Analysis of Sound Transmission Loss on Perforated-Natural Fibre Sandwich Panels

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ABSTRACT

Sound transmission loss (STL) is a study about the sound energy that is prevented from transmitting through a wall or a partition, it is essential especially for noise insulation applications. The main aim of this study is to investigate and analyse the STL capability of perforated-natural fibre sandwich panels, which acted as sound insulation material. The objective of this study is to determine the effect of perforation diameter of perforated panel on STL, as well as to determine the optimum hybridisation combination sandwich panel of perforated panel with natural fibre that deliver good STL. In this study, STL measurement was carried out by using two-load impedance tube method coupled with LMS Test Lab software and LMS SCADAS Mobile DAQ system. Natural fibres used in this study are coconut fibre, oil palm fibre, and pineapple leaf fibre. The natural fibres were prepared in cylindrical shape with three different thicknesses of 1 cm, 2 cm, and 3 cm to fit into the sample holder of impedance tube. Each natural fibre will be tested after it was hybridised with a perforated panel of different perforation diameter size and the STL measurement results are obtained and analysed. The measurement results show all samples had reached their highest STL at the frequency range 3000 Hz to 4000 Hz. In addition, pineapple leaf fibre hybridised with a perforated panel of 3 mm's perforation diameter is considered the optimum combination where it achieved the highest STL of 71.80 dB among all the test samples.

Keywords: *Sound transmission loss (STL), impedance tube, perforated-panel, natural fibre.*

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Introduction

Sound is a wave that produced through the vibration of an object. It is transmitted in the form of a wave where it might reflect or refract just like the other form of a wave. Sound transmission loss (STL) is much related to the noise reduction where high STL panels will have greater capability to reduce the noise produced from pass through the panels. A typical method used to measure the STL of a sound insulation material is two rooms method, also be known as reverberation room method [1]. Impedance tube is another common method used to study about acoustic performance especially on the STL of a sound absorbent material in the previous studies [1]–[4].

In sound controlling applications, perforated panels are usually used in controlling the noise from a sound source. The perforations on the panels able to reduce the surface volume velocity of a vibrating structure and the structural noise radiation [5]. For a perforated panel, the thickness, perforations size and perforations porosity will affect the STL. Vincent Phong and Dimitri Papamoschou investigated the sound response of the perforated panel when the sound wave is perpendicular to the panel [6]. The perforated panel studied is either brass or steel with varying perforation size, porosity and thickness. Experimental outcome is matched to the theoretical expectation and result showed that perforation size affects the STL of panel significantly by comparing to the other parameters, such as thickness or porosity of the panel. Therefore, it is believed that perforated panel with different perforations diameter size and pattern will deliver diverse outcome and enhancement on the STL.

Natural fibre is a kind of material that performs well on sound absorption and insulation [7]–[9]. They are mainly come from plant and animal while it was classified by how and where it is being extracted. Kenaf fibre, coconut fibre, bamboo fibre and oil palm fibre are the natural fibres which are renewable, low-priced, eco-friendly and decomposable. At the same time, natural fibre also can be obtained from agriculture by-products, such as rice straw fibre, coconut coir fibre, pineapple leaf fibre, and oil palm mesocarp fibre. Some of the acoustic performance studies on natural fibre had been conducted and found that it is able to provide the promising acoustic performance [10,11]. Besides this, natural fibre can replace the synthetic fibre due to the facts that synthetic fibre produces harmful dust particles, causing serious negative effect to our health like lung cancer after a long period of exposure. Thus, natural fibre is considered relatively safe and environment friendly compared with synthetic fibre [9].

In this study, sound transmission loss (STL) of perforated-natural fibre sandwich panels are studied and analysed. The sandwich panels are made from perforated panel coupled with natural fibre. Agriculture by-products fibre, such as coconut fibre, oil palm fibre and pineapple leaf fibre are considered in this study. It is expected that the effect of perforation diameter size on STL will be determined and optimum combination of perforated-natural fibre sandwich panel can be obtained. By hybridising perforated panel with natural fibre, it is believed that the STL performance will be further improved and enhanced.

