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Analysis of Sound Transmission Loss in Hybrid Mufflers for Automotive Applications

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Abstract

An exhaust system's noise level can be reduced with the use of a muffler. There is general recognition that baffled exhaust mufflers reduce noise emissions and increase the loss of sound transmission. The reduction of sound transmission can be further achieved by inserting sound-absorbing materials inside the muffler. Exhaust muffler systems with strategically positioned baffles have been shown to effectively reduce noise emissions, thereby improving acoustic performance. Baffles divert and disrupt sound waves, reducing the amount of unwanted noise that is transmitted and fostering a more peaceful and controlled acoustic environment. Sound-absorbing materials being included into mufflers is a major advancement in noise reduction technology. The current research purpose is to explore the changes in internal design of muffler with control volume influence towards the acoustic sound transmission loss. The design parameters were altered with constant volume and their variation was evaluated. In this work, by changing the number and position of the baffle, perforation percentage in the central and in outlet pipe. It has been seen that what is the difference in the sound transmission loss and finally, the sound transmission loss has been measured by filling the sound absorbing material into the constant volume muffler and observed how much the sound transmission loss has increased.

Keywords: word; 1-D analysis, acoustics, muffler, sound transmission loss, wave 1-D

INTRODUCTION

The Internal Combustion Engine (ICE) continued to be widely used as the major power source in the automotive industry despite the rising demand for technology in Plug-In Hybrid Vehicles (PHEVs) and Hybrid Electric Vehicles (HEVs) [1]. As a result, the muffler continues to be a crucial part responsible for reducing the noise the engine makes.

Incorporating a hybrid muffler that includes both reactive and dissipative components is currently the prevailing strategy in vehicle design [2]. In order to successfully manage noise levels, this integration illustrates the fusion of these ideas. Notably, contemporary mufflers have advanced past passive noise reduction and transformed into active components that help regulate and modulate noise levels [3]. A reactive muffler's internal geometry-related factors affect how much noise is reduced there. The primary muffler volume, pipe diameter, perforations on the pipe, pipe length, spacing of the baffles, and perforations on the baffles are all factors that collectively affect how well the muffler performs in terms of sound attenuation and sound transmission loss [4].

Another internal geometry of a muffler that might increase Sound transmission losses is a baffle plate. The peak of the sound transmission losses shifts to the left or right of the graph in the presence

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of a baffle plate with a varied location or distance [5]. However, the baffle plate causes a greater pressure drop across the silencer. Multiple holes were added to the baffle plate to reduce the pressure drop. However, several holes may dissipate an unstable vortex and result in the loss of acoustic energy.

Porosity appears as holes in pipe and baffle plates. The ratio of void surface to total surface area is known as porosity [6]. The number of holes and the size of the holes determine porosity [5]. The wall thickness of the perforated tube and the hole width have no discernible impact on the loss of sound transmission.

The literature review reveals that there haven't been many studies done on the internal geometry parameter of mufflers. Most studies use a straightforward geometry muffler; however, this study makes use of a commercial muffler with a variety of internal geometries [6]. Additionally, the study's scope for each parameter was constrained to a particular range. Therefore, the goal of the work is to investigate how modifications in internal muffler shape affect the loss of sound transmission. Main muffler volume, pipe diameter, perforated on baffle, and perforated on pipe were the four criteria that were prioritized [7]. And finally, after selecting the optimized muffler design, the optimized muffler was filled with sound absorbing material and observed which material increased the sound transmission loss and which material gave maximum sound transmission loss.

Theories Relating to Mufflers

Mufflers come in three different varieties: Absorptive, Reactive and Hybrid. Absorptive mufflers function by absorbing the sound of exhaust gases [8]. Absorbent materials, such as rock wool, glass wool, advantex are wrapped around the perforated exhaust tube, where they absorb the sound and turn it into very minute amounts of heat [9]. The absorbing substance was thought to be homogeneous. However, in practical car situations, this assumption is not always true, hence for fibrous materials, heterogeneous acoustic properties were taken into consideration [10]. Reactive mufflers operate on the resonance principle; the length of the muffler cylinder is created in such a way that the exhaust sound waves are reflected back, causing the exhaust sound to be cancelled. Mufflers that combine the two ideas make use of several chambers termed as hybrid muffler [11].

