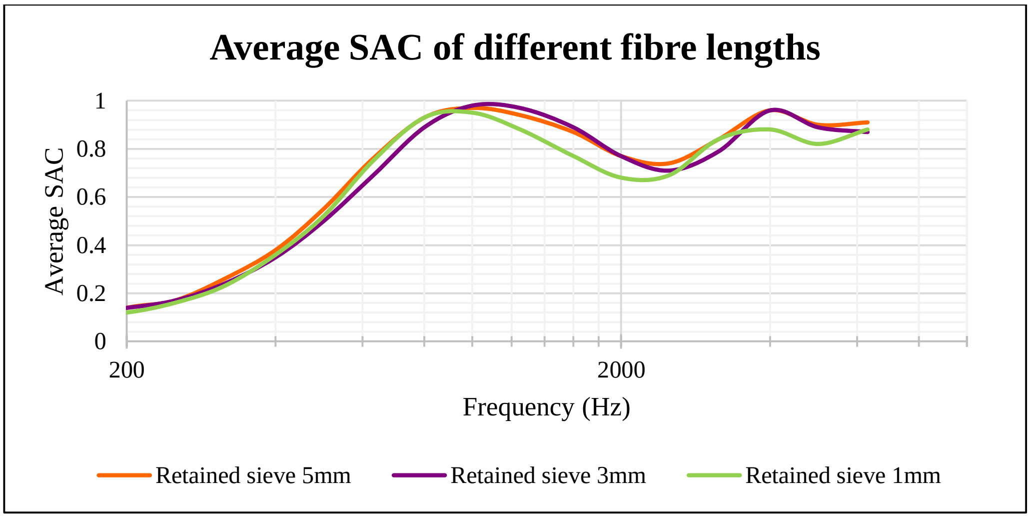

Figure 2: Average SAC of different fibre lengths

Figure 2 shows the sound absorption coefficient over the frequency spectrum of EFB samples with different fiber lengths as measured by the impedance tube. It was found that the absorption coefficient of the three different lengths of EFB samples initially increased from 0.1 to 0.98 but then decreased in the range of 0.68-0.77 at between 1250 Hz to 2500 Hz before reaching a peak of 0.88 - 0.96 at 4000 Hz. In essence, the sound absorption spectrum obtained corresponds to previously published data where it shows a standard pattern for absorbent materials.

The results revealed that in the medium frequency range, the three varied lengths of the EFB sample had greater sound absorption coefficients, with an average absorption range of 0.95 - 0.98. On 3mm and 5mm sieves, the EFB exhibited the best acoustic performance against the frequency. The EFB retained at 3mm and 5mm sieves obtained maximum values of sound absorption coefficients of 0.98

and 0.97 at 1000 Hz, respectively, and these two fibers also demonstrated the highest value range from medium to high frequencies. The fibre retained on the 1mm sieve showed less improvement since their absorption value was greater only at 1000 Hz. The sac values dropped from medium to high-frequency levels significantly and showed clear differences between the other fibers. These results indicate that the longer EFB absorbs sound better than the shorter EFB. Although, the fibers retained on the 1mm sieve showed a drop in value after 1000 Hz, the average value of the overall sound absorption at the middle frequency is higher.

Sound wavelength that is audio able to human's ranges from 0.5 inch up to 50 ft long. As stated earlier in the chapter 2, human hearing extends from 20 Hz to 20,000 Hz, with people being more sensitive to sound around frequencies of 3,000 Hz to 4,000 Hz (this is equivalent to 7-10 cm wavelength). The frequency-wavelength relationship was represented in the frequency-wavelength nomograph by Stein and Reynolds (2000). Sound wavelength is longer at low frequencies, and that as the frequency rises, the wavelength decreases. Because acoustic studies in buildings are concerned with three frequency ranges: low, medium, and high, which correspond to 50 to 200Hz, 250 to 1000Hz, and 1250 to 5000Hz, respectively, the wavelength size is critical in determining fibre length. Longer fibre length has better sound absorption coefficient.

4.2 Noise Reduction Coefficient (NRC) Analysis and Relationship between Fibre Length and Sound

Absorption Performance of EFB Fibre Board

Table 4 is represented NRC (Noise Reduction Coefficient) for sound absorption capability of porous materials using specimens that make difference between the length of fibres.

