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The Effects of Acoustic Absorbing Materials in Noise Reduction of Exhaust Muffler System

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ABSTRACT

Mufflers with acoustic absorbing materials are known as absorptive muffler. The absorptive muffler is the classic dissipative design, deriving its noise control properties from the basic fact that noise energy is effectively “absorbed” by various types of fibrous packing materials. The experimental study aims to observe the effects of the different types of acoustic absorbing materials in the exhaust muffler system through the transmission loss of the muffler and the comparison of transmission loss of a muffler with and without an acoustic absorbing material. The acoustic performance of the muffler system can be determined by insertion loss, noise reduction and transmission loss. The two-load method was used in this experiment because this method is suitable for being used in the experiment to observe the transmission loss of the different type of acoustic absorbing materials and make a comparison between which acoustic absorbing material has the highest transmission loss. Different acoustic absorbing material was used to see the effects of the transmission loss in a two-expansion chamber. Those materials are steel wool, fibreglass wool and ceramic wool. When comparing the results attained is that the transmission loss of each acoustic absorbing material is different to one another. At lower frequency from 0 Hz to 1000 Hz, fibreglass has the highest transmission loss when compared to steel wool and ceramic wool. At higher frequency from 1000 Hz and above ceramic wool has the highest transmission loss when compared to the other two materials. The Root Mean Square (RMS) value of transmission loss is the highest for fibreglass wool when compared to the other two materials used. In addition, from the experiment it can be verified that by adding acoustic absorbing material it increases the transmission loss of the empty muffler system. The RMS value of transmission loss attained from the experiment for the empty muffler system was the lowest when being compared to RMS value of transmission loss of the acoustic absorbing materials. Since the transmission loss increase, the noise reduction in the muffler increases. Hence, it can be said that the addition of the acoustic absorbing material will help in the reduction of noise in the muffler system.

Keywords:
Acoustic; noise reduction; exhaust muffler system

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1. Introduction

Noise can be defined as unnecessary sound which is unpleasant and disruptive to hearing, therefore noise pollution is unwanted or excessive sound that can have deleterious effects on human health, wildlife, and environmental quality [1]. According to American Conference of Industrial Hygienists, the threshold limit value for noise is 85 dBA while the permissible exposure limit of sound is 90 dBA [2]. Noise made by various machines can be controlled either by extinguishing the disturbance producing components or, then by utilizing the noise proofing materials which help to diminish the acoustic wave energy by blocking or absorption [3].

The engine exhaust is one of the main noise sources in a vehicle. Muffler technology has not changed very much over the past 100 years. The exhaust is passed through a series of chambers in reactive type mufflers or straight through a perforated pipe wrapped with sound deadening material in an absorptive type muffler. The muffler in the exhaust system helps to reduce the exhaust noise and intake system noise. Different exhaust systems with mufflers are being designed to reduce this noise, in order to meet the required noise levels and sound quality.

Mufflers with acoustic absorbing materials are known as absorptive muffler. The absorptive muffler is the classic dissipative design, deriving its noise control properties from the basic fact that noise energy is effectively “absorbed” by various types of fibrous packing materials. As the sound waves pass through the spaces between the tightly packed, small diameter fibers of the absorptive material, the resulting viscous friction dissipates the sound energy as small amounts of heat [4].

Transmission loss (TL) is one of the methods to determine the acoustic performance of the muffler system. Transmission loss is the difference in sound power between the incident wave entering and the transmitted wave exiting the muffler when the muffler termination is anechoic [5].

Several studies had been carried out regarding the transmission loss of the muffler system. Many experiments were conducted to improve the noise reduction of the muffler system via mathematical method, simulation method or experimental method. The observation and research done by researches shows that it is possible to increase the transmission loss of the muffler system. Even though there are experiments involving the transmission of loss of the muffler system via either simulation or experimental, there are researches studies done for mufflers with acoustic absorbing materials like steel wool, fibreglass wool and ceramic wool. Hence in this section, further explain more on previous research done on noise reduction in the muffler in terms transmission loss, the techniques used to determine the transmission loss in a muffler exhaust system and effectiveness of acoustic absorbing material in a muffler.

There are several ways to determine the performance the muffler system which are insertion loss, noise reduction and transmission loss. These three ways are the main characteristic used to express the acoustic performance of the exhaust muffler system of a vehicle [4-7].