Methodology

Material

In this study, natural fibres were prepared in the loose form. The natural fibres were fabricated into 3 different thickness, which are 1 cm, 2 cm, and 3 cm. It was weighted in 0.5 g, 1 g, and 1.5 g with respect to the thickness of 1 cm, 2 cm, and 3 cm sample preparation. There are 3 types of natural fibre were used, include coconut fibre, oil palm fibre, and pineapple leaf fibre which are shown in Figure 1, Figure 2, and Figure 3 respectively. The sample was fabricated using a self-made molding tool. It consists of a wooden base, 3 cm inner diameter PVC pipe mold and a small G-clamp. The 3 cm inner diameter size of PVC pipe mold was used as its size equals to the diameter of impedance tube in order to ensure the fabricated samples were well-fitted into the impedance tube during the STL test as shown in Figure 4. For the sample preparation, natural fibre was first weighted to ensure the mass within the control, followed by inserting it into the mold to shape it as cylindrical shape of sample. The shape of sample is then secured by using holding spray on it.

Figure 1: Sample of coconut fibre.

Figure 2: Sample of oil palm fibre.

Figure 3: Sample of pineapple leaf fibre.

Figure 4: Pineapple leaf fibre inserted in the sample holder.

For perforated panel, it is fabricated using the material of aluminium which is easily obtained from any hardware seller in the market. The thickness of aluminium panel is 0.2 mm and it was cut into square shape of 40 mm x 40 mm before perforation is made. The perforations were drilled by power hand drill according to the designed perforation as shown in Figure 5. In this study, there are 2 perforation diameter sizes are considered, which are 3 mm and 4.5 mm. The fabricated perforated panels are shown in Figure 6(a) and Figure 6(b) respectively.

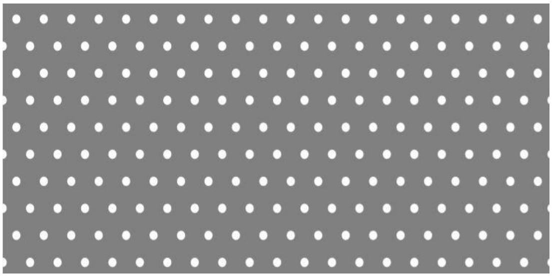
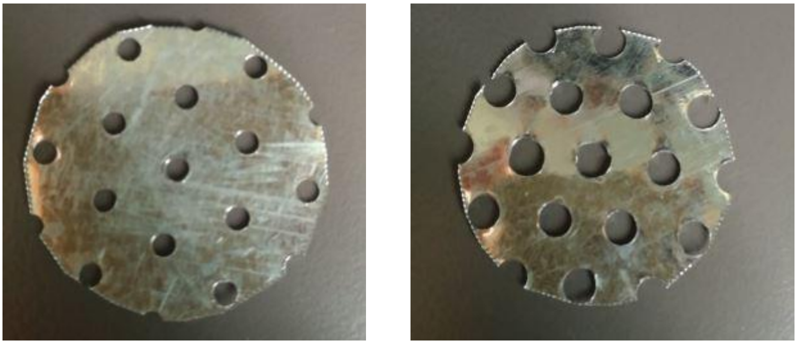


Figure 5: 60 degree staggered perforation.



(a) (b)

Figure 6: Perforated panel, (a) 3 mm perforation diameter, (b) 4.5 mm perforation diameter.

Two load transfer function method

The method used to measure the sound transmission loss (STL) for this study is two load transfer function method (TFM) as shown in Figure 7. It is considered a relatively simple and easy method as STL measurement only involving by switching the end cap of impedance tube in order to obtain rigid and anechoic termination. Sound pressure level of the sound waves inside the impedance tube is measured by the mounted microphones. After that, DAQ coupled with post-processing analysis software is used to determine the STL of measured samples.

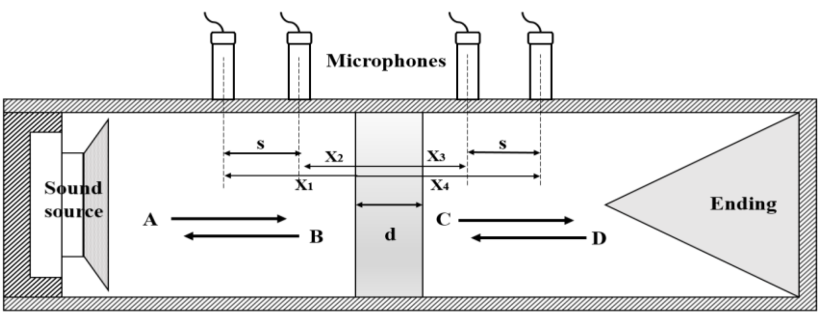


Figure 7: Schematic diagram of two load transfer function method for impedance tube [3].

