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Original Article

Investigation of Sound Absorption Performance of Roof Panels in Automobiles

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Abstract *- Vehicle interior noise is a factor that directly affects users' perception of the quality of passenger cars. Research shows that there has been more focus on NVH (Noise, Vibration, Harshness) studies in modern vehicles in recent years. Ceiling tiles are extremely important in controlling vehicle interior noise. With the developing technology, automotive companies focused on ceiling tiles and invested in NVH analysis. In this study, the material properties and acoustic test methods of the ceiling tiles of the vehicles were investigated. Sound absorption of ceiling tiles was carried out using an impedance tube. The sound absorption coefficients of ceiling tiles of different materials and different thicknesses were estimated and compared with the test results.*

Keywords *- Headlining, Composite materials, Thickness, Optimization, Coustics.*

1. Introduction

The panel in automobiles have been used in passenger cars, commercial vehicles, tractors and construction machines since the beginning of the automotive industry. Headlining is a decorative and functional flooring that covers the underside of the ceiling panel. The headliner was originally born out of the need to make the vehicle's interior (roof/ceiling) look good. It was intended to reduce the impact of hard surfaces felt in the operator's touch areas. Recently, what has been desired from ceiling tiles is to appeal to the ear. The sound insulation inside the cabin also shapes the quality understanding of the users today.

In the development period of motor vehicles from the past to the present, interior flooring and sound insulation have been used to reduce the amount of sound entering from the outside. Although headliners are primarily designed for their aesthetic qualities, researchers have realized that these parts play an important role in influencing the acoustics in the vehicle cabin. The headliner has been an integral part of the overall acoustic package, primarily due to its contribution to the absorption of sound inside the cabin. Other acoustic properties, such as sound transmission loss and damping, also play an important role in controlling the overall acoustic performance of the vehicle. The primary functional requirements of a headliner are the basic vehicle needs that are met (or can be met) by the headliner and are difficult or impossible to meet without such a part. These requirements are appearance, tactility, acoustics and performance. Acoustics, system integration, weight and cost considerations drive substrate selection for headliner composites. However, the acoustic contribution of the ceiling tiles plays a primary role in their design. Headliners are an important sound-absorbing surface in the car due to the larger available surface area and the path of incoming sound waves. Figure 1 shows the sound absorption contribution of various interior trim components in an automobile (excluding seats). Headliners make up a large part of the sound absorption in the car [1].

In a modern vehicle, certain requirements must be met at a high level. Requirements falling into this category; environmental stability, integrity, odour, color continuity, cleanability, resistance to trace formation durability. These specified requirements (and others) driven by users are specified in considerable detail in materials testing specifications used by various vehicle companies [2- 3].

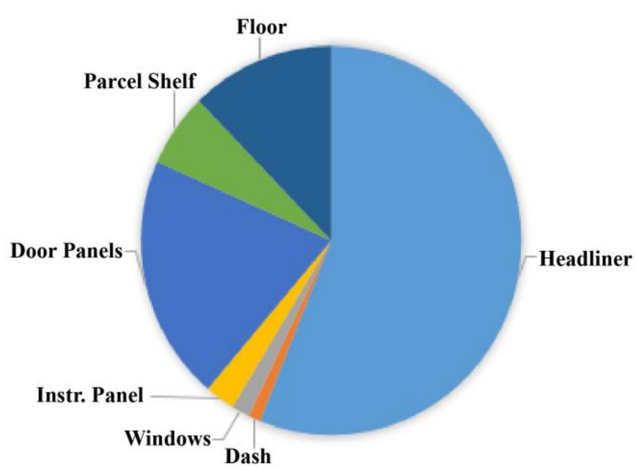

Fig. 1 Sound absorption contribution of various interior trim components in the interior of the car at 2000 Hz [1]

2. Literature Review

Various studies have been conducted on the sound conductivity of ceiling tiles. Richard et al. investigated the acoustic properties of ceiling tiles. Ceiling tiles are considered porous elastic material systems. They demonstrated that by assuming a porous elastic material system in the headliner, a wider variety of structures could be optimized to provide better product selection [4]. Duval et al. highlighted the importance of the airflow resistance of a headliner for better acoustic performance. He discussed how the thickness of the ceiling tiles and the air gap between the roof and the roof affect the acoustics and showed that the ideal value of the specific airflow resistance depends on the ceiling tile thickness but is mostly affected by the air gap between the roof and the roof [5].