The insertion loss is defined as the difference between the acoustic power radiated without any filter and with filter. Insertion loss is not only dependent on the muffler but also on the source impedance and the radiation impedance. Because of this insertion loss is easy to measure and difficult to calculate, however insertion loss is the most relevant measure to describe the muffler performance.

Noise reduction is the sound pressure level difference across the muffler. It is an easily measurable parameter but difficult to calculate and a property which is not reliable for muffler design since it depends on the termination and the muffler.

Transmission loss on the other hand is the difference in sound power between the incident wave entering and the transmitted wave exiting the muffler when the muffler termination is anechoic. Generally, transmission loss is calculated as $TL = LT1 - LT2$, in which $LT1$ and $LT2$ are sound power level of the entrance of incident and sound power level of the muffler outlet with no reflective end respectively. In normal circumstances, the cross-sectional area and the condition of the muffler inlet is the same.

Transmission loss is a property dependent entirely on the muffler. Since it is difficult to realize a fully anechoic termination, transmission loss is difficult to measure but easy to calculate for theoretical studies. Although noise reduction makes measuring noise power easier, it is more difficult to predict because the information needed about radiation impedance is limited.

Prolong exposure to noise that reaches more than 85dB and above will cause damage to our auditory system. The muffler system in the vehicle act as a device to reduce the noise coming from the vehicle. To further improve the muffler system, acoustic absorbing materials are added to reduce noise in the muffler system.

An absorptive material can greatly increase the transmission loss of an exhaust system in the mid to high frequency ranges. As an absorption material is placed inside the muffler the effective expansion area reduces and this sound absorption material absorbs the pressure waves and reflects very little [8].

Mufflers with acoustic absorbing materials are known as absorptive muffler. The absorptive muffler is the classic dissipative design, deriving its noise control properties from the basic fact that noise energy is effectively “absorbed” by various types of fibrous packing materials. As the sound waves pass through the spaces between the tightly packed, small diameter fibers of the absorptive material, the resulting viscous friction dissipates the sound energy as small amounts of heat [4].

Absorptive mufflers are highly effective on high-frequency noise (1000-8000 Hz) [4]. Since noise is absorbed by the acoustic absorbing material, absorptive mufflers generally employ straight-through or annular internal designs, which impose very little restrictions on air flow. Therefore, the effects of the acoustic absorbing material are important to improve the noise reduction of the muffler system.

The effect of the thickness of absorptive material and spacing play an important role in sound attenuation. The attenuation increases sharply at high frequencies as the spacing is small. Better performance at lower frequency is obtained as the thickness of the absorbing material is increased.

The outcome of this study will help to identify if the acoustic absorbing material has help in the reduction of noise in the muffler system. The noise reduction of the muffler system has produced much better level of noise exposure from the vehicle to the environment. Besides that, by applying absorbing material such as steel wool, fibreglass wool and ceramic wool will help to reduce noise emission and at the same time reduce the production to lower the noise in the muffler system.

This study observed the effects of the different types of acoustic absorbing materials in the exhaust muffler system through the transmission loss of the muffler and the comparison of transmission loss of a muffler with and without an acoustic absorbing material. The outcome of this study has help to identify if the acoustic absorbing material has help in the reduction of noise in the muffler system. The noise reduction of the muffler system has produced much better level of noise exposure from the vehicle to the environment.

2. Methodology

2.1 Material Selection

This study focused on conducting the experiment to find the transmission loss of different types of acoustic absorbing materials such as steel wool, fibreglass wool and ceramic wool in reducing the noise of the exhaust muffler system. The type of exhaust muffler system that was used in the experiment is a Two Expansion Chamber (TEC). The data would then be obtained from the experiment and compared to the previous research done for the transmission loss of an exhaust muffler system without an acoustic absorbing material.

Several materials were chosen to see whether they would give any effect towards the transmission loss in the muffler system. The following were the materials (Figure 1) that were used in the experiment:

(a) (b) (c)

Fig. 1. Material selection (a) Steel wool (b) Fibreglass wool and (c) Ceramic wool

Table 1 shows the density and thickness of each acoustic absorbing material. The density and the thickness for steel wool was not able to be determined. The assumptions made for the density and thickness for the steel wool is that the value should be lower than fibreglass and ceramic wool.