For two load transfer function method, there are 2 wave components at both upstream and downstream of impedance tube. By referring to Figure 7, A represents incident wave component from the sound source while C is the transmitted wave component. Meanwhile, B and D are the reflected wave components. These four wave components are used to compute the sound pressures in the impedance tube as shown in the Equation (1) - Equation (4).

$$P_1 = Ae^{j(\omega t - kx_1)} + Be^{j(\omega t - kx_1)} \quad (1)$$

$$P_2 = Ae^{j(\omega t - kx_2)} + Be^{j(\omega t - kx_2)} \quad (2)$$

$$P_3 = Ce^{j(\omega t - kx_3)} + De^{j(\omega t - kx_3)} \quad (3)$$

$$P_4 = Ce^{j(\omega t - kx_4)} + De^{j(\omega t - kx_4)} \quad (4)$$

where k is the wave number.

By solving Equation (1) to Equation (4), the following Equation (5) to Equation (8) are obtained.

$$A = \frac{j(P_1 e^{jkx_2} - P_2 e^{jkx_1})}{2 \sin k(x_1 - x_2)} \quad (5)$$

$$B = \frac{j(P_2 e^{-jkx_1} - P_1 e^{-jkx_2})}{2 \sin k(x_1 - x_2)} \quad (6)$$

$$C = \frac{j(P_3 e^{jkx_4} - P_4 e^{jkx_3})}{2 \sin k(x_3 - x_4)} \quad (7)$$

$$D = \frac{j(P_4 e^{-jkx_3} - P_3 e^{-jkx_4})}{2 \sin k(x_3 - x_4)} \quad (8)$$

At last, sound transmission loss (STL) can be obtained by using the expressions below:

$$\begin{Bmatrix} A \\ B \end{Bmatrix} = \begin{bmatrix} \alpha & \beta \\ \gamma & \delta \end{bmatrix} \begin{Bmatrix} C \\ D \end{Bmatrix} \quad (9)$$

$$STL = -20 log(\| \alpha \|) \quad (10)$$

where α is the sound transmission loss coefficient. The sound transmission loss (STL) is obtained through the calculation will be in the unit of decibels (dB).

Sound transmission loss measurement setup

In this study, the impedance tube was built for two load transfer function method sound transmission loss (STL) measurement according to ASTM E2611 [12]. In general, there are 2 microphones each at the upstream and the downstream of the tube. The flange in the middle of tube (sample holder) is used to hold test sample, upstream and downstream of the tube. The impedance tube was placed on a holder firmly when conducting the measurement. Figure 8 shows the impedance tube used for measuring STL in this study.

Figure 9 shows the STL measurement setup in the laboratory. Basically, STL measurement setup consists of LMS SCADAS Mobile DAQ, impedance tube with microphones, laptop with post-processing software, and sound source. Before conducting the measurement, all the microphones were calibrated using sound level calibrator to ensure its accuracy of measurement. Then, the test sample was placed into the sample holder of the impedance tube as shown in the Figure 4. STL measurement only will be started when all the setting is well set.

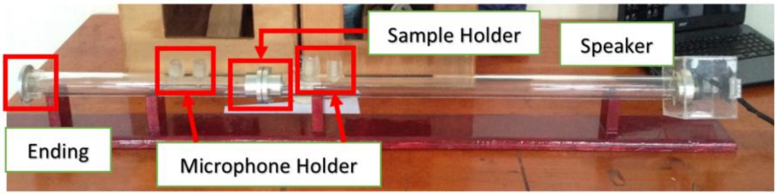


Figure 8: Impedance tube used for STL measurement.

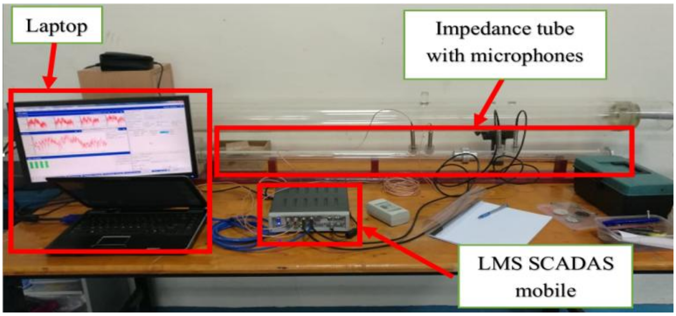


Figure 9: Apparatus set up for the measurement of sound transmission loss.

