Sound Transmission Loss of Natural Fiber Panel

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***Abstract*-- Natural fibers have been known of its good acoustic damping properties. These agricultural by-products can be used in many aspects such as sound insulation. The main purpose of this study is to determine which natural fiber panels can deliver high sound transmission loss (STL). There are three different natural fibers will be utilized as the tested panels, which are coir, kenaf, and kapok fiber. The natural fiber panels will undergo the treatment and fabrication process before they can be used as a tested panel. The STL was measured using two microphones transfer function in the small scale of reverberation chambers. LMS Test Lab software coupled with LMS Scadas Mobile data acquisition (DAQ) unit is used to determine the sound pressure level in both chambers. The sound pressure level was recorded for both source and receiver chamber by having known sound power across the 16 tested one-third octave frequency bands between 125 Hz to 4 kHz. The results of STL has been analyzed and discussed in the discussion section. For selected frequency range, high frequencies (1 kHz and 3.15 kHz) are having low STL compared with low frequencies (125 Hz to 630 Hz). It is because lower frequencies sound wave could transmit better than higher frequencies sound wave through the panels.**

***Index Term*-- Sound transmission loss (STL); natural fiber; sound pressure level; frequency.**

INTRODUCTION

Sound is something that can be heard by the human's and animal's sense of hearing. Sound can be described as a vibration that travels through the solid, liquid or gases and produced by continuous and regular vibrations. The use of sound is for communication and interaction between people around. Nowadays, the sound also widely used in the medical fields such as in ultrasound and healing wounds.

Sound transmission loss (STL) is a measure of the sound insulation value of a partition, the amount in decibels (dB) which the intensity of sound is reduced in the transmission through the partition. Figure 1 shows the basic concept of sound transmission. When sound strikes on the partition, partially of the sound waves are absorbed by the partition between two rooms, some will reflect back into the room, and some will transmit into the adjacent room through the wall [2-3].

A panel is a flat or curved component that forms or set into the surface of a door, wall or ceiling. The panel can be made from any materials that suit for the test method. Figure 2 shows the classification of fibers that are divided into two categories which are natural fibers and man-made fibers. Normally, natural fibers are obtained from the plants, animals, mineral sources, and natural rubber [5-6]. These agricultural by-products have been proved that the concrete containing them will perform as a good absorptive material for acoustical [1].

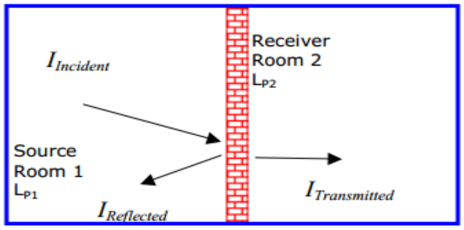

Fig. 1. Basic concept of sound transmission [1].

According to the research was conducted by Praščevic et al., a possible way to control and solve a noise problem is adjusting the acoustic transmission path or the paths between the noise and the receiver [3]. Installing partition panels are considered a common method for diminishing noise. By installing the partitions, it able to reflect a large portion of the noise and transmit the rest. It is due to the major changes of acoustic impedance in the transmission path by the partition [7]. At the same time, it is also found that acoustical materials able to perform one of two acoustical roles for controlling the undesired sound which proved in the earlier study of Owens Corning [8].

Karlinasari et al. had described that bamboo is one of the non-wood lignocellulose material. The bamboo fiber can be expanded consideration as an alternative material for wood-based development and composites [9]. At the same time, the study conducted by P. Senthilkumar and S. Kandaswamy showed that coconut shell could be used for replacing the aggregates used in construction. In the study, it proves that the use of agricultural wastes (normally is natural fiber) as granular in Ferro-cement panels open a new range of possibilities in the use of materials in construction industry [10].

There are several methods that can be used to measure STL. The methods are impedance tube and reverberation room. Jung et al. had conducted an experiment to measure STL using transfer function method impedance tube system which shown in Figure 3 [11]. For the transfer function method, two microphones called as microphone 1 (MP1) and microphone 2 (MP2) was mounted in the upstream tube. The other two microphones, microphone 3 (MP3) and microphone 4 (MP4) was mounted in the downstream tube. As the both sides of the tubes were mounted with the microphones, the incident and reflected sound waves could be obtained. Then, the sound pressure level of incident and reflected sound wave are taken into account for the STL calculation.

