Utilizing Natural Fibre as a Sustainable Acoustic Absorber

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Abstract The availability of agricultural waste as sound absorptive materials can be used in indoor and outdoor application. This study aims the potential of natural fibre from agricultural waste as materials for measurement of sound absorption coefficient (SAC). The fibre selected in this study are oil palm, coconut and banana. The natural fibre samples were treated by alkaline treatment during processing stage. The mixture proportion with 95% of natural fibre and 5% of sodium hydroxide (NaOH) as a binder and all the samples follow the fixed ratio of 95:5 for every weight of selected natural fibre. Then, the treated and mixed natural fibre were put into a mould for compaction process to produce diameter of 100 mm and 30 mm with thickness of 20 mm and 30 mm, respectively. All natural fibre samples were tested using Impendence Tube Method (ITM) based on ASTM E1050-09. The tests were conducted according to standard ISO10534-2 with high frequency range and low frequency. As a result, samples of coconut fibre with 20 mm thickness showed a good SAC value at low frequency which is 0.31, meanwhile oil palm fibre with 30 mm thickness attained 0.41. For high frequency testing, coconut fibre sample of 20 mm thickness resulted the highest SAC value at 0.41 and oil palm fibre sample of 30 mm thickness had the highest SAC value which is 0.81. Therefore, natural fibre showed respectable potential as an absorption material for sound reduction.

Keywords Impendence Tube Method (ITM) · Natural fibre · Sound Absorption Coefficient (SAC)

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M. A. A. Zaini et al. (eds.), *Proceedings of the 3rd International Conference on Separation Technology*, Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-16-0742-4_17

1 Introduction

Noise pollution is unwanted or excessive sound that can have adverse effect on human health and environment quality [1]. Noise pollution can lead to a great influence on the environment, human health, economy and noise pollution has become the third pollution resource [2]. As the issue of undesirable and possibly hazardous noise has turned out to become serious, the interest of better environment and residential security is expanded and turns into a major necessity. Different studies focusing acoustic properties have been performed. Acoustical material plays significant roles in acoustic building, for example, the control of room acoustics, industrial noise control, studio acoustics and automotive acoustics [3]. Noise from building can be controlled by implementing a good design for the building. Overall building interior can reduce noise by the extensive use of materials that can absorb sound. Moreover, the advancement study of the acoustic attenuation technique of porous materials offers a wide opportunity [4]. The available usage of agricultural waste as sound absorptive materials can be used in indoor and outdoor application. Agricultural wastes that contain numerous amounts of fibre selected in this study are oil palm, coconut and banana. Overall, 998 million tons of agricultural waste are produced annually, and 1.2 million tons of agricultural waste are disposed of annually in Malaysia in landfills [5].

As indicated by researcher, Malaysia is at present the world's biggest producer and exporter of palm oil [6]. Palm tree is Malaysia biggest agricultural plantation with the aggregate of 4.69 million hectares with existence cycle of 25–30 years for beneficial oil palm. It is estimated that in dry load there would be in excess of seven million tons of oil palm trunk wastage available every year [5]. Malaysia was ranked ninth, before Tanzania, in the top ten coconut producers in the world in 2016 by producing 555,120 tons per year, according to the United Nations Food and Agriculture Organization. Besides coconut wastes generation through processing operations in coconut-based industry, abundant coconut waste is also generated in Malaysia from stalls where coconut juice is sold and the inner part is ground for coconut milk. This leaves the whole part of the coconut head as waste. Malaysia has different type of natural materials that drive the development of small art businesses with eco-friendly idea. Being a potential material, banana bark as the waste delivered by banana plantation is yet underestimated and less famous contrasted with other materials [7]. Despite its plentiful availability in Malaysia, banana bark usage is yet lacking in further improvement.

Most of the building structure used synthetic materials for sound absorption.

panel and still a regular practise for them. The higher amount usage of synthetic materials can cause pollution to the environment and human health in a very short time. The objectives of this study are to investigate alternative materials for sound absorption using natural fibre and selecting the best natural fibre to be used as a replacement for synthetic materials. Due to the problem, natural based materials are selected to replace the synthetic materials because the materials are naturally biodegradable, less hazardous to human health and non-harmful to the environment.