Methodological Approach

In this section, the methodology explains how the muffler has been designed with the help of 1-D software and the design has been verified through an experimental setup. Finite volume method and Wave Build have been used for simulation and research work. Figure 1 show the initial CAD design of muffler.

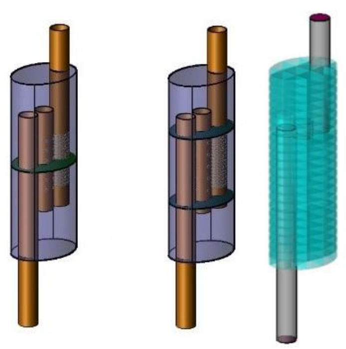

Figure 1. Finite volume design and mesh modelling of hybrid muffler

Finite Volume Method

The interior volume of the muffler was discretized into control volumes using the finite volume method for muffler analysis. The muffler designs could be optimized for noise reduction, backpressure

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control, and enhanced engine performance since it provided the solution approach for fluid flow equations so as to forecast exhaust gas behavior and acoustic qualities [12].

Wave Build Analysis

Using the finite element method (FEM), a wave build analysis for muffler sound transmission loss (STL) simulated how sound waves propagate through the muffler. For the purpose of forecasting STL over a wide frequency range, wave construct was employed to model the acoustic behavior, including wave reflection, absorption, and transmission[13].

Sound Transmission Loss

The performance of a muffler in an internal combustion engine exhaust system is modelled and examined using wave analysis, a simulation application for automotive engineering. Designing mufflers that meet standards for noise reduction, emissions, and performance requires this kind of analysis. Sound transmission loss was conducted using finite volume method. 3-D model was developed in wave software and then exported to wave build software for simulation analysis.

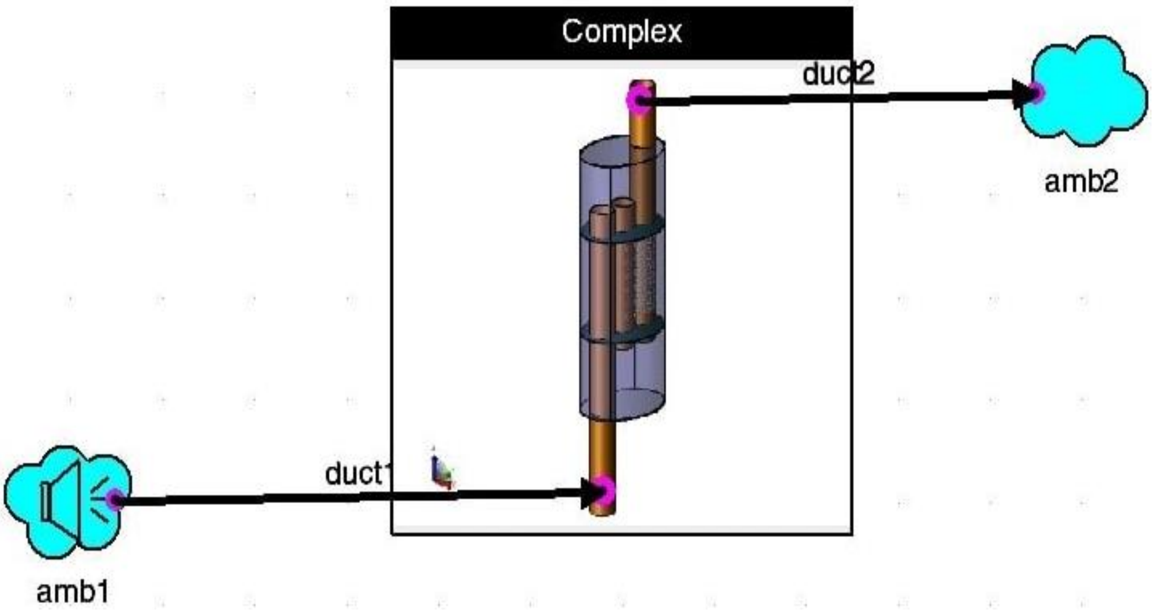

Figure 2. Simulation model for analysis of muffler design

As shown in above Figure 2, an ambient termination was placed at the downstream pipe, and an acoustic piston speaker was placed on the upstream pipe. From 50 to 3000 Hz, the speaker produced a sinusoidal step noise. The upstream and downstream tube diameters are selected to follow the pipe diameter in the parametric investigation on the effect of pipe diameter. This is done to prevent any area discontinuity that can impair the loss of sound transmission. The initial conditions were 300 K and 1.0 bar.