Result and Discussion

The collected data from sound transmission loss (STL) measurement are analyzed based on the effect of perforation diameter size and the effect of hybridisation of perforated panel with natural fibre. Figure 10 shows the comparison of STL of perforated panel with different perforation diameter.

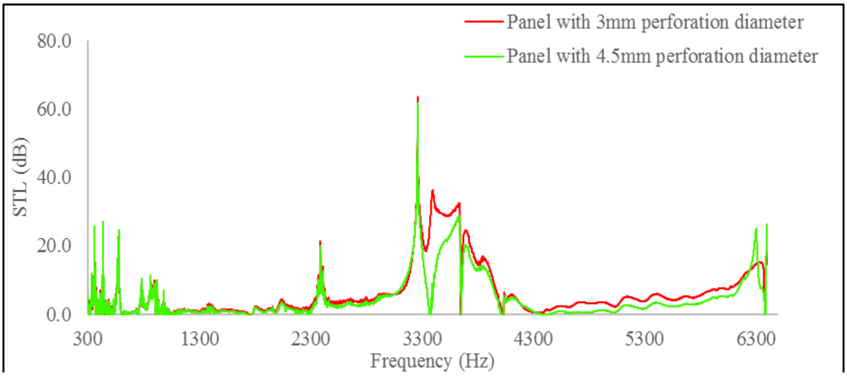


Figure 10: Sound transmission loss of perforated panel with different perforation diameter size.

According to Figure 10, the STL results show both panels having fluctuations at frequency below 1000 Hz and then go steadily until frequency 2300 Hz. For the frequency 3260 Hz, both panels have the highest value of STL, which are 63.61 dB and 61.66 dB for the panels with perforation diameters size of 3 mm and 4.5 mm respectively. The test is repeated twice in order to confirm the result is remained identical and repeatability. Based on the measurement, it is observed that STL of perforated panel is highly rely on the perforation ratio where STL will be decreased as the perforation ratio is increasing due to the resistive force in the holes is being reduced. Therefore, only 3 mm’s perforation diameter size of perforated panel will be considered for hybridisation with natural fibres in the following result and discussion section.

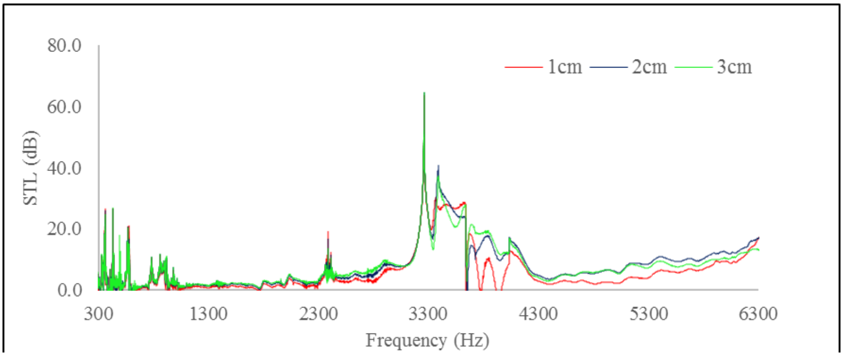


Figure 11: 3 mm's perforation diameter perforated panel with different thickness of coconut fibre.

Figure 11 shows the STL measurement results for 3 mm's perforation diameter perforated panel hybridised with different thickness of coconut fibre. The result shows that STL of the samples are increased gradually from 1000 Hz to 3148.44 Hz where sample with 3 cm's thick coconut fibre leads the other two. The peak of STL for all samples are dropped at 3260.94 Hz. For the frequency range 3300 Hz to 4300 Hz, each sample shows STL is fluctuating and decreased to 10 dB and lower. Among all, it is found that sample with 3 cm's thickness of coconut fibre provides the best STL results, which is 64.71 dB. As such, this shows that the sample with thicker coconut fibre will deliver higher STL.