Therefore, the urgency of this study is to produce a practical and high quality of sound absorber for selected natural fibre.

2 Literature Review

Literature review discuss on benefits of natural fibre composites for sound absorber, sustainable panel, alkaline treatment, SAC and fibre size.

2.1 Benefits of Natural Fibre Composites for Sound Absorber

The use of natural fibre, for example, coconut, palm oil and banana reinforced composites have drawn a lot of attention for sound absorption material. Due to their biodegradable, lightweight, less expensive, nontoxic and nonabrasive characteristics, natural fibre are accepting much consideration in composites as a substitute for synthetic fibre for acoustic absorption purposes [8]. The natural fibre with desirable physical and mechanical properties are shown as high performance composites with environmental and economic advantages [4].

The needs of natural fibre to substitute synthetic fibre such as glass wool and rock wool had been discussed among the acoustician today. There are a lot of benefits of natural fibre and can be utilized for sound absorption materials. Natural fibre has been known as a green material because of its biodegradability. Natural fibre additionally known to be lower density contrasted with synthetic fibre, less expensive and renewable [3].

Aside from that, natural fibre processing is more economical and greener towards environment contrasted with synthetic material because of the advancement of technology [5]. Moreover, natural fibre is likewise a lot more secure for human health contrasted with synthetic fibre as it doesn't require any dealing with safety measures. Production of natural fibre includes fundamentally lower carbon emission contrasted with synthetic fibre [8]. In this way, natural fibre has been sorted as environmentally green material, and may hold the key to produce greener sound absorption later on.

2.2 Sustainable Sound Absorption Panel

In recent time, green technology proposed used manufacture materials from agricultural as sustainable material for noise absorption purposes. Natural fibre like oil palm fibre, coconut fibre and banana fibre have numerous advantages, for instance low weight, low density, low cost, acceptable specific properties and recyclable or biodegradable [9]. These materials have shown great highlights from the both of part of sound qualities and mechanical. Previous study showed, at low recurrence, 0 to

500 Hz, sound absorption of rice husk was higher than virgin polyurethane with the estimation of 0.899 at 250 Hz [8].Though, the virgin polyurethane recorded higher absorption at a higher frequency, 2000 Hz with an estimation of 0.679. This demonstrates natural fibre have the potential as filler material of sound absorbent material [8].

Nowadays, in agro-industrial and estate of crop industry, high value of crop waste, which is right now treated as solid waste were created. In practice this residue is burned which contributes to environmental pollution issues in almost regions and offers restricted value to the industry [10]. By thinking about this situation, an alternative practice should be considered by the crop industry to commercialize the residue from crop waste to recycle without causing environmental pollution and produce another product like sound absorption panel. This practice will require less energy, and lessens pollution in modern effluents, as well as being financially advantageous because of its reduced expenses [7].

2.3 Alkaline Treatment

Improvement of hydroxyl groups by hydrophilization may increase the mechanical properties of fibre and produce a stronger bond by enhancing the wetting effect of the resin on the fibre [7]. The research also found an increment in fibre surface roughness and surface area after alkaline treatment. Removal of some impurities through alkaline treatment has made every single fibre clearly observed and exhibits excellent mechanical properties compared to others. Therefore, a treatment is applied. Alkaline treatment increases the surface roughness of fibre by evacuating some important substances like lignin, gelatine, and hemicelluloses of the fibre. In spite of the fact that the removal of these substances brings down the acoustic absorption coefficient of the material, it permits better fibre-binder interface bond, fibre fitness, life span, and anti-fungus quality and in particular reduce the diameter of the fibre [11].