Sound Transmission Loss Simulation Parameters

Muffler geometry preparation

Create or load a 3D CAD model of the muffler into wave analysis to get started. Make sure the geometry is accurate, without any gaps or mistakes [14].

Creating Meshes

In Finite Volume Analysis, mesh generation entails breaking down a complex geometric model into more manageable pieces, such as triangles or quadrilaterals for 2D or tetrahedra or hexahedra for 3D.

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This discretization makes it easier to analyses and resolve structural, thermal, and fluid challenges, resulting in accurate and effective outcomes [15].

Flow and Acoustic Analysis

Analyzing a muffler's sound attenuation and exhaust gas flow includes doing an acoustic and flow investigation [16]. Simulations analysis enhance the engine performance and lower noise pollution by optimizing muffler design for noise reduction, minimizing backpressure, and ensuring compliance with emissions requirements [17].

Interpretation of Results from FEM and Wave Build Analyses

In the first stage, muffler was firstly designed by finite volume method and sound transmission loss was measured by installing single and double baffle in that design. As shown below in Figure 3, the sound transmission loss with a single baffle comes out to be 13.5 decibels and the sound transmission loss with a double baffle with 35.9 decibels. From this analysis it is concluded that double baffle is causing more sound transmission loss, it would be etter to use double baffles.

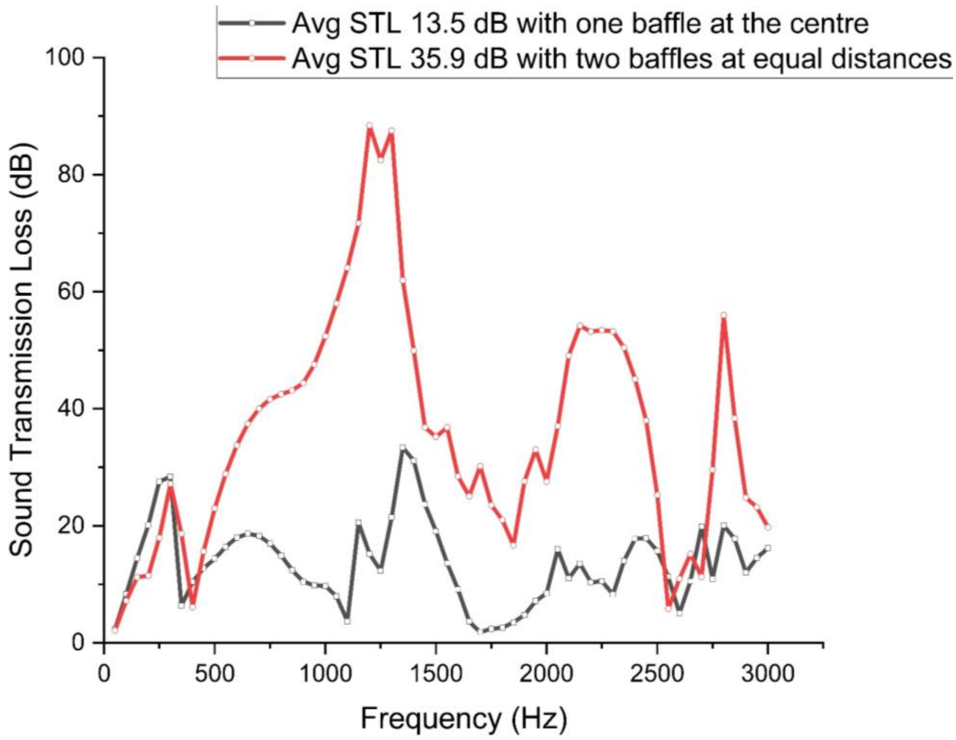

Figure 3. Effect of single and double baffle

In the second stage as shown below in Figure 4, further analysis was conducted on the double baffle's mufflers. The sound transmission loss in the outlet pipe has been measured on the basis of performance based on different flow percentages, which is almost the same in every case. This leads to the conclusion that perforation in the outlet pipe does not contribute to the sound transmission loss. Whether or not there is perforation in it, there will be no change in the sound transmission loss.