Acoustic performance is generally the only engineering variable of controllable importance. In addition, the acoustic performance of the headlining can be significantly affected by material and design considerations and has been found to significantly impact the interior noise performance of a vehicle [6]. Katherine Tao et al. ceiling tiles based on thermoset polyurethane substrate; It has been subjected to various tests with the addition of multiple air spaces, different absorbent PE coating areas and coating material. It has been proven that the sound absorption coefficient for air-gapped surfaces is quite high [7].

When a vehicle's engine is running, the vehicle or part of it exhibits an oscillating motion called vibration. Adjacent air also exhibits vibrations called sound. Vehicle audio includes desirable and unwanted sounds. The unwanted sound is noise. Vibration and noise can cause users discomfort and damage the customer's perception of vehicle quality. The sound sought is typically engine related and can contribute to the customer's perception of quality or sound quality. Vibration, noise and sound quality are essential vehicle characteristics. They are often among the essential features of any vehicle type. In Figure 2. shows the internal noise sources of a vehicle.

Appropriate internal noise is obtained by controlling various parameters in the source-path-receiver systems that make up the vehicle. In the simplified system shown In Figure 3, the sources can be the powertrain or the road surface/tire interface; roads can be airborne, structure-borne or quite often compound structure-borne/airborne roads. The receiver in this model is the passenger compartment [2, 8, 9]. The combination of vibration and sound is a vehicle's most important performance indicator.