2.4 Sound Absorption Coefficient (SAC)

Sound Absorption Coefficient (SAC) is defined as ratio of absorbed energy to incident energy noting the amount of sound being absorbed by a material [12]. The absorption coefficient ranges between zero and one, one meaning no sound energy is reflected and the sound is either absorbed or transmitted. The higher the percentages, the better the absorption is, indicating most of the sound being absorbed and less is being reflected and is portrayed in the work [7]. As illustrated in Fig. 2.1, it is observed that there are three types of waves encountered by a certain material which are incident sound, reflected sound and transmitted sound. Incident waves are being projected onto a material and it can be reflected or transmitted [1].

Sound absorption coefficient can be calculated, the absorbing coefficient can be mathematically presented as follows in Eq. (1) and (2) [13]:

$$\alpha = \mathrm{EA}/\mathrm{EI} \tag{1}$$

$$\alpha = 1 - |\,\mathrm{r}\,|^2 \tag{2}$$

where;

α = sound absorption coefficient, EI = incident energy, EA = absorbed energy, r = incident reflection factor, IAbs = Sound intensity absorbed.

2.5 Fibre Size

Fibre diameter is the most significant physical parameter for enhancement of the sound absorption performance of any fibrous material. The decreasing amount in fibre distance leads to an increased value of the sound absorption coefficient. This is due to more fibre are required to achieve a similar volume density at a similar thickness of the sample material. This results in a higher airflow resistance inside the sample material. Therefore, the acoustical performance of the sample material increases because of the viscous friction through air vibration [11]. The diameter of coconut fibre is 397 μm, oil palm fibre 300 μm and banana fibre 25 μm respectively [14]. All the natural fibres were cut with same length which is 20 mm for sample preparation.

3 Methodology

The method of study involved from selection of natural fibre, then preparation of samples and finally was testing the sample. Details of each process were discussed as below.

3.1 Selection of Natural Fibre

Many studies focused on a similar group of natural fibre, which have been discovered and suggested to be used as acoustical panel. Natural based materials are selected because the materials are naturally bio-degradable, less hazardous to human health and non-harmful to the environment [10]. Malaysia has produced a large amount of agricultural waste [5]. This study aims to study about sound absorption of three different natural fibre materials that are abundance in Malaysia. The chosen materials

Table 1 Chemical properties of natural fibre

Fibre	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Tensile strength (MPa)	Diameter (μm)
Coconut	68	22	20.6	88.63	397
Oil palm	48	22	25	350 ±7	300
Banana	63	19	5	550 ± 6.8	25

are natural fibre which are coconut coir fibre, oil palm fibre and banana trunk fibre. All of the natural fibre were obtained from Koperasi Pekebun Kecil Daerah Kluang (KOPEDAK) in Simpang Renggam. Table 1 shows the properties of selected natural fibre [14].

3.2 *Raw Materials Preparation*

Natural fibre waste was collected at KOPEDAK and extracted by using hand scrapping method. Then, the processed fibre were sun-dried for two weeks with an average temperature, 31.5 °C and average relative humidity of 96%. Sun-dried method was used to ensure the natural fibre went completely dried and ready to be used before panel formation. Figure 2 shows the flow of raw natural fibre preparation.

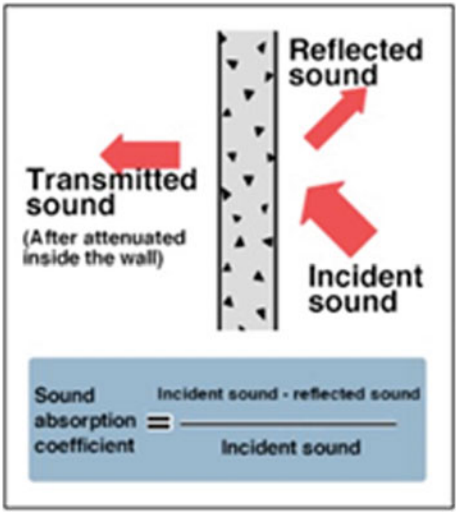

Fig. 1 Schematic representation of sound absorption coefficient

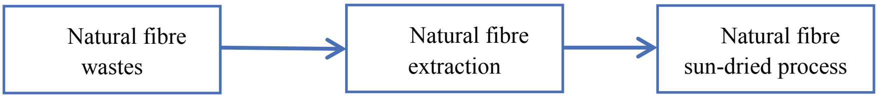

Fig. 2 Raw natural fibre preparation process

3.3 Natural Fibre Sample Preparation

Figure 3 shows the flow of natural fibre samples preparation. There were 6 steps for the sample preparation.