Table 1
The density and thickness of the acoustic absorbing material

Type of Material	Density of Material (kg/m3)	Thickness (mm)
Steel Wool	-	-
Fibreglass Wool	100	21
Ceramic Wool	130	25

2.2 Two-Load Method

The two-load method was standardized in ASTME2611-09 [9]. While this criterion was aimed at evaluating the loss of transmission through a sound absorbing medium, the algorithm and technique can be extended to the loss of transmission of muffler measurement.

As noted in the standard, two different loads are selected. Both Munjal and Doige [10] and Åbom [11] pointed out that a potential challenge is to find two different loads at all frequencies of interest. If the two loads are too close, the determined transmission loss is prone to error. The standard recommends using one absorptive load, which allows minimal reflection.

The other preferred load is an open or closed termination. Four microphones are mounted along the impedance tube with two upstream and two downstream of the mufflers. A reference signal is selected prior to the test, which can be one of the four microphones, the source signal for driving the loudspeaker or a fifth microphone. Based on the reference selected, three or four transfer functions for each load are measured. From these transfer functions; the so-called four-pole parameters for the muffler can be determined along with the transmission loss.

Figure 2 shows the setup of the two-load method done [15]. This method is suitable for being used in the experiment to observe the transmission loss of the different type of acoustic absorbing materials and make a comparison between which acoustic absorbing material has the highest transmission loss.

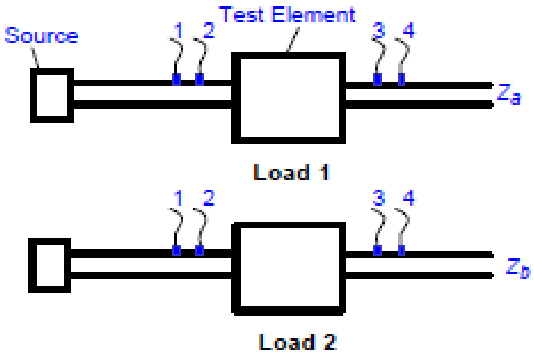


Fig. 2. Setup of two-load method [15]

In a study conducted by Tao and Seybert [15], stated that the two-loads method were achieved by a tube with and without absorbing material. Commonly, two-load can be two different length tubes, a single tube and without absorbing material, or even two different mufflers.

2.3 Experimental Setup Based on the Two-Load Method

The modular construction of the experimental set-up is presented in Figure 3. It enables easy changing of the experimental configuration and measurements of different acoustical characteristics.