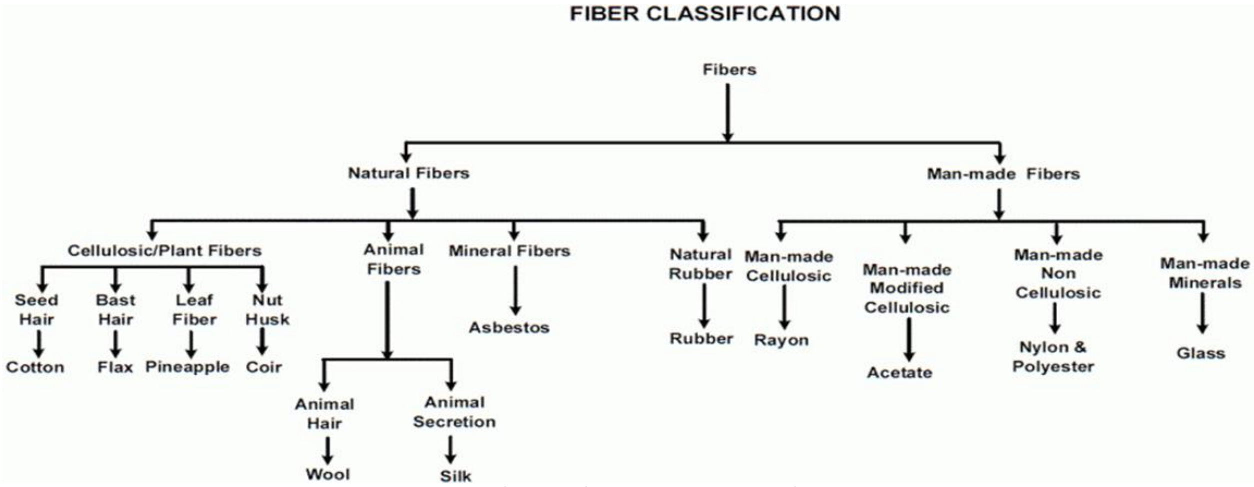

Fig. 2. Classification of natural and man-made fibers [4].

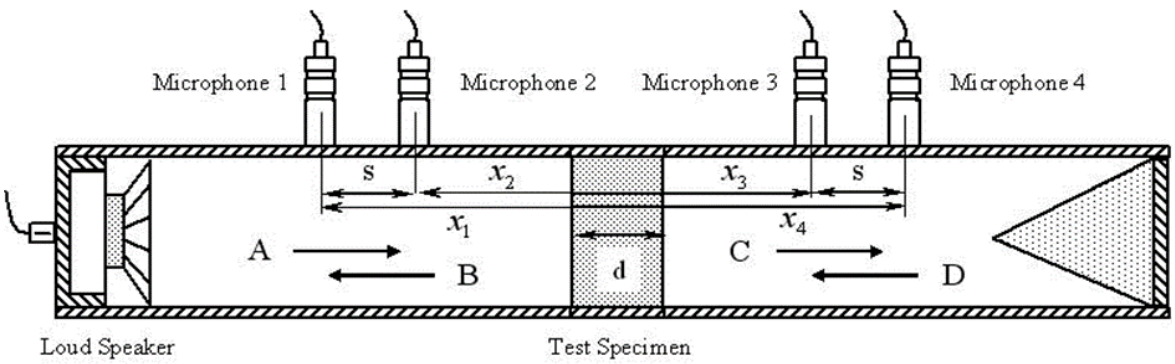

Fig. 3. Schematic diagram of transfer function method impedance tube STL measurement system [11].

Another STL measurement method is using the reverberation room as shown in Figure 4. Based on Figure 4, the room on the right side has settled microphone to compute average sound pressure level. The room on the left side has a consistently moving microphone to compute normal sound pressure level [12]. Normally both rooms will have the same microphone framework. The amplifiers or sound sources in the rooms create the incident sound fields for the estimation of level contrasts or sound decay rates. Both rooms are separated with test specimen that will be made of any materials of interest [13].

In this study, STL performance of natural fiber panels will be investigated and studied. There are many types of materials can be considered to make a panel or partition. For this study, only three different natural fibers will be considered for the testing specimens.

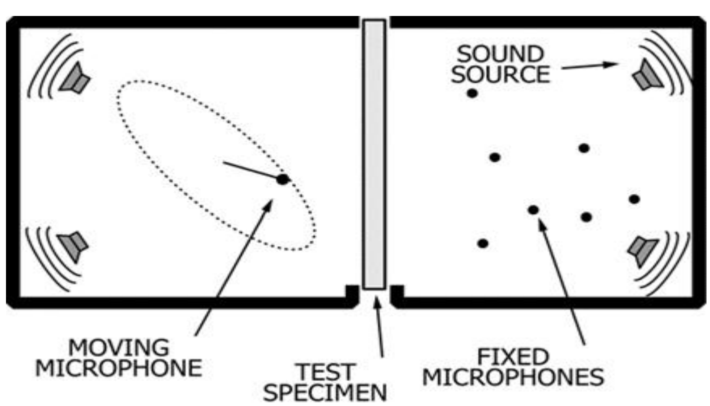

Fig. 4. Illustration showing conceptual arrangement of a wall sound transmission loss suite [12].