3.3.1 Weighting of Natural Fibre

The materials were being weighted separately and mixed with 50% sodium hydroxide (NaOH) solution for alkaline treatment. The mixing proportion ratio for each natural fibre sample was fixed at 95:5 with 30 and 20 mm thickness as shown in Table 2 for sample 100 mm diameter and Table 3 for 30 mm diameter. All the natural fibre went through the same procedure for sample preparation.

3.3.2 Alkaline Treatment

After raw natural fibre went through drying process, the natural fibre were cut with the same length of 20 mm. Mixing proportion of each natural fibre and NaOH solution was fixed at ratio 95:5. Alkaline treatment act as a binder which increases the surface roughness of fibre by evacuating some important substances like lignin, gelatine, and hemicelluloses of the fibre.

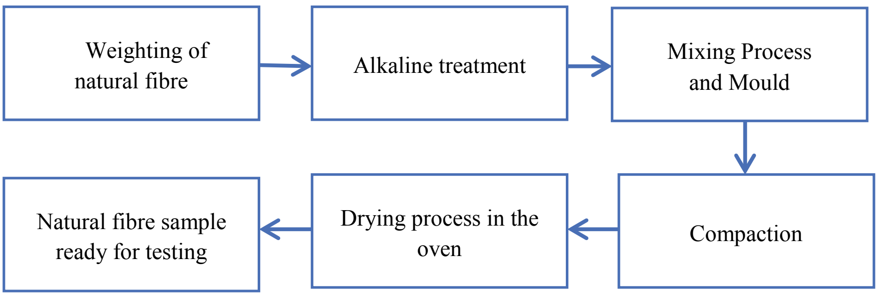

Fig. 3 Flow of natural fibre sample preparation

Table 2 Mixing proportion of 100 mm diameter of natural fibre sample

100 mm diameter samples	Ratio of NaOH to natural fibre
Oil palm fibre sample (30 mm thickness)	150 g: 8.33 g
Coconut fibre sample (30 mm thickness)	150 g: 8.33 g
Banana fibre sample (30 mm thickness)	150 g: 8.33 g
Oil palm fibre sample (20 mm thickness)	100 g: 5.55 g
Coconut fibre sample (20 mm thickness)	100 g: 5.55 g
Banana fibre sample (20 mm thickness)	100 g: 5.55 g

Table 3 Mixing proportion of 30 mm diameter of natural fibre sample

30 mm diameter samples	Ratio of NaOH to natural fibre
Oil palm fibre sample (30 mm thickness)	50 g: 2.63 g
Coconut fibre sample (30 mm thickness)	50 g: 2.63 g
Banana fibre sample (30 mm thickness)	50 g: 2.63 g
Oil palm fibre sample (20 mm thickness)	30 g: 1.57 g
Coconut fibre sample (20 mm thickness)	30 g: 1.57 g
Banana fibre sample (20 mm thickness)	30 g: 1.57 g

3.3.3 Mixing Process and Mould

For Sound Absorption Coefficient (SAC) testing inside Impendence Tube, 30 mm sample diameter was required for high frequency testing and 100 mm sample diameter was required for low frequency testing. Each sample had two different thickness, 20 mm and 30 mm (Fig. 4).

3.3.4 Compaction

Compaction process was conducted by using soil compactor. The average blow pressure of the rammer into the mould is 3.7 kPa to ensure the natural fibre bind and compact together to produce panel absorption board.