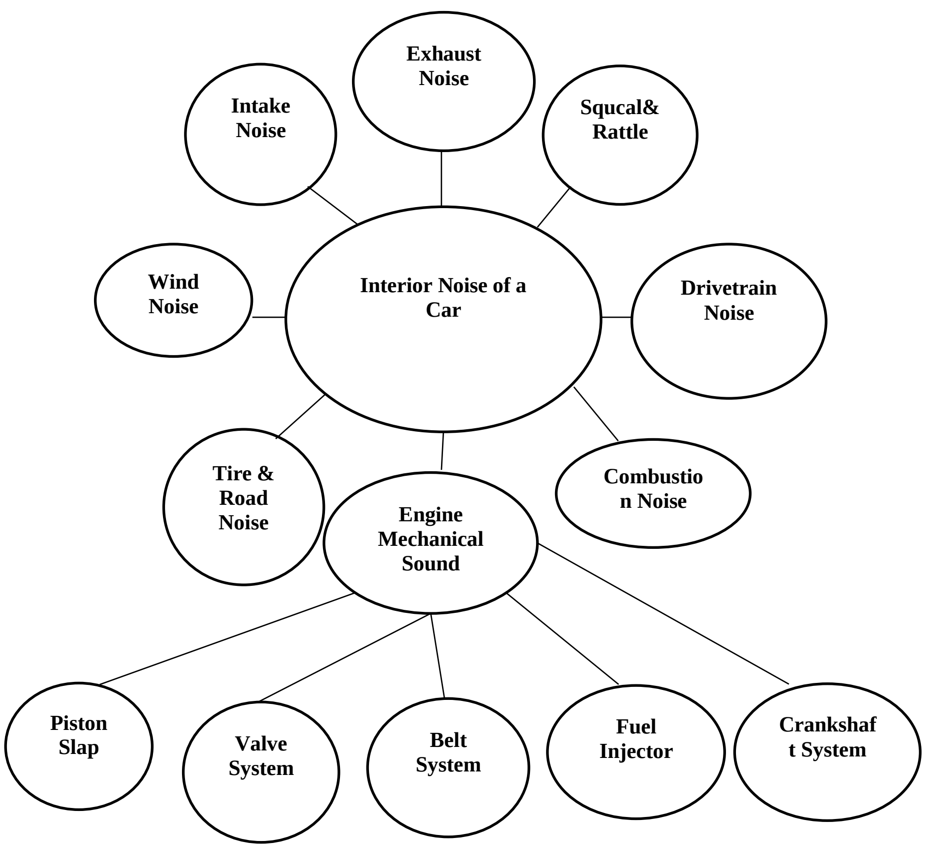

Fig. 2 Internal noise sources of a vehicle [2]

A vehicle's sound quality design, interior noise control, and vibration reduction are critical to attracting customers. Figure 4 shows the parts used for vibration and sound dampening in vehicles [10-11]. The absorption coefficient is a measure of the sound absorption efficiency of a material, which varies according to the frequency and the angle at which the sound comes into the structure. Its size depends on material thickness, airspace and material density. Body panels are often damped to control resonance vibration. The inside of the body is also lined with an absorbent treatment (such as fiberglass mat or open-cell foam) to prevent internal reverberating sound [12, 13, 14].

This study was conducted to propose a design with improved acoustics while maintaining the performance characteristics of ceiling tiles, such as safety, stiffness, and vibration. The design process was done with the NX Unigraphics software. Acoustic experiments were performed in an impedance tube.

3. Material and Method

This study compared the sound absorption coefficient results of different materials and different thicknesses of a car's headliner. The test method used when making the comparison was the impedance tube. The use of small sample sizes and the result in a short time were effective in choosing this method. Different thickness ceiling tile production and test time cost to raise. For this reason, the alpha cabin measurement method was not preferred. Ceiling tile The design was made in the NX Unigraphics program, and the weights were calculated in the same program.

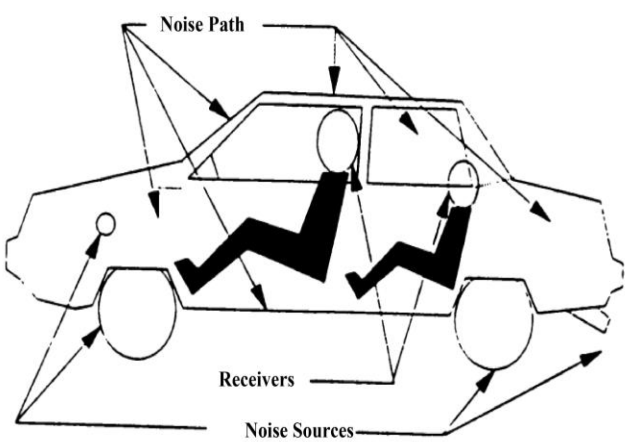

Fig. 3 Source-path-receiver systems that make up the vehicle [1]

3.1. Noise Control Through Absorption Material

When a sound wave propagates on the surface of a fiber or porous material, the airflow movement and friction dissipate some of the sound energy into heat. The spaces between solid structures (such as fibers) play a critical role in the energy dissipation process.

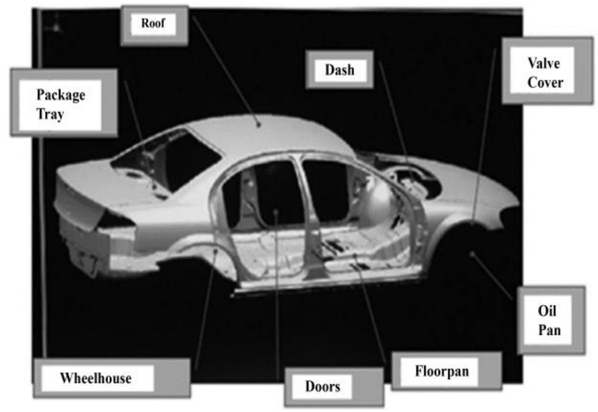

Fig. 4 Typical parts used for damping in a car [7]

This function of fiber or porous materials can be used for noise absorption in a vehicle. Noise-absorbing materials are usually sheets, foams, fabrics, carpets or cushions. The sound absorption capacity of a material is characterized by the absorption coefficient of the material, which is the ratio of the absorbed acoustic power to the incident acoustic power.