They will be evaluated regarding the material and mass of one-third octave band frequency. Other than that, this conducted study also to determine the most effective parameters of the panel which deliveries the high STL for the selected frequency range.

EXPERIMENTAL SET UP

In this study, the small scale of reverberation chambers will be used for the sound transmission loss (STL) measurement for the natural fiber panels. Figure 5 shows the schematic diagram of experiment setup. For the STL measurement, there are both source and receiver rooms has one open window. The window in the source room will be placed the tested natural fiber panel. There are two microphones will be used; one in source room and another one in receiver room. Before conducting the measurement, both microphones will be calibrated using the sound level calibrator. The sound source will be supplied by the speaker in the source room. The measurement data will be collected using LMS Scadas Mobile data acquisition (DAQ) unit which connected to the computer.

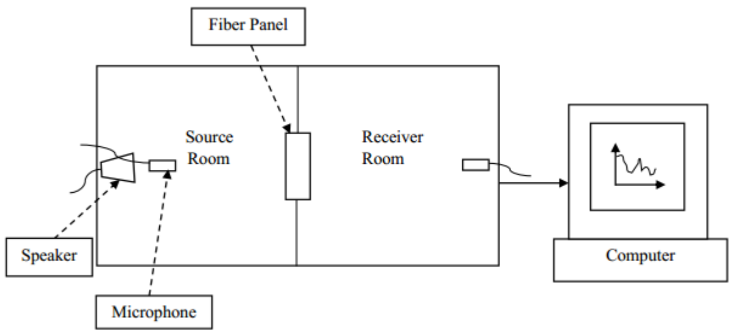

Fig. 5. Schematic diagram of experiment setup.

Design of the Reverberation Chamber

There are two types of the chamber that can be constructed to measure the sound transmission loss (STL) which are large and small reverberation chamber. For this study, the small scale of reverberation chamber was used.

The dimension of the full design of the chamber is 0.4 m (*L*) x 0.4 m (*W*) x 0.4 m (*H*). The suggested material for fabricating the test chamber is plywood as it is easy to be fabricated and relatively low for the cost. The thickness of the plywood is 2.54 cm. Figure 6 shows the drawing of the split chamber design (for both source and receiver rooms) while Figure 7 shows the chamber that has been constructed.

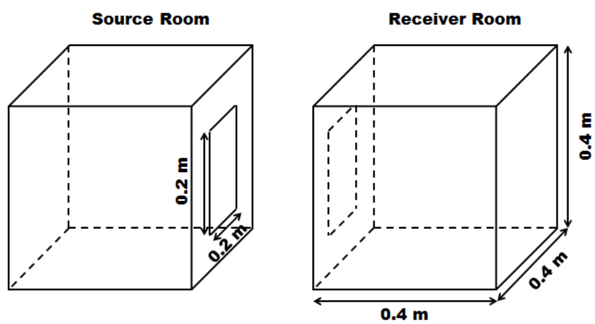

Fig. 6. Design drawing of the split chamber design (for both source and receiver rooms).

Fig. 7. Reverberation chamber.

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Preparation for Fiber Panels

Coir, kenaf and kapok fibers were chosen for the sound transmission loss (STL) investigation in this study as it is common in Malaysia market. Figure 8 shows the fibers ((a) coir, (b) kenaf and (c) kapok) that were obtained in loose form. The fiber must be separated from impurities and resolved before they can be compressed into plate form using the hydraulic compressor machine with a compressing force of 10MPa. To make the fibers turn into the plate form, the steel plate was acted as a mould used to place the fiber before they can be compressed. The size for all of the tested fibers is 0.2 m x 0.2 m. As the natural fiber was used for measuring its STL, all of the fibers have been mixed well with egg white. The egg white will act as glue for the natural fibers. Figure 9 and 10 show the steel plate used to place the fiber and the fiber that has been compressed into the plate form, respectively. As the fiber has been compressed into the plate form, the density of each fiber can be calculated.

Fig. 8. Loose forms: (a) Coir Fiber (b) Kenaf Fiber (c) Kapok Fiber.

Figure 11 shows the fiber panel that has been labelled as panel one until 9. While Table 1 shows the physical characteristics for each natural fiber panels. The dimension for each panel was measured using vernier caliper, and the mass is weighted by using the weighing scale.