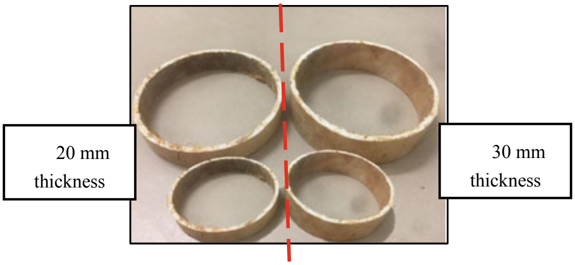

Fig. 4 Mould with diameter of 100 mm and 30 mm for sample preparation

3.3.5 Drying Process in the Oven

After all the natural fibre samples were fully compacted, the samples were demoulded and placed into dry oven for 2 h at 100 °C. To ensure all the natural fibre samples completely dried, all the samples were placed again into the oven for 3 days at temperature of 35 °C. Drying process of natural fibre samples was conducted at Highway Laboratory, UTHM Pagoh Campus.

3.3.6 Natural Fibre Samples

Figure 5 shows natural fibre samples after completely dried in the oven. After that, the samples were exposed at room temperature for 24 h to ensure it totally dried and ready for Impendence Tube Method (ITM) testing.

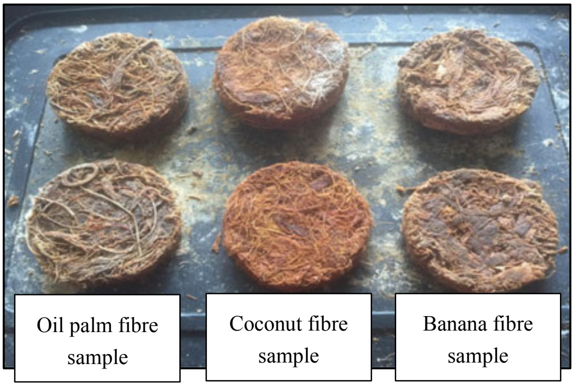

Fig. 5 Natural fibre samples with 100 mm diameter and 20 mm thickness

3.4 Impendence Tube Method Testing

Sound absorption properties of the samples were tested at Building Services Laboratory, UTHM Pagoh Campus by using impendence tube method (ITM). This ITM used two microphones to transfer the sound wave and it required two sample size diameter which are 30 and 100 mm to test the frequency from 75 to 5000 Hz as indicated by ISO 10,534-2 standard [15]. Factors such as the surrounding setting of air, temperature, relative humidity, and atmospheric pressure inside the room at the start of the procedure and the sample's insertion are important and must be considered [16]. The test sample was placed at one end of a straight, rigid, and smooth impedance tube. Two microphones position will transfer the frequency and the SAC value will be determined. The absorption coefficient can be assessed from the direct measurement of the reflection coefficient. Plane waves are produced in the tube by a sound source, and the sound pressures are assessed at two locations from a short distance to the sample [17]. The complex acoustic transfer function of the two microphone signals is identified and used to compute normal-incidence absorption coefficient of test material. "AED 1001" is a computer software that is used to interpret sound absorption coefficient of samples.

4 Result and Discussions

After all the testing being done for three types of fibre, the results were recorded and analyse for two different frequency (low and high) with two thickness (20 mm and 30 mm).

4.1 Low Frequency Testing

Samples of 100 mm diameter were used to test low frequency of SAC ranging from 75 to 500 Hz. The sound pressure will be measured in two microphones positions and the transfer function between them will be determined. The absorption coefficient can be assessed from the direct measurement of the reflection coefficient.

4.1.1 Natural Fibre 20 mm Thickness

Figure 6 shows the comparison of the sound absorption coefficient (SAC) of three different fibre which are oil palm fibre, coconut fibre and banana fibre for thickness of 20 mm. Coconut fibre sample shows the highest SAC value among all other natural fibre. The highest SAC value for the three natural fibre samples at low frequency