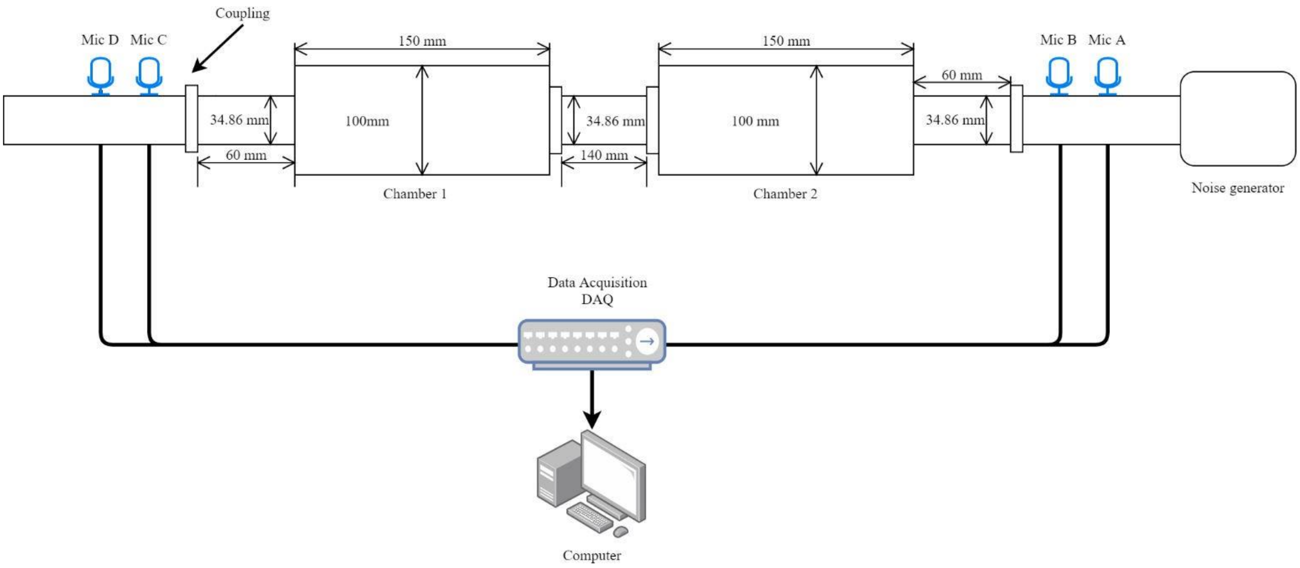
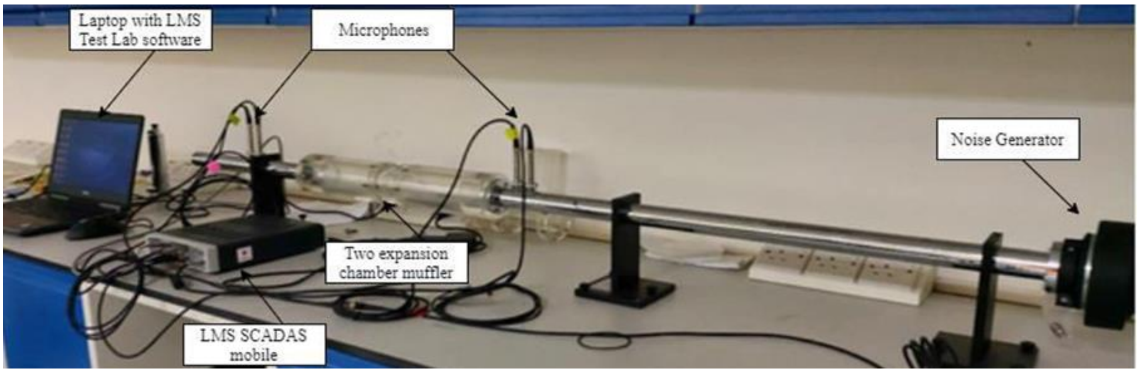
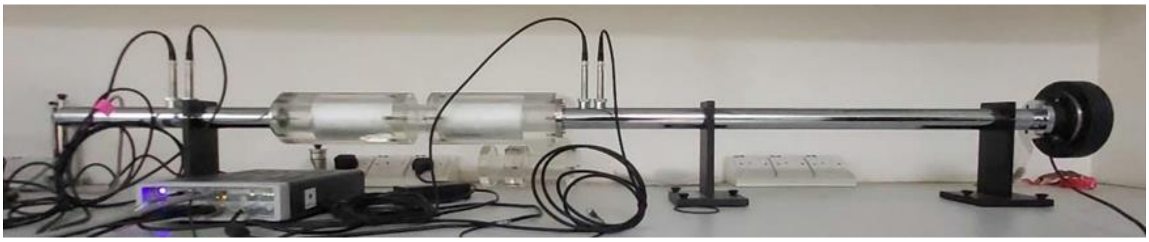


Fig. 3. Schematic experiment layout

Figure 4(a) shows the experimental setup for measuring the transmission loss of two expansion chamber muffler without acoustic absorbing material while in Figure 4(b) the setup for measuring the transmission loss of two expansion chamber muffler with acoustic absorbing material.



(a)



(b)

Fig. 4. Experimental setup for measuring the transmission loss of two expansion chamber muffler (a) Without acoustic absorbing material (b) With acoustic absorbing material

The impedance tube was made from two steel pipes which has the length of 900 mm and 41 mm respectively. The upstream part of the impedance tube is connected to the speaker and two holes which houses pressure microphone A and B. The downstream part consists a hollow end which allow the two-load of end termination to measure the transmission loss and two holes which houses pressure microphone C and D.

3. Results and Discussion

The two-load method approach was used in this experiment to determine the transmission loss (TL) of the muffler system with the acoustic absorbing materials. The acoustic absorbing materials that were used in the experiment are steel wool, fiberglass wool and ceramic wool. In this research, the effects of the muffler with and without acoustic absorbing materials are studied.

The maximum frequency that used in this experiment was 6400 Hz. For the observation of this experiment, the transmission loss of the acoustic absorbing material was observed up to 2000 Hz.

3.1 Expected Result

Alinaghi *et al.*, [12] and Gupta and Tiwari [15] showed that by adding acoustic absorbing material into the muffler the transmission loss of the muffler system increases. Hence, the expected results from the experiment that was conducted is that by that adding acoustic absorbing materials the transmission loss of the muffler increases more than the transmission loss that is in Figure 5.