Experimental Procedure

According to the American Society for Testing and Materials (ASTM E90-09), there are two methods that commonly used for sampling sound fields in reverberation rooms which are stationary microphones or moving microphones. For this experiment, the method used is by placing the microphone in fixed position. The microphone will be placed 0.15 m from the test opening. While the speaker will be placed 0.2 m far from the test opening of the source room as shown in Figure 12. Figure 13 shows the placement of the microphone in the receiver room that is same as in the source room. The fiber panel will be installed in the test opening of the source room. Each side of the test opening was affixed with plasticine to lay the tested fiber panel. The plasticine was used as an adhesive. The placement of the tested panel is shown in Figure 14.

Fig. 9. Steel plate.

Fig. 10. Fibers in plate forms: (a) Coir Fiber (b) Kenaf Fiber (c) Kapok Fiber

Fig. 11. Sample of tested fiber panels.

Table I
Physical characteristics of natural fiber panels.

No.	Mass (g)	Area (m^2)	Thickness ($x10^{-3}$ m)	Volume ($x10^{-3}$ m3)	Density (kg/m^3)
1	10	0.04	6.18	0.247	40.453
2	20	0.04	10.00	0.400	50.000
3	30	0.04	17.70	0.708	42.373
4	10	0.04	6.04	0.242	41.391
5	20	0.04	9.72	0.389	51.440
6	30	0.04	14.22	0.569	52.743
7	10	0.04	5.00	0.200	50.000
8	20	0.04	6.00	0.240	83.333
9	30	0.04	7.90	0.316	94.937

Microphones are used to measure sound pressure level in the source and receiver rooms. The type of microphone used is BSWA MA211. The microphones are calibrated using sound level calibrator (ANSI S1.40 – 1984) [14]. The calibrator has been setup to 94 dB with the frequency of 1 kHz, which is the standard sensitivity for the microphone.

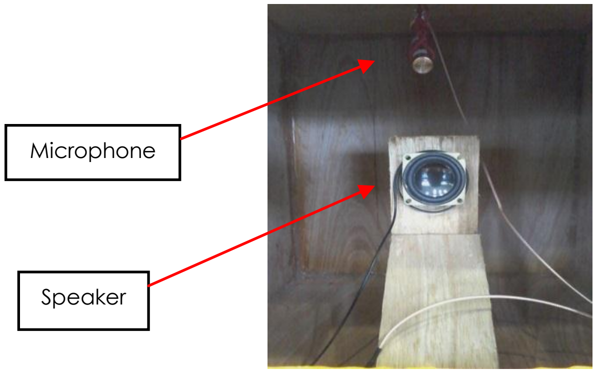

Fig. 12. Assembly of microphone and speaker in source room.

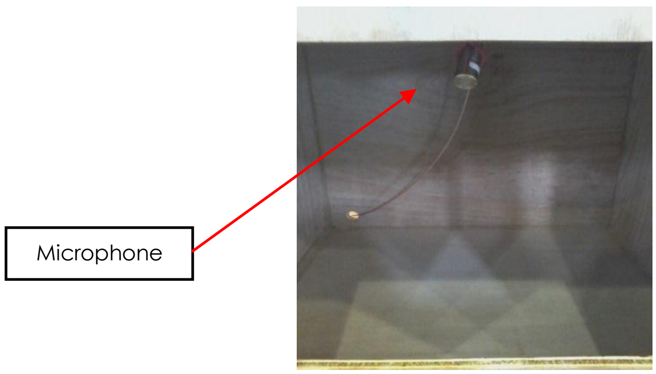

Fig. 13. Assembly of microphone in receiver room.

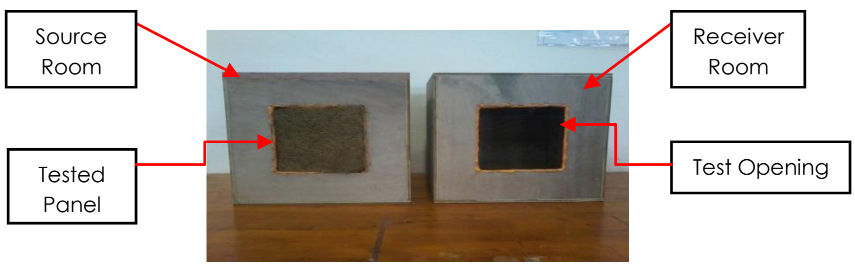

Fig. 14. Placement of the tested panel.

RESULTS AND DISCUSSION

For this section, the results collected from the experiment will be presented and discussed in detail. The results of the sound transmission loss (STL) of natural fibers will be evaluated in the graphical form. The STL performance of the natural fiber panels will be compared in the aspect of mass, fiber type, and frequency.