Table 4: Length of fibre retained on sieves

Length of Fibre Retained on Sieve (Mm)	NRC
1	0.58
3	0.61
5	0.62

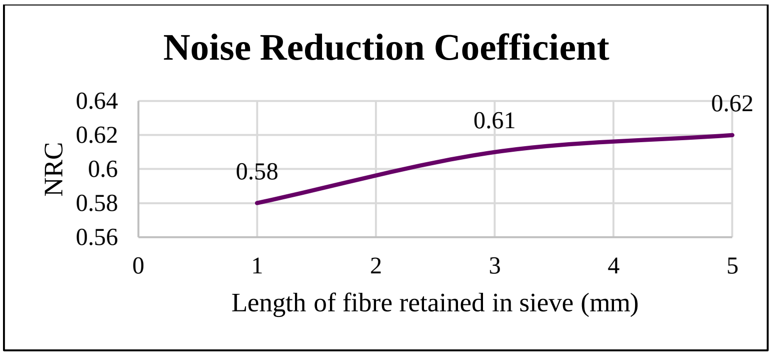

Figure 3: Overall NRC of different length of fibre's

Figure 3 shows a linear relationship between the length of fibre retained in the sieve and the noise reduction coefficient. The NRC values ranged from 0.58-0.62. It was found that NRCs for all samples are above 0.5, thus specify EFB is highly absorptive [14]. The optimum value with the most significant increase of NRC value at 0.62 obtained by the fibre retained on sieve 5mm while the lowest is 0.58 obtained by the fibre retained sieve 1mm. The 0.62 indicates 62% of noise in the space is absorbed, while the other 38% is reflected. Less differences were found when the fibre length increase but as the fibre length decreases, the NRC of EFB significantly drop. However, the length of fibre retained sieve 5mm is consider good absorber for acoustic applications.

As stated in past research, fibre length shows some effect on the sound absorption performance of the cement-fibre board. Few different sizes of fibre length used in conducting this study research. Theoretically, the greater the fibre length, the higher the absorption rate. Sound is transmitted by frictional force so that sound waves can enter the porous material. The number, size and type of pores are the main factors determining the characteristics of a porous material. Hence, there should be sufficient pores on the surface itself for the wave pass through and dampened. Porous absorber is the most effective sound absorber for medium and high frequency sound. Hence, the major losses of sound energy for porous absorber occur at a distance of a quarter wavelength from the backing wall when the partially reflected waves interferes with the incoming waves [13]. Since at lower frequency, the wavelength is longer, therefore less pores material able to give high resistance and allows for enough time for the wave to be converted to heat.

Long fibre is suitable for use as a material in board manufacturing because it will allow sound to pass through the spaces between fibres and absorb in as there will be more voids compare to short fibres. Short fibres will reduce the voids and affect absorption. It will be more worst if dust particles mix while manufacturing board as dust particles will fill up all the gaps and cover the voids between the fibres and affect the sound absorption and cause the sound reflect to the space. Porosity plays a crucial role in sound absorption as sufficient pores needed for the wave to pass through and dampened. When the porosity increases up to 70%, the absorbency of materials also increases. This indicates that the absorption of the materials in the fibreboard produced was more than 70%, this is why the noise reduction value tends to increase and reached 0.62. The fibres retained in sieve 5mm is suitable to use as the material in producing fibre board as the fibre length is longer compare to the others and more voids are there for the sound to travel. Other than that, the longer the fibre, the bigger the surface area. So it will have more resistance to let the sound wave penetrate. When resistance high due to a big surface area, the absorbency will cause a loss of wave energy to heat energy. Small fibres will diminish the holes in this scenario since they have a small surface area and less absorption, causing the sound to reflect.

5. Conclusion

The sac value obtained for each of the fibre board by using different length of fibre retained sieve 1mm, 3mm and 5mm shows the peak value at the frequency of 1000 Hz in the range of 0.94 – 0.98 which in the same range with the value acquire by the average sac value for three samples that obtained from each of the fibre lengths. Even though there is a drop and uneven rise and fall in the graphs, maximum sound absorbed by the fibres retained at 3mm and 5mm sieve at medium to high frequency since fibers retained on the 1mm sieve exhibit a decline in the value after 1000 Hz. Therefore, sound absorption coefficient using different fibre length was observed. The drop in the sound absorption in between the specific ranges has not been defined yet by Delanye-Bazley model or the Allard model too. This was done by using data from the literature for non-acoustic microstructural features, however it did not significantly enhance the theoretical predictions. Since the board fabricated according to the BS EN 634-2:2007 which the fibre board is suitable to use in dry, humid and exterior conditions so the board produced is suitable to absorb traffic noises too other than internal noises.

In order to determine the NRC value of oil palm empty fruit bunch fibreboards using different fibre lengths, the average SAC value has been averaged at 1/3 octave band. The highest NRC value obtained by the fibre length retained on sieve 5mm. 0.62 indicates that 62% of noise absorbed while balance 38% of the noises reflected back to the space. This shows an excellence absorbent since its more than half of the absorbent and tend to reduce noise and provide comfort for the user. From the overall result obtained, it can be concluded that the longer the fibre length, the higher the NRC value. According to the result obtained in data analysis, it has been concluded that fibre retained on sieve 5mm is the suitable length in in this this study as it allows sound wave to travel through and absorb more sound and reduce maximum noise as well. Porosity plays an important role in sound absorption as the longer the fibre, the more voids will be in between of the fibres meanwhile the dust particle will totally fill the gap or void between the fibres. Furthermore, if the fibre is long, the surface area will be bigger. Bigger surface area will have more resistance to let the sound to penetrate. The absorbency causes a loss of wave energy to heat energy when resistance is high due to a large surface area.

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