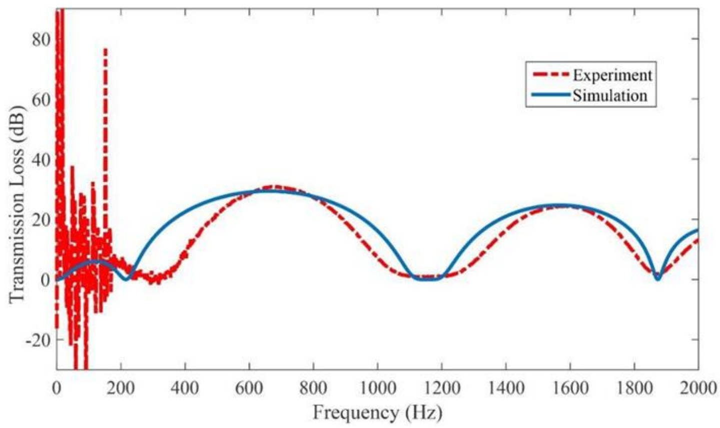


Fig. 5. Transmission loss between numerical and experiment

3.2 Transmission Loss of the Acoustic Absorbing Materials

Figure 6 shows the transmission loss of steel wool. According to Hanida [14], frequency below 200 Hz is ignored due to the leakage of sound from the surrounding and medium quality of the impedance tube. The highest peak of the transmission loss curve for steel wool is 14.85 dB at frequency of 657.81 Hz. The RMS value for steel wool is 11.14 dB.

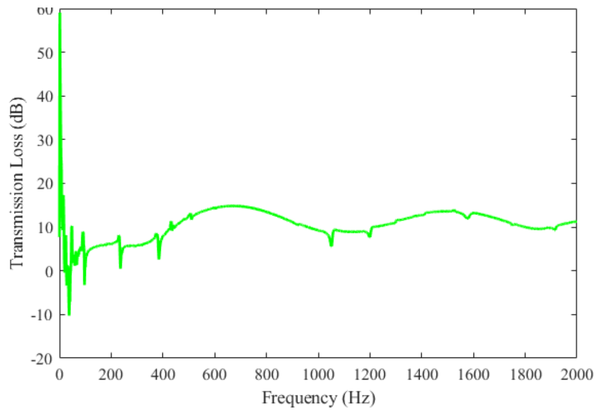


Fig. 6. Transmission loss of steel wool

Figure 7 shows the transmission loss for fibreglass wool when it is placed in the two-expansion chamber muffler. The highest peak of the transmission loss curve is 95.27 dB at frequency of 1912.5 Hz. The RMS value for fibreglass is 73.5 dB.

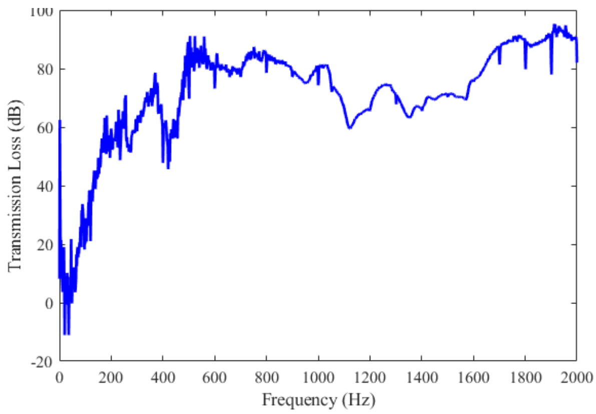


Fig. 7. Transmission loss of fibreglass wool

Figure 8 shows the transmission loss for ceramic wool when it is placed in the two-expansion chamber muffler. The highest peak of the transmission loss curve is 97.66 dB at frequency of 1996.88 Hz. The RMS value for fibreglass is 66.18 dB.

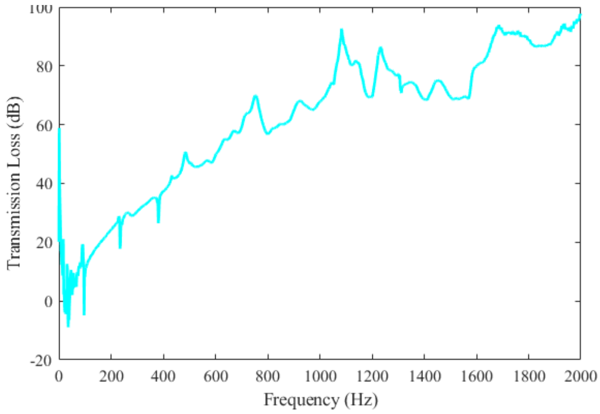


Fig. 8. Transmission loss of ceramic wool

3.3 Comparison of the Transmission Loss between the Acoustic Absorbing Materials

A comparison of the transmission loss between the acoustic absorbing materials in the two expansion chamber muffler was made.