Analysis of Sound Transmission Loss (STL)

Figure 15 shows the coir fiber panel with the different mass. Coir fiber panel with 10 g labelled as panel 1, 20 g as panel 2, and 30 g as panel 3. The experimental results of sound transmission loss (STL) for the coir fiber have an averaged value of 14 dB. For the frequency 250 Hz to 630 Hz, panel 2 shows the highest value of the transmission compared with panel1 and panel 3. Based on the observation, the highest STL which can be gained by looking the highest peak of the graph, which is panel 2 at frequency 160 Hz with STL 16.29 dB. Obviously, panel 3 gives the highest STL with 12.20 dB when 2.5 kHz is applied to the tested panel. This is occurred due to the thickness of the panel that can transmit high sound wave.

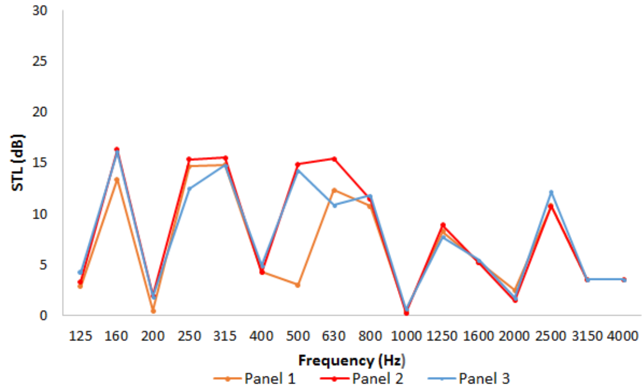

Fig. 15. Sound transmission loss (STL) for coir fiber panel.

Figure 16 shows the STL results for the kenaf fiber panels that have been labelled as panel 4, 5, and 6 with the mass of 10 g, 20 g, and 30 g respectively. For these results, it is observed that STL of different weight of kenaf fiber panels give the similar value at frequency 2.5 kHz, and this phenomenon coincides with the STL results of coir fiber panels which are depicted in Figure 15. At the same time, it is also found that panel 6 with higher thickness always shows the higher value of STL as compared with panel 4 and panel 5.

The STL results of kapok fiber panels are shown in Figure 16. All of the tested panels have been labelled as panel 7, 8, and 9. The three panels have different mass, which are 10 g, 20 g, and 30 g. Based on Figure 16, the highest peak of STL occurred at frequency 2.5 kHz with the value of 27.33dB for panel 8. While panel 9 shows the highest peak at around 250 Hz with STL of 15.52 dB. Panel 7 gives the highest STL of 19.83 dB at 2.5 kHz.

By referring Figure 15 to 17 for different natural fibers and different mass of test panels, it can be observed that the distributions of STL curve are inconsistent and unable to give a significant relationship between the STL with the types natural fiber. However, the phenomenon of thicker fiber panel will give higher STL is shown obviously from the graphs in Figure 15, 16, and 17. This is concluded that the thicker of the panel, the lower of the sound waves transmit through the natural fiber panels.

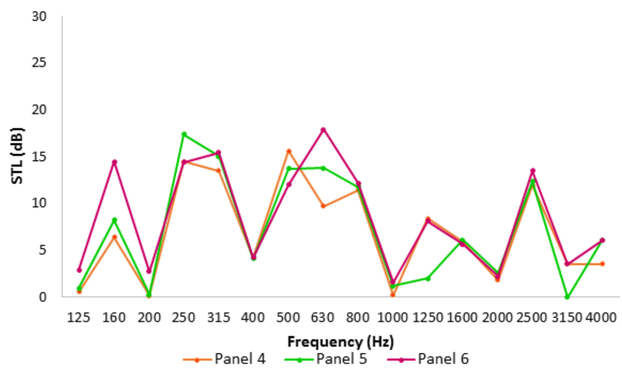

Fig. 16. Sound transmission loss (STL) for kenaf fiber panel.

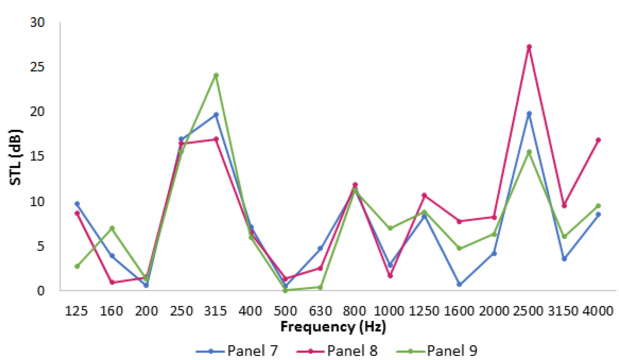

Fig. 17. Sound transmission loss (STL) for kapok fiber panel.