The absorption coefficient is a measure of the sound absorption efficiency of a material, which varies according to the frequency and the angle at which the sound comes into the structure. Its size depends on material thickness, airspace and material density [15].

Body panels are often damped to control resonant vibration. The inside of the body is lined with an absorbent treatment (such as a fiberglass mat or open-cell foam) to prevent internal reverberating sound.

3.2. Introduction of the Test Setup

ELWIS-A was used as the impedance tube brand. ELWIS (Evaluation of Light Weight Impedance System) offers a complete, reliable and rapid characterization of porous materials' physical parameters (Biot-Allard parameters). The system consists of ELWIS-A and ELWIS-S devices, which can be used independently of each other, although both applications are needed for complete material modelling.

By ISO 10534-2 standards, the sound absorption coefficient test was tested in the impedance tube test system. Each sample was tested in the large tube for detecting acoustic values at low frequencies and in the small tube for detecting acoustic values at high frequencies. The sample cut in the form of a circle was prepared for the large tube with a diameter of 59.95±0.05mm. The sample cut into circles was prepared for the small tube with a diameter of 29.95±0.05mm. Sample pieces were prepared for 3 large tubes and 3 small tubes from each sample to compensate for the errors that may occur due to test sensitivity.

3.3. Characteristics of Test Samples

In the tests, 3 samples of different materials and thicknesses were selected. The properties of materials numbered 1 and 2 of these samples are given below. Sample 1; It is 7 mm thick. Its layers are shown in Figure 5. Sample 2; It is 10 mm thick. Its layers are shown in Figure 6.