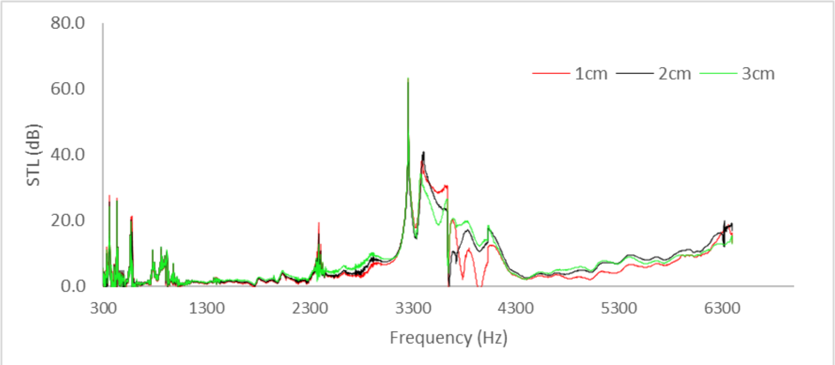


Figure 12: 3 mm's perforation diameter perforated panel with different thickness of oil palm fibre.

The STL measurement results for 3 mm's perforation diameter perforated panel hybridised with different thickness of oil palm fibre is depicted in Figure 12. The result shows that STL of the samples are increased gradually from 1000 Hz to 3131.25 Hz. The peak of STL is found dropped at 3260.94 Hz for all the samples, whereas sample with 3 cm's thickness of oil palm fibre is recorded as 63.33 dB and it is the highest STL compared with other samples. Each sample shows STL is fluctuating and decreased to 10 dB and lower for the frequency range 3300 Hz to 4300 Hz. Again, the phenomenon of sample with thicker oil palm fibre will deliver higher STL which is similar observation for coconut fibre.

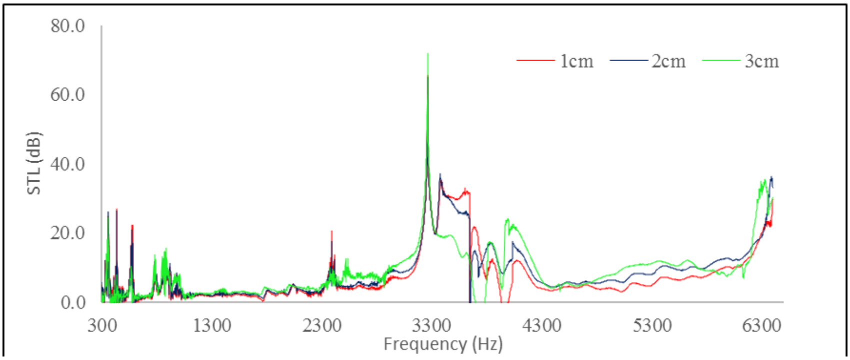


Figure 13: 3 mm's perforation diameter perforated panel with different thickness of pineapple leaf fibre.

Figure 13 shows the STL measurement of 3 mm's perforation diameter perforated panel with 1 cm, 2 cm, and 3 cm thickness of pineapple leaf fibre. According to Figure 13, STL for all samples are increased gradually from 1000 Hz up to the peak STL at 3260 Hz. All samples reach the highest STL of 65.45 dB, 65.05 dB, and 71.80 dB for the pineapple leaf fibre thickness of 1 cm, 2 cm, and 3 cm respectively. For the frequency range 2300 Hz - 3300 Hz, the sample with 1 cm's thick pineapple leaf fibre performs lower peak STL, which is recorded as 20.51 dB at 2389.06 Hz, while the sample of 2 cm's thick pineapple leaf fibre shows 17.50 dB of STL. However, the STL of sample with 3 cm's thick pineapple leaf fibre drops below 10 dB for the frequency 3266 Hz, while the others are still having another peak at 3373.44 Hz. In general, the sample with 3 cm's thick pineapple leaf fibre provides relatively high STL over the frequency range 300 Hz to 6300 Hz and its highest STL is recorded as 71.80 Hz.

Conclusion

In this study, the sound transmission loss (STL) of perforated panel hybridised with natural fibre has been presented. Based on the measurement and analysis, the perforated panel with 3 cm's perforation diameter size achieves the highest STL of 63.61 dB for the frequency 3260 Hz. Its STL is higher than perforated panel with 4.5 cm's perforation diameter size. This finding prove that the sound energy can pass through the panel with lesser trouble as the perforation diameter size on the panel is getting bigger. 3 cm's perforation diameter perforated panel hybridised with pineapple leaf fibre is considered an optimum perforated-natural fibre sandwich panel, which provide the greatest STL of 71.8 dB in this study.

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