Comparison of Sound Transmission Loss (STL) and Mass at Different Frequency

Sound transmission loss (STL) of the testing panels with different frequency are calculated based on the obtained sound pressure level using the LMS Scadas Mobile data acquisition (DAQ) unit coupled with LMS Test Lab application. Some of the significant frequencies will be selected for the analysis and discussed. The selected frequencies are 125 Hz, 500 Hz, and 630 Hz for lower frequency, and 1 kHz and 3.15 kHz for higher frequency. Those frequencies are selected to determine the STL performance of the natural fiber panels while having low and high range of frequencies.

Based on Figure 18, the coir and kenaf fiber show the increment of STL as the mass increases. However, STL of kapok fiber shows the different result. As the mass and thickness increase, the STL decrease from 9.73 dB for panel 7 followed by 8.73 dB for panel 8 and 2.69 dB for panel 9. The results slightly vary with another panel.

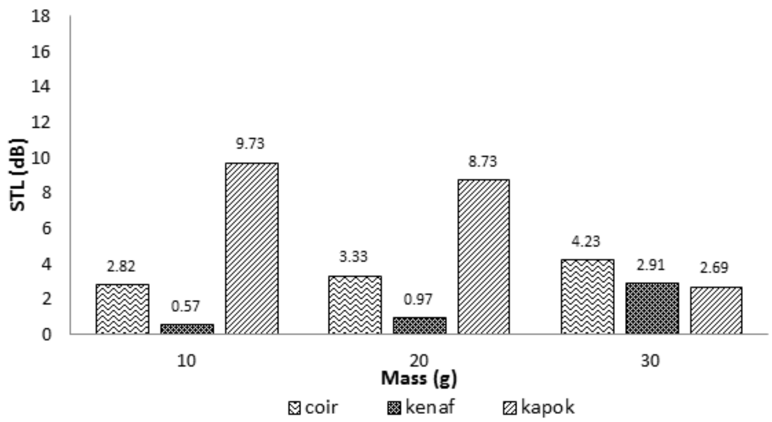

Fig. 18. Sound transmission loss (STL) of different type natural fiber panels for frequency 125 Hz.

For the frequency 500 Hz, the highest STL – 15.60 dB among the tested panel is kenaf fiber panel (panel 4) with the mass of 10 g, which is shown in Figure 19. It also gives a big difference STL value between kapok fiber panel (panel 7). Obviously, kenaf fiber panels are having a dramatic decline of STL as the amount of the fiber increase. Figure 20 shows the STL results for the frequency of 630 Hz. For the mass of 10 g and 20 g, coir fiber panels show the highest STL result compared with other panels which are 12.36 dB and 15.43 dB respectively. As can be seen, kenaf fiber panel (panel 6) with the mass of 30 g shows the highest STL result which is 17.86 dB.

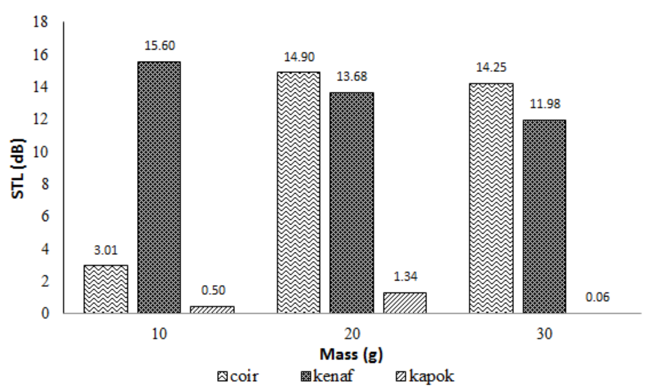

Fig. 19. Sound transmission loss (STL) of different type natural fiber panels for frequency 500 Hz.

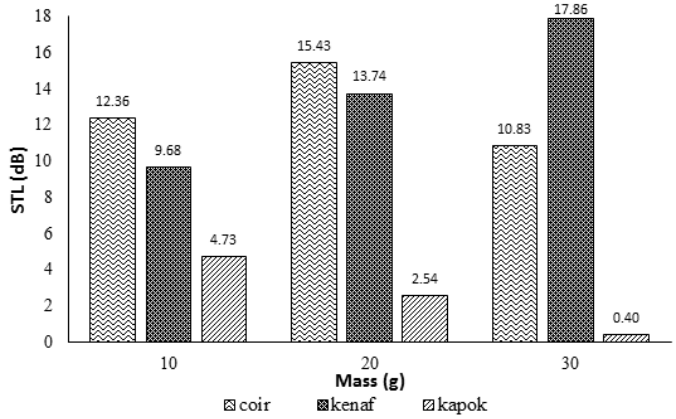

Fig. 20. Sound transmission loss (STL) of different type natural fiber panels for frequency 630 Hz.