In the third stage as shown below in Figure 5, further analysis was conducted on the double baffle's mufflers. Sound transmission loss has been measured based on different flow percentages in the central pipe. In this analysis, sound transmission loss has been measured at different flow performance, in which it has been concluded that the highest sound transmission loss of 36.1 decibels is found with 6% flow performance.

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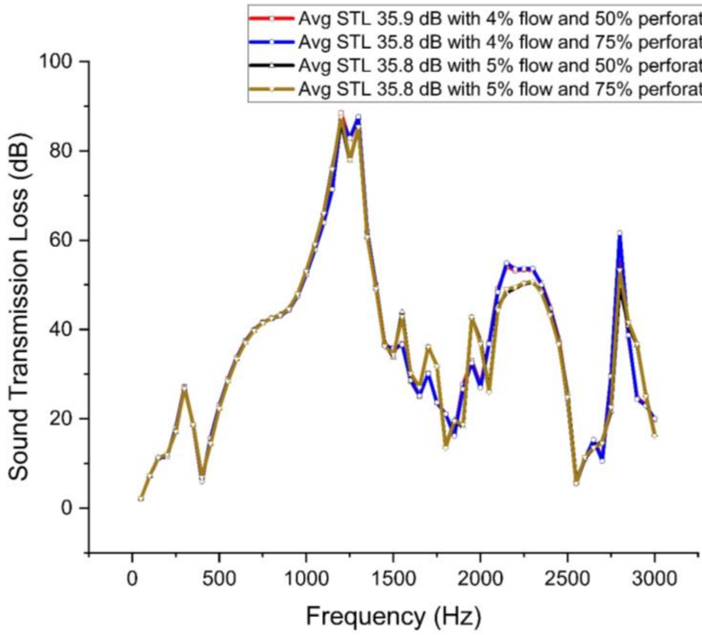

Figure 4. Effect of sound transmission loss in perforation of outlet pipe

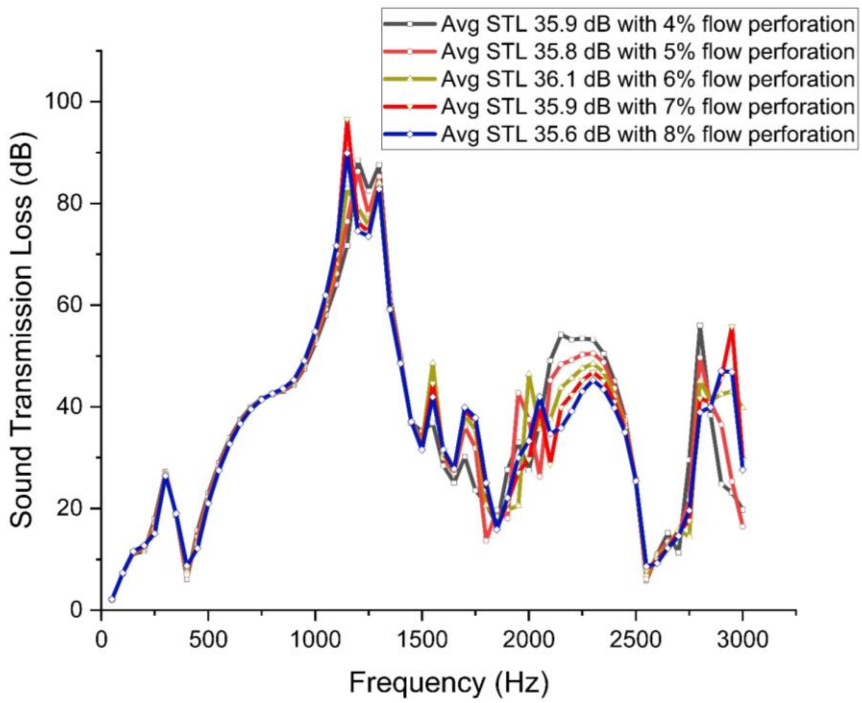

Figure 5. Effect of sound transmission loss in perforation of central pipe

In the last stage as shown below in Figure 6, the optimum design that has emerged in the final analysis has been filled with sound absorbing material. First, Advantex was filled with 20% density and the change in sound transmission loss was observed, and after that rock wool was also filled with 20% density and the sound transmission loss was measured. The sound transmission loss with Advantex is 41.4 dB while with Rockwool it is 51.2 dB. However, the weight of Rockwool is almost double that of Advantex and this will also increase the weight of the muffler, hence the middle part of the muffler is filled with Rockwool with 20% density, or the remaining part is filled with Advantex with 20% density, in which the sound transmission loss comes out to be 45.9 dB