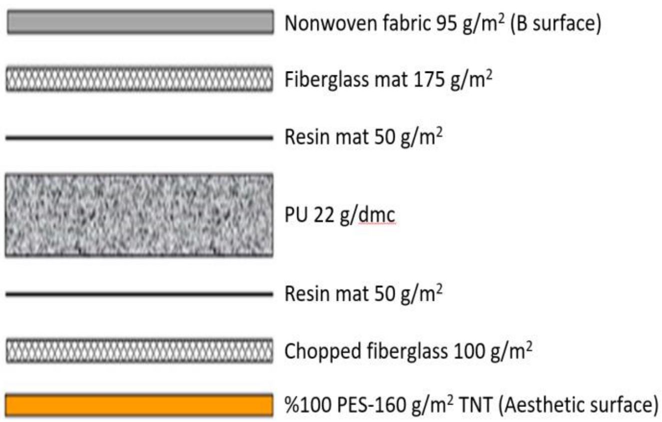

Fig. 5 Layers of sample 1

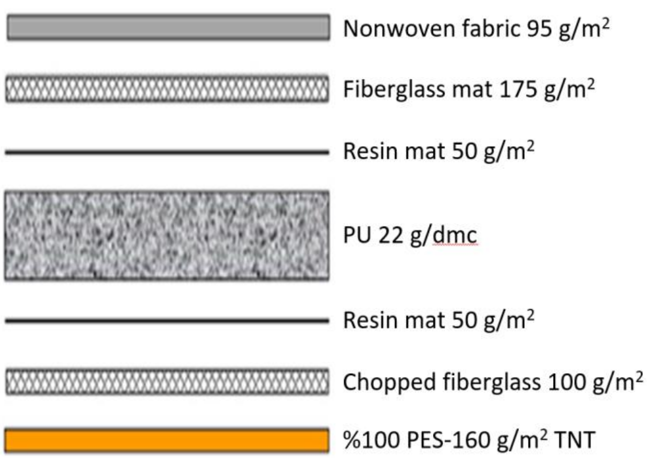

Fig. 6 Layers of sample 2

4. Results and Discussion

4.1. Test Results

The results of the impedance tube used in measuring the sound absorption coefficient in the tests were compared. The sound absorption coefficient results of samples 1 and 2 are shown in Figures 7 and 8. The sound absorption coefficient graph of sample 3 is shown in Figure 9.

4.2. Ceiling Tile Design

A ceiling tile that complies with the design norms and meets the regulation conditions was drawn in the NX Unigraphics program. The three-dimensional design is shown in Figure 10. Table 1. shows the comparison of the thickness and weight of the designs.