By referring to Figure 21, it is observed that kapok fiber panels show the good STL performance at the frequency 1 kHz. The highest STL is recorded as 6.97 dB by kapok fiber panel (panel 7). At 1 kHz frequency, coir and kenaf fiber panel were not showing the promising STL performance compared with other frequencies that have been tested

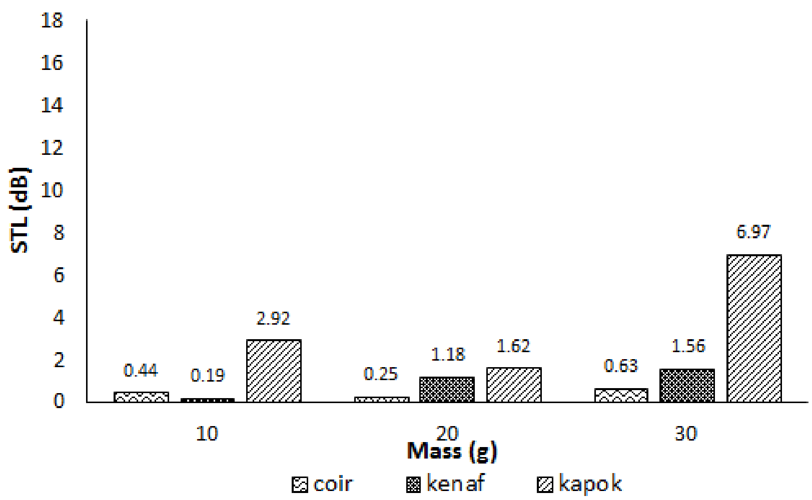

Fig. 21. Sound transmission loss (STL) of different type natural fiber panels for frequency 1 kHz.

Graphical data shown in Figure 22 is the STL result of different type natural fibers at frequency 3.15 kHz. Three different natural fiber panels show similar STL of 3.52 dB when the mass is 10 g. The highest STL is obtained by kapok fiber (panel 8) with the STL of 9.54 dB. It gives good STL performance in transmitting the sound wave compared with the coir fiber that has STL value of 3.52 dB and 0 dB scored by kenaf fiber.

Through the observation, the STL performance of natural fiber panels does not follow the general assumption that higher mass will deliver higher STL. It can be proved in this analysis that 10 g of kapok fiber panel could score highest STL compared with the panels having the mass of 20 g and 30 g. Besides, this phenomenon also same for the thickest coir fiber panel (0.0177 m), where the STL only is 14.25 dB.

In general, coir and kenaf fiber panels are showing good increment of STL as the thickness increase for the selected frequency of 125 Hz. While kapok fiber panels show the decrement of STL as the thickness and mass increase. This happened might due to the errors occurred during the panel fabrication process. In additional, the background noise also may cause the errors in the data collection and result in inconsistent of STL. This can be observed in the frequency 500 Hz; there are inconsistent STL for three different type natural fiber panels. Kapok fiber panels show the worst performance in transmitting the sound wave.

On the other hand, coir and kenaf fiber panels are showing good STL performance at frequency 630 Hz. Kenaf fiber panel with the mass of 30 g gains the STL up to 17.86 dB which is the highest value for frequency 630 Hz. However, for higher frequency range of 1 kHz to 3.15 kHz, kapok fiber panels are showing great performance of STL. Overall, these natural fibers give the good performance of STL for the low to medium range of frequencies, and the STL performance is deteriorated for higher frequencies. Thus, the most effective natural fiber panel that delivery high STL at lower frequency range are kenaf fiber panels and kapok fiber panels give higher STL for higher frequency.

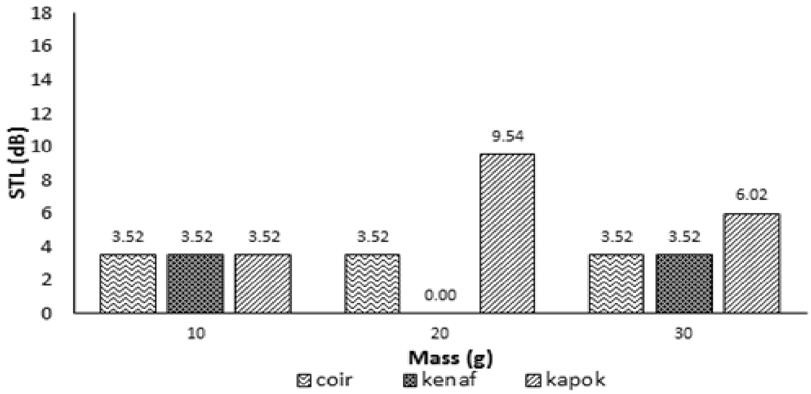

Fig. 22. Sound transmission loss (STL) of different type natural fiber panels for frequency 3.15 kHz.