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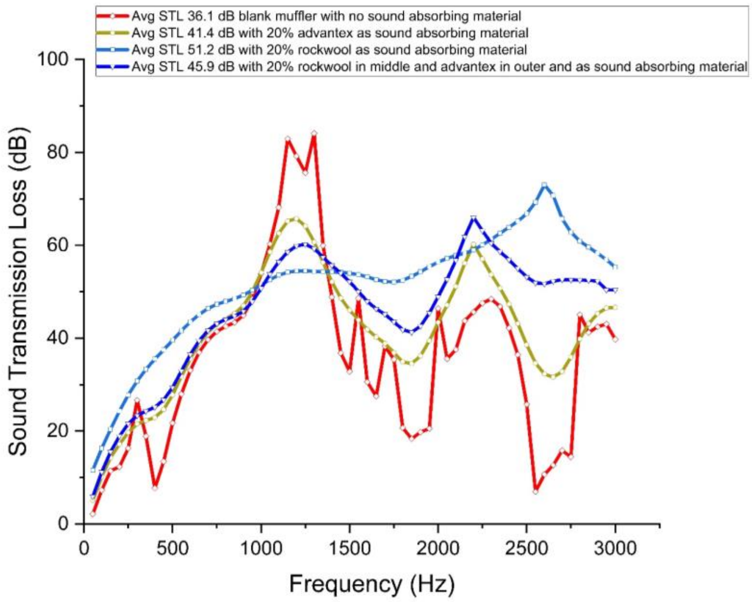

Figure 6. Compression of STL with different and combination of sound absorbing material

Testing and Validation

Validation of Finite Volume Results for an Empty Circular Cylindrical Muffler Based on Experimental Data

The amount of sound transmission loss induced by the empty muffler was observed using an experimental setup as shown in Figure 7 that was built in the lab, which also included an amplifier, sound analyzer, speaker, and load. Following the physical filling of the muffler with sound-absorbing materials like glass wool and rock wool, the STL was measured to see how it changed. The specification of equipment used in the experimental set up is indicated in table 1. The same design is then created in FEA as shown in figure 8, and after doing a wave analysis, error is determined to determine how much the STLs of the two are different. The inaccuracy varied from 5% to 7%, proving that finite volume analysis was feasible. The mashing parameter used in FEA analysis is indicated in table 2.

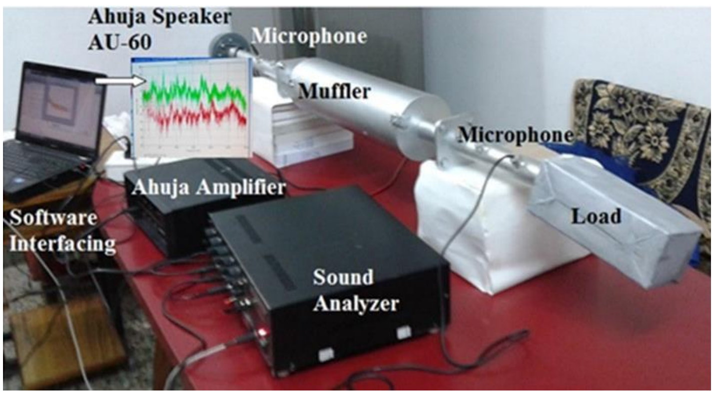

Figure 7. Testing and validation setup for hybrid muffler arrangement

Table 1. Testing and validation specifications for hybrid muffler

Specifications	Number count / Description
Tube Diameter (mm)	35
Microphone	2
Speaker	60 Watt
Method	Two load method