3.3.1 Steel wool versus fibreglass wool

Figure 9 shows the comparison between the transmission loss of steel wool and fibreglass wool. Based on figure above, the transmission loss curve for fibreglass wool is higher than steel wool. The RMS value for steel wool and fibreglass wool is 11.14 dB and 73.5 dB respectively. Since RMS value for the transmission loss of the fibreglass wool is higher than that of steel wool, fibreglass wool is a better acoustic absorbing material as compared to steel wool.

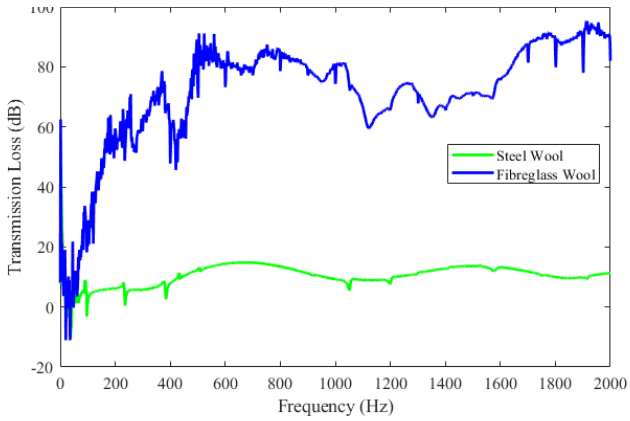


Fig. 9. Transmission loss of steel wool vs fibreglass wool

3.3.2 Steel wool versus ceramic wool

Figure 10 shows the comparison between the transmission loss of steel wool and ceramic wool. Based on the figure above, the transmission loss curve for ceramic wool is higher than steel wool. The RMS value for steel wool and ceramic wool is 11.14 dB and 66.8 dB respectively. Since RMS value for the transmission loss of the ceramic wool is higher than that of steel wool, ceramic wool is a better acoustic absorbing material as compared to steel wool.

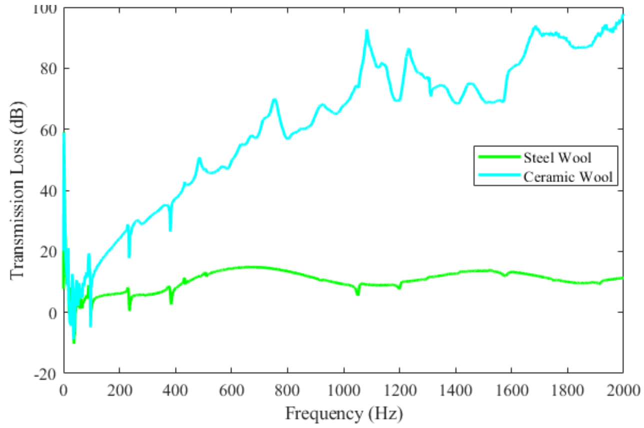


Fig. 10. Transmission loss of steel wool vs fibreglass wool

3.3.3 Fibreglass wool versus ceramic wool

Figure 11 shows the comparison between the transmission loss of fibreglass wool and ceramic wool. Based on the figure above, at higher frequency the transmission loss for ceramic wool is higher than fibreglass wool while at lower frequency the transmission loss for fibreglass wool is higher. To know which material is a better acoustic absorbing material, the RMS value was used. From the data attained from the experiment the RMS value for fibreglass and ceramic wool is 73.5 dB and 66.8 dB respectively. Since RMS value for the transmission loss of the fibreglass is higher than that of ceramic wool. Fibreglass wool is a better acoustic absorbing material as compared to ceramic wool.