Lastly, the biggest source of error on this study would be structural noise borne. For this study, all measurements and calculations assumed as airborne noise. However, structural borne noise still plays the role which will affect the sound source either from known power source or the speaker exciting the attached chamber walls. This structural noise would more or less increase the measured sound pressure level during the process of measurement.

CONCLUSION

In this study, the evaluation of sound transmission loss (STL) for the natural fiber panels in the aspect of thickness, density and size has been achieved. It was found that coir, kenaf, and kapok fiber could be used as the acoustical panels for the reduction of noise. By utilizing these agricultural by-products, it not only will solve the problem of handling the waste of natural fibers and it also might generate an extra income for the farmers. Overall, for the selected frequency range in this study, it is observed that higher frequencies (1 kHz and 3.15 kHz) are having low STL compared with lower frequencies (125 Hz to 630 Hz). It is because lower frequencies sound wave could transmit better than higher frequencies sound wave through the panel. Besides this, it is also found that the most effective way to enhance the STL is increasing the mass of the natural fiber panels. Therefore, the mass of the natural fiber panel is one of the important parameters which can be tuned for STL enhancement for the applications of sound insulation.

ACKNOWLEDGEMENTS

Authors would like to acknowledge the Ministry of Higher Education of Malaysia (MOHE) for supporting this research through the FRGS Grant (9003-00435). Support from Universiti Malaysia Perlis (UniMAP) Incentive Grant (9007-00252) also is greatly acknowledged.

REFERENCES

[1] C. Crane Company Inc. 2015. Ear bud Safety-How to Prevent Ear Damage. http://www.centerpointaudio.com/earbudsafety.aspx. (Accessed: 30 November 2015).

[2] Mohan P. 2011. Noise Control of Buildings. http://civilenggseminar.blogspot.my/2011/12/chapter-1-introduction-acoustical.html. (Accessed: 23 November 2015).

[3] Praščević, M., Cvetković, D., and Mihajlov, D. 2012. Comparasion of Prediction and Measurement Methods for Sound Insulation of Lightweight Partitions. Facta universitatis-series: Architecture and Civil Engineering, 10(2):155-167.

[4] Desai, R. 2012. An Educational Blog: Clothing. http://drrajivdesaimd.com/?p=3458. (Accessed: 23 October 2015).

[5] Zulkifli, R., Mohd. Nor, M.J., Mat Tahir, M.F., Ismail, A.R. and Nuawi, M.Z.. 2008. Acoustic properties of multi-layer coir fibres sound absorption panel. Journal of Applied Science. 20: 3709-3714.

[6] BSW Berleburger Schaumstoffwerk GmbH. 2014. Vibration Isolation of Buildings. https://www.berleburger.com/en/products/impact-sound-insulation-vibration-isolation/vibration-isolation-of-buildings/faq/faq/article/wie-unterscheide-ich-zwischen-koerper-und-luftschall/. (Accessed: 13 November 2015).

[7] Singh, D.P. 2012. Sound Transmission through Lightweight Panels. PhD Thesis. Ch. Charan Singh University, Meerut.

[8] Owen Corning World Headquarters. 2004. Noise Control: Design Guide. Ohio, USA.

[9] Karlinasari, L., Hermawan, D., Maddu, A., Martianto, B., Lucky, I.K., Nughoro, N. and Hadi, Y.S. 2012. Acoustical properties of particleboards made from betung bamboo (Dendrocalamus asper) as building construction materials. Bio Resources. 7(4): 5700-5702.

[10] Senthilkumar, P. and Kandaswamy, S. 2012. Performance of sound transmission on coconut fiber impregnated cavity ferrocement panels with and without absorptive material using statistical energy analysis. Building Research Journal. 60: 81-88.

[11] Jung, S.S., Kim, Y.T., and Lee, Y.B. 2008. Measurement of sound transmission loss by using impedance tubes. Journal of the Korean Physical Society. 53: 596-600.

[12] ASTM E90-09. 2009. Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements. ASTM International, West Conshohocken, PA.

[13] Roush Enterprises. 2015. Material Testing: Acoustic Properties. https://www.roush.com/Portals/1/OurCapabilities/Engineering/NoiseVibrationEngineering/MaterialTestingReference/tabid/116/Default.aspx. (Accessed: 12 November 2015).

[14] ANSI S1.40-1984 (R 2001). American National Standard Specification for Acoustical Calibrators.