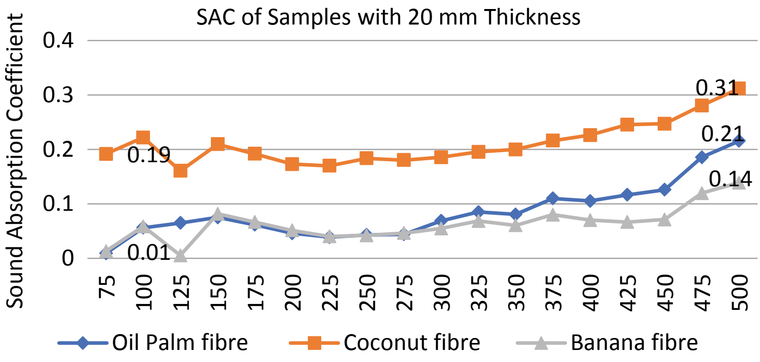

Fig. 6 Low frequency of SAC for three samples with 20 mm thickness

range were at 500 Hz. Coconut fibre sample had the highest SAC value which is 0.31 followed by oil palm fibre sample; 0.21 and banana fibre sample at 0.14.

4.1.2 Natural Fibre 30 mm Thickness

Figure 7 shows the graph SAC value against frequency of three different fibre which are oil palm fibre, coconut fibre and banana fibre for thickness of 30 mm. SAC of banana fibre was the highest at the beginning which was 0.19 compared to oil palm and coconut fibre which was 0.008 and 0.006 respectively. Banana fibre had higher potential of SAC at frequency 75–325 Hz, but oil palm fibre had higher potential of SAC at frequency 350–500 Hz. Maximum value of SAC reached by the three natural fibre sample was at frequency 500 Hz. Oil palm fibre had the highest SAC value at low frequency range which is 0.53 followed by coconut fibre at 0.35 and banana fibre at 0.31.

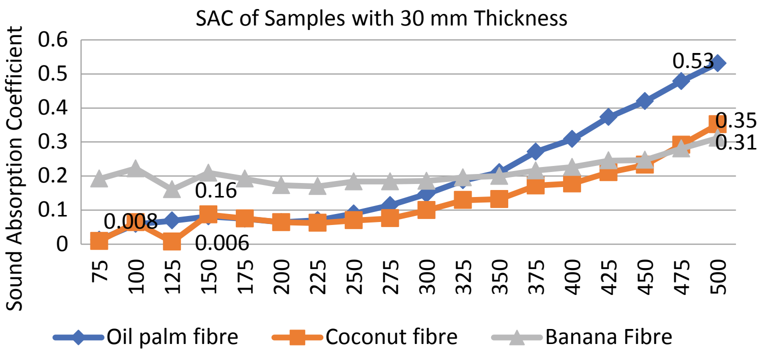

Fig. 7 Low frequency of SAC for three samples with 30 mm thickness

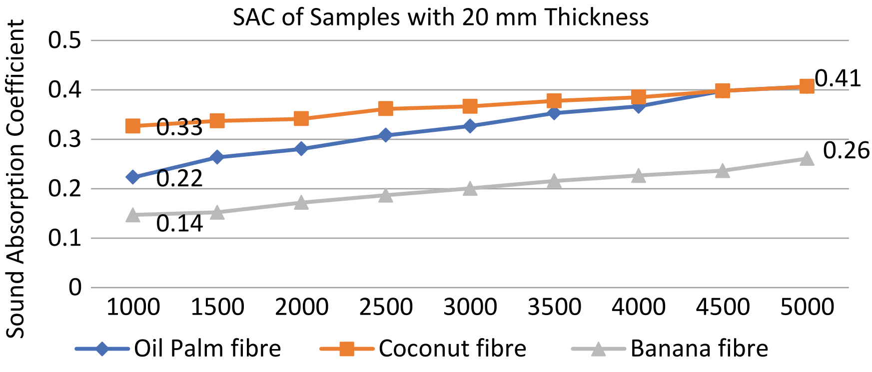

Fig. 8 High frequency of SAC for three samples with 20 mm thickness

4.2 *High Frequency Testing*

Samples with 30 mm diameter were used to test high frequency of SAC ranging from 1000 to 5000 Hz. For absorption coefficient measurements using impedance tube method, it is important to consider the surrounding setting of air temperature, relative humidity, and atmospheric pressure inside the room from beginning of the procedure and the sample's insertion.