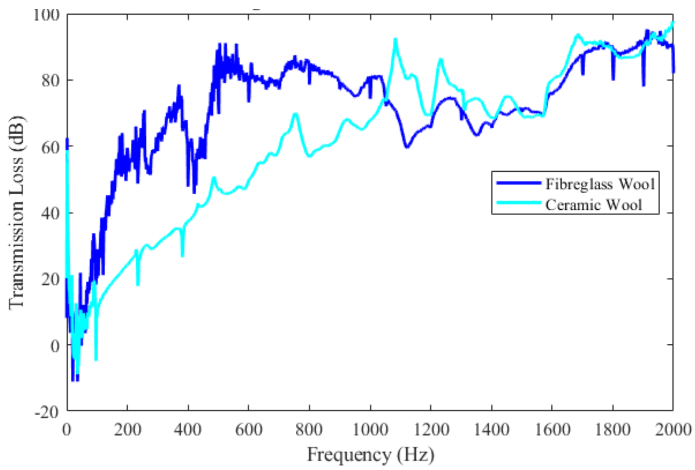


Fig. 11. Transmission loss of fibreglass wool vs ceramic wool

3.3.4 Comparison between steel wool, fibreglass wool and ceramic wool

Figure 12 shows the overall comparison of the transmission loss of the acoustic absorbing materials. From the figure we can conclude that the transmission loss of each acoustic absorbing material is different to one another. At lower frequency from 0 Hz to 1000 Hz, fibreglass has the highest transmission loss when compared to steel wool and ceramic wool. At higher frequency from 1000 Hz and above ceramic wool has transmission loss higher transmission loss when compared to the other two materials. To know which material has the highest transmission loss, the RMS value of the transmission loss of each material was calculated.

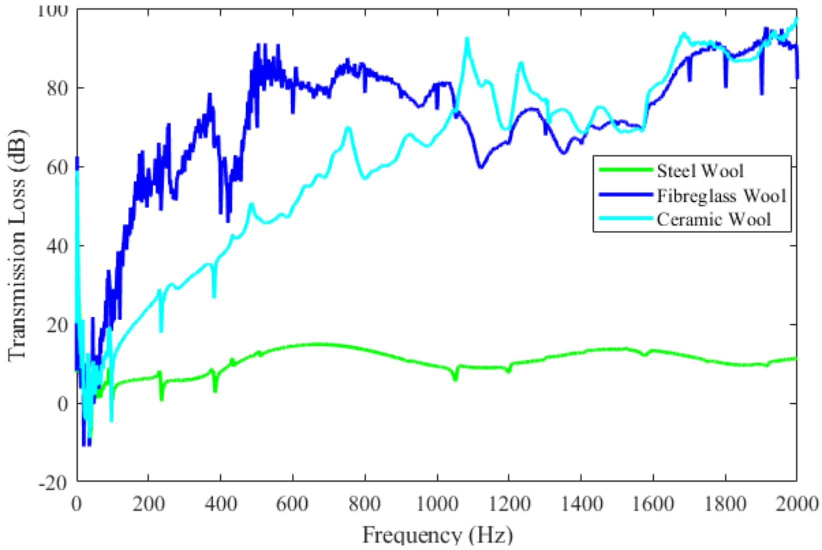


Fig. 12. Overall comparison of transmission loss of the acoustic absorbing materials

Table 2 shows the root mean square (RMS) value of the transmission loss of the acoustic absorbing material respectively. From the table above, fibreglass has the highest RMS among all the materials. Hence, fibreglass wool is the better acoustic absorbing material compared to steel wool and ceramic wool.

Table 2
The root mean square value of transmission loss of the acoustic absorbing materials

Type of Material	Transmission Loss (dB)
Steel Wool	11.14
Fibreglass Wool	73.5
Ceramic Wool	66.18

3.4 Comparison of the Transmission Loss of the Two Expansion Chamber Muffler

Comparison of the transmission loss of the two expansion chamber muffler with and without acoustic absorbing material was made.

3.4.1 Transmission loss of an empty two expansion chamber muffler

Based on Hanida *et al.,* [13], the transmission loss of the two-expansion chamber muffler without an acoustic absorbing material looks like the graph in Figure 5. In Figure 13 it shows that a similar graph was attained from the experiment conducted with the same two-expansion chamber muffler used in the research done by Hanida *et al.,* [13]. The highest peak of the transmission loss curve for the empty two-expansion chamber muffler is 12.6 dB at frequency of 681.25 Hz. The RMS value for the empty two-expansion chamber is 7.17 dB.