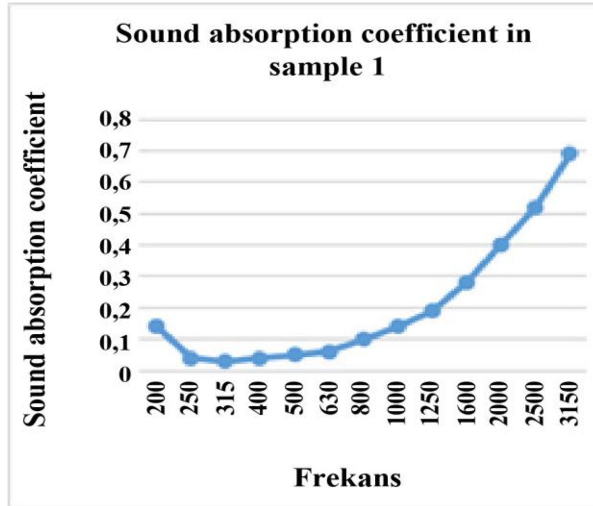

Fig. 7 Sound absorption coefficient measurements of sample 1

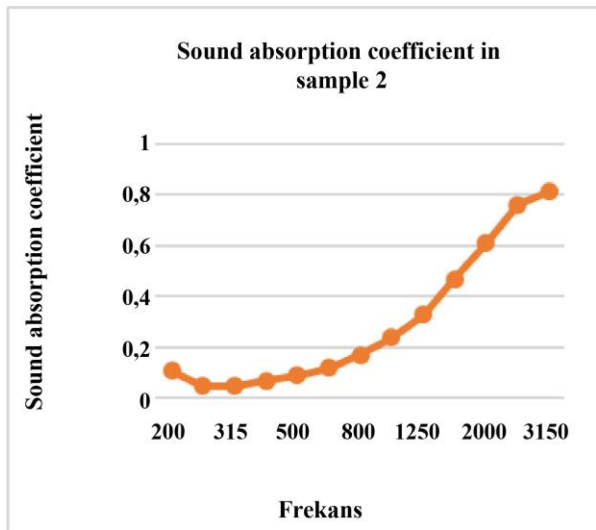

Fig. 8 Sound absorption coefficient measurements of sample 2

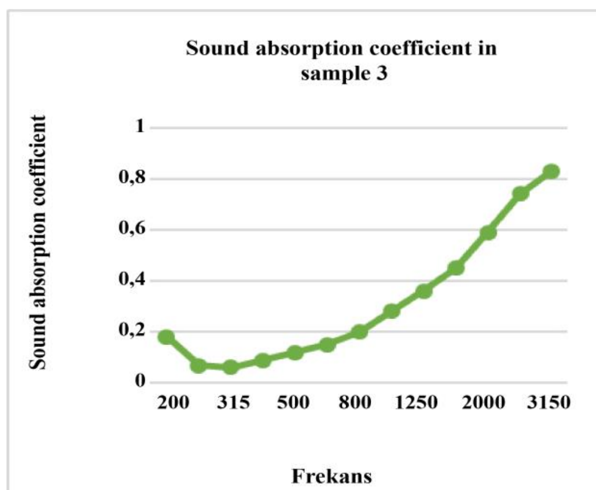

Fig. 9 Sound absorption coefficient measurements of sample 3

Fig. 10 Three-dimensional design of the ceiling tile

Table 1. Thickness and weight comparison of designs

	Thickness (mm)	Weight (Kg)
Sample 1	7	1.85
Sample 2	10	2.651
Sample 3	11.5	3.05

4.3. Comparison of Test Results

In the tests, 2 samples made of the same material and having different thicknesses were examined. The effectiveness of thickness on sound damping has been demonstrated. The sample is 1.7 mm thick. Sample 3 is 11.5 mm thick. This thickness increase had a negative effect on the vehicle weight by increasing the part weight by 1.2 kg. By optimizing the thickness, it is aimed to reduce the thickness of the part and lighten the weight. The test results are shown in Figure 11.

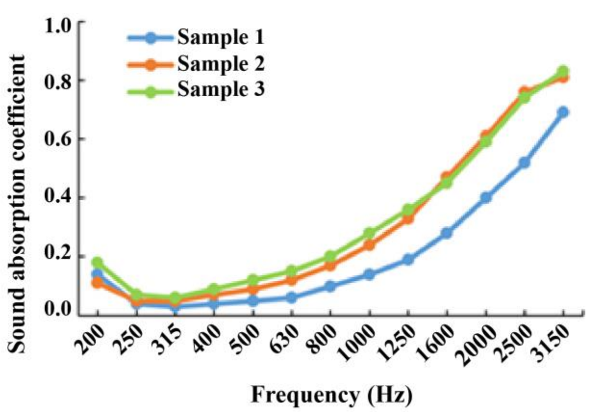

Fig. 11 Comparison of the sound absorption coefficient of samples 1, 2 and 3

In experimental studies, the thickness of both samples was increased. In sample 2, 10 mm thickness was obtained using a 3 mm interlayer material PU sponge compared to sample 1.

In sample 3, the thickness was increased by 4.5 mm, keeping the material properties the same compared to sample 1. The total thickness was taken as 11.5 mm. When the results were examined, both samples showed similar results. As a result of the experiments, the addition of interlayer material reduced the thickness of the part by 1.5 mm and the weight by 0.4 kg. Thus, it was possible to reduce the thickness and weight of the parts by preserving the acoustics inside the vehicle.

5. Conclusion

This study investigated the acoustic behaviour of the headlining used in vehicles. Ceiling tile production methods, materials used, the importance of part thickness, ceiling tile's contribution to acoustics, parameters affecting acoustics, and test methods used during product development were examined.

The acoustic parameter measurement methods described in the study are the methods used by major automotive manufacturers to test acoustic materials. In particular, impedance tube measurements are preferred more than other methods because of the short measurement process time and the easy preparation of the samples. Lightweight has recently become one of the most discussed terms in the automotive industry. While examining every detail to reduce the car's total weight, it also meets the users' interior comfort and exterior design demands.

It has been seen as a result of both theoretical and experimental studies that the acoustic performances of ceiling tiles vary depending on many properties, such as thickness, density, and airflow permeability. Finally, the increase in part weight due to the increase in thickness of the ceiling tile has been compared with the acoustic performance of the ceiling tile, emphasizing the importance of optimizing the thickness.

In the experimental part of the study, the effect of thickness and material layers on acoustic parameters, which are properties that affect acoustic performance, was examined using the impedance tube test method. Three different thicknesses of ceiling tile layers were selected to be examined in this context. As a result, as the thickness of the materials increases, it has been observed that the sound-damping capabilities of the materials have similar properties, especially in the low-frequency band (0-400 Hz), and it has increased noticeably in the high-frequency ranges (800-4000 Hz).

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