A hybrid absorptive muffler encased with various components is used in this experimental configuration. These elements consist of a defined load, two microphones, and a speaker with an AU-60 capacity. An amplifier, sound analyzer, and software device are all connected to the system. The experiment's goal is to calculate sound transmission loss in frequencies between 50 and 3000 Hz

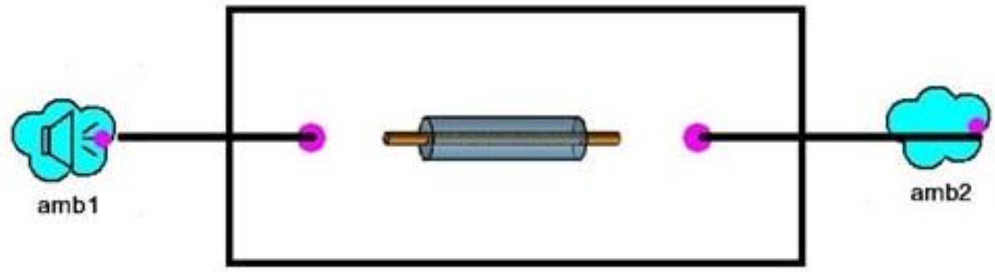

Figure 8. Schematic view of muffler incorporating 2 ambient sound sources

Table 2. Meshing Parameters

Axis	Complex Muffler mm
Cavity Dx	50
Cavity Dy	50
Cavity Dz	20

In the present work, an empty muffler has been made by finite volume method and it has been seen from wave 1D analysis that the sound transmission loss is 14.4 decibels. To experimentally validate this result, an experimental setup has been made and in it to load The sound transmission loss calculated from the method is 16.66 decibels which is almost equal to the software analysis. The results of both have been compared as shown below.

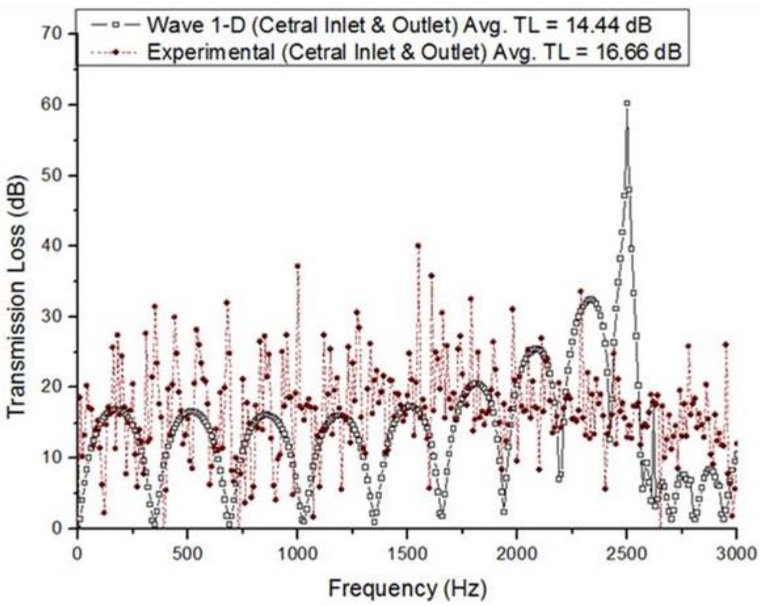

Figure 9. Compression of eave results and experimental setup results

CONCLUSIONS

The results of the simulated and experimental sound transmission loss were correlated, in conclusion. The STL curve displays good agreement between experiment and models for a basic design like the expansion chamber, with an error of 2.4%.

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When double baffles were installed in the muffler instead of single, there was a huge increase in sound transmission loss which was almost double of the previous one to 35.9 dB. After this, the optimum condition was observed by changing the perforation percentage in the central pipe, in which the sound transmission loss increased to 36.1 dB at 6% flow performance.

The muffler design that was finally derived was first filled with advantex with 20% density, in which the sound transmission loss increased to 41.4 dB, while with 20% rockwool, the sound transmission loss indicated an increment of 51.2 dB, which was the highest. Since, rockwool is heavy in weight, an optimum condition was also attained in which rockwool and advantex were filled altogether having 1/3rd filled with rockwool and 2/3rd filled with advantex. In this condition, the sound transmission loss was computed to be 45.9 dB.

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