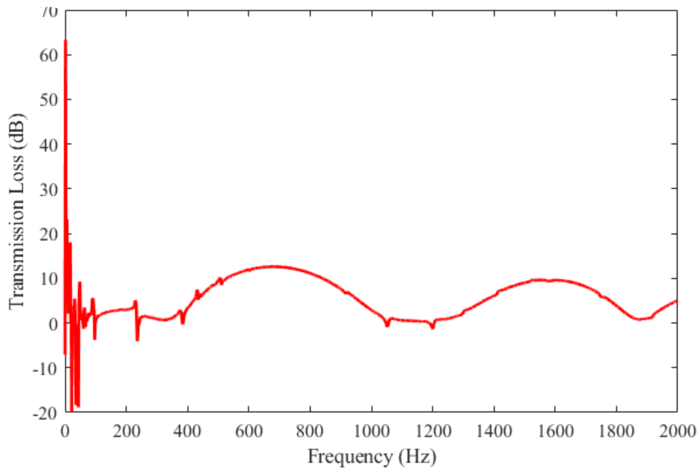


Fig. 13. Transmission loss of an empty two expansion chamber

3.4.2 Overall comparison of the transmission loss of the two expansion chamber muffler with and without acoustic absorbing material

Figure 14 shows the overall comparison of the transmission loss of the two-expansion chamber muffler with and without acoustic absorbing material. From the graph above, the transmission loss curve for the muffler without the acoustic absorbing material is the lowest when compared to the transmission loss curve of the muffler with the acoustic absorbing material. Besides that, the RMS value of the transmission loss for the muffler without the acoustic absorbing material is 7.17 dB. When comparing the RMS values of the muffler with the acoustic absorbing material as shown in Table 3, the muffler without the acoustic absorbing material has the lowest value. This proves that the addition of the acoustic absorbing material increases the transmission loss of the muffler.

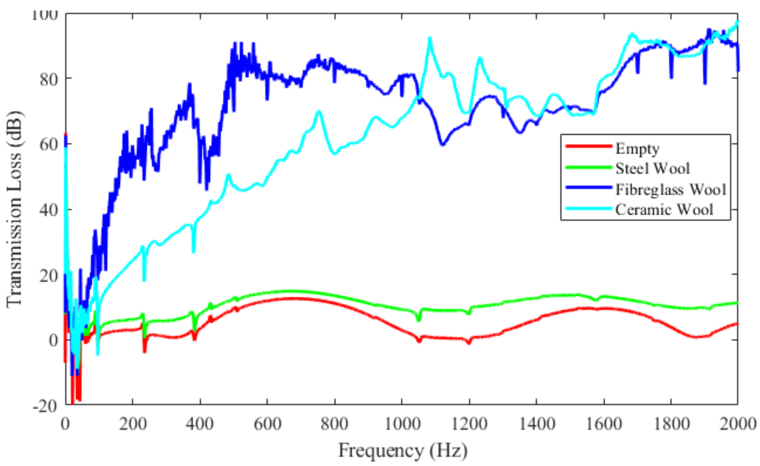


Fig. 14. Overall comparison of the transmission loss of the two expansion chamber muffler with and without acoustic absorbing material

Table 3
Overall root mean square value of transmission loss of the two expansion chamber muffler with and without acoustic absorbing material

Type of Material	Transmission Loss (dB)
Steel Wool	11.14
Fibreglass Wool	73.5
Ceramic Wool	66.18
Empty Muffler	7.17

4. Conclusions

The findings show that each of the materials have different type of transmission loss. The RMS of the transmission loss of steel wool, fibreglass wool and ceramic are 11.14d B, 73.5 dB and 66.18 dB respectively. The higher the value of the transmission loss the better the noise reduction. Since fibreglass has the highest value of RMS for the transmission loss, it is the most preferable material to be used in muffler in terms of noise reduction when compared to steel wool and ceramic wool.

In addition, from the experiment it can be verified that by adding acoustic absorbing material it increases the transmission loss of the empty muffler system. The RMS value of transmission loss attained from the experiment for the empty muffler system is 7.17 dB. When compared to the RMS value of transmission loss of the acoustic absorbing materials, there is an increment in transmission loss. As the transmission loss increases, the noise reduction in the muffler increases. Hence, it can be said that the addition of the acoustic absorbing material has help in the reduction of noise in the muffler system.

The noise reduction of the muffler system produces lower levels of noise exposure from the vehicle, which is much better from the environment. Besides that, applying absorbing material such as steel wool, fibreglass wool and ceramic wool it can help to reduce noise emission in the muffler system.

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