4.2.1 Natural Fibre 20 mm Thickness

Figure 8 shows the comparison of the sound absorption coefficient (SAC) of three different fibre for thickness of 20 mm at high frequency range. Coconut fibre sample shows the highest SAC value for high range frequency compared to oil palm fibre and banana fibre. SAC of banana fibre is the lowest at high range frequency as its maximum value does not reach minimum value of coconut fibre sample. At frequency of 4500 Hz and 5000 Hz, oil palm fibre and coconut fibre meet the same value of SAC. Both oil palm fibre and coconut fibre reach SAC value of 0.41 at 5000 Hz.

4.2.2 Natural Fibre 30 mm Thickness

Figure 9 shows the comparison of the sound absorption coefficient (SAC) of three different fibre for thickness of 30 mm at high frequency range. For the graph obtained from Impendence Tube Method (ITM), oil palm fibre shows great performance at high frequency range compared to other natural fibre. The SAC increases with frequency and reach maximum value at 5000 Hz. The highest SAC value obtained by banana fibre which is 0.52 did not reach the minimum SAC value of oil palm fibre at high frequency range. The highest SAC value that obtained by oil palm fibre

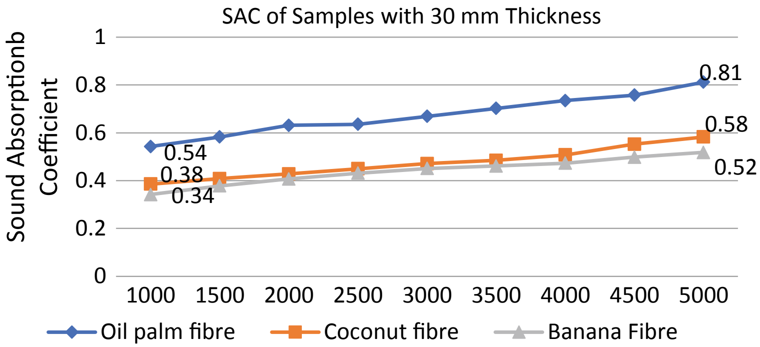

Fig. 9 High frequency of SAC for three samples with 30 mm thickness

and coconut fibre sample is 0.81 at 5000 Hz. SAC of oil palm fibre is the highest at 5000 Hz compared to coconut and banana which are 0.58 and 0.52 respectively.

5 Conclusion

This study showed that by using the Impedance Tube Method (ITM) test to determine sound absorption coefficients of selected natural fibre have been successfully carried out. Samples of sound absorber have been made from natural fibre with 5% alkaline treatment. The sample testing showed that these natural fibre can be good alternatives for sound absorber panel to be installed in the building. Coconut fibre sample with thickness of 20 mm showed great SAC value at low frequency but oil palm fibre sample showed great SAC value with thickness of 30 mm. The highest value obtained by coconut fibre sample with thickness of 20 mm in low frequency range was 0.31. For high frequency range for the sample thickness of 20 mm, SAC value of coconut fibre sample was 0.41 which is the highest. For the sample thickness of 30 mm at high frequency range, the highest SAC value was obtained by oil palm fibre sample which is 0.81. For overall data obtained from ITM testing, the SAC value for the samples might be different according to the type of material used and the thickness of sample. Compared to the study carried out by Yang et al. [2], The result showed that the highest SAC that can be achieved by synthetic fibre for fibre carbon and fibre glass were 0.43 and 0.41 respectively. This showed that natural fibre composite had greater SAC value compared to fibre carbon and fibre glass due to their unique hollow lumen. Thus, natural fibre has high potential to be used as a material for sound absorption panel and alternative replacement for the current synthetic fibre materials.

Acknowledgements Researchers would like to express gratitude and appreciation to Tun Hussein Onn University of Malaysia (UTHM) and all the research partners that contributed their knowledge and expertise in assisting to complete this study.

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