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Optimization of Composite Materials for Enhanced Acoustic Performance in Headliners

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ABSTRACT

This study investigates the acoustic performance of automotive headliner composites by examining the impact of various factors in the headliner composites, including the density, pore structure and thickness of the foam, the amount and type of fiberglass, and the type and weight of the fabric. The research aims to reveal the relationship between these variables and their effects on the overall acoustic properties of automobile headliner composites. Through a systematic examination, various combinations of fiberglass types, foam densities, foam structures/roughness, and fabric types are analyzed to determine their influence on sound absorption, transmission, and overall in-car acoustic comfort. The findings of this study have significant implications for the design and production of headliner composites, providing valuable insights for optimizing them to enhance sound performance within the automobile interior. This research contributes to an improved understanding of material and design factors crucial for achieving optimal acoustic conditions in automotive interiors.

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1. INTRODUCTION

1.1. Headliner Composite in Automotive Industry

In the contemporary automotive industry, the focus has shifted beyond being merely a means of transportation to providing a comfortable driving experience. In-car comfort is a significant factor for both drivers and passengers, and this comfort is closely related not only to ergonomic seats or modern interior design but also to acoustic comfort, as illustrated by the effects on acoustics in vehicle interior components shown in Figure 1 [1]. At this stage, acoustic studies on automotive headliner composites (Figure 2) hold critical importance in maximizing sound comfort in the automotive sector.

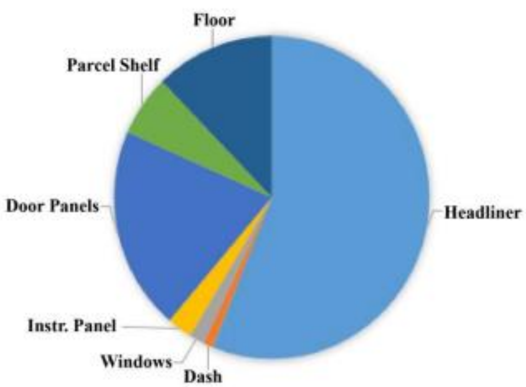

Figure 1. Effect of vehicle interior components on acoustics [2].

Figure 2. Example of headliner composite [3].

Headliner composites are designed with chosen materials that offer superior sound performance beyond other materials. Parameters such as the thickness, structure, and density of the foam used in these composite materials, as well as the characteristics and density of the fabric used, the density of fiberglass, among other factors, are crucial in influencing the sound insulation and absorption within the vehicle. Therefore, optimizing these parameters in headliner composites is a critical step in achieving a comfortable sound environment during driving.

This study will focus on improving sound comfort in the automotive industry, with a particular emphasis on acoustic studies conducted on headliner composites. Optimizing the acoustic performance of the foam and other materials in headliner composites has the potential to offer drivers and passengers a quieter and more enjoyable driving experience.

1.2. Development of Headliner Composites

Headliner composites typically have a multi-layered structure, designed to optimize the acoustic performance of each layer. This composite structure often includes fiber-reinforced layers, filling materials consisting of sponge structures, and specialized coatings. Fiber-reinforced layers control sound transmission and are typically made of materials such as fiberglass or carbon fiber. Filling materials in the sponge structure can reduce echoes and enhance acoustic performance through their sound absorption properties. When these layers come together, ceiling cladding composites provide both structural integrity and effective sound control, offering a comfortable acoustic environment in interiors.

Several studies have investigated methods for enhancing the acoustic performance of automotive components. Lee and colleagues developed sound-absorbing materials using PET hollow fibers that exhibit better acoustic performance than traditional products [4]. Haque developed fiberglass non-woven fabrics with isotropic properties for headliner composites using the AcoustiMax product [5]. Additionally, Da Silva and collaborators conducted a comprehensive study demonstrating how changes in the design of headliner composites can affect acoustic performance. These studies underscored the potential for enhancing acoustic performance through design adjustments, bringing attention to this aspect [6].

These studies highlight the potential of various materials and design changes to enhance the acoustic performance of automotive components. The acoustic testing of headliner composites involves evaluating the sound absorption and insulation properties of the materials used within an alpha cabin in Figure 3. This test evaluates the capacity of headliner composite materials, such as foams, fabrics, and fiberglass, to absorb and block sound waves, enabling the assessment of acoustic comfort within the vehicle cabin. The acoustic performance of headliner composites is crucial for providing passengers in the vehicle with a quiet and comfortable interior environment.

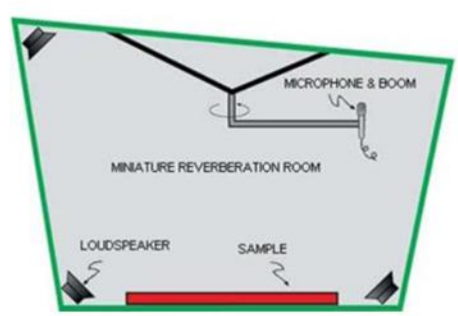

Figure 3. Alpha cabin test [7].

In summary, the acoustic performance of vehicle headliner composites can be enhanced through the use of materials such as polyurethane foams, fiberglass, and fabrics. These materials undergo acoustic testing to evaluate their sound absorption and insulation properties, contributing to a quieter and more comfortable vehicle cabin environment.

2. MATERIALS AND METHODS

2.1. Materials

The sponge used in the study was formulated with isocyanate named ISO 123/5 supplied by BASF, and two different densities of Elastoflex E3963/102 (22 kg/m^3) and E3963/102 (26 kg/m^3) polyols which also supplied by BASF. Chopped glass fibers added to the headliner composite in different ratios (100, 150, and 200 g/m^2) were supplied by Jushi, and the glass fiber mat (150 g/m^2) was obtained from P-D GLASSEİDEN GMBH. Non-woven fabrics used on the A surface of the headliner composites, including Printex fabric, non-woven fabric, and chemical barrier non-woven fabric, were sourced from Texno SRL.

2.2. Processing of Headliner Composites

Headliner composites were created using the hand lay-up method to form the composite structure. Subsequently, they were assembled in a mold heated to 110°C using a 100-ton Hürsan press machine. Afterward, excess parts were cut using a water jet, resulting in the preparation of the headliner composites.

Figure 4. Headliner composite process [8]

2.3. Test Methods

To evaluate the acoustic performance of the developed composite materials, sound absorption coefficient tests were carried out by the alpha cabin test device 7.R7401 specification. During these tests, our objective was to achieve the highest attainable sound absorption coefficient for frequencies above 2000 Hz.

3. RESULTS AND DISCUSSION

Within the scope of the study, separate studies were carried out on the materials in the headliner composites to obtain the best acoustic performance in the headliner composite. It is aimed to use the data obtained as a result of the studies in the headliner composite that will provide the best acoustic performance.

3.1. Selection of Foam Block Region

Tests were performed on the bottom, middle, and top regions of the sponge block to examine the noise, vibration, and harshness (NVH) performance of foam samples taken from different regions for headliner composite use. Acoustic testing, conducted within the frequency range of 1600 Hz to 10000 Hz, provided valuable insights into the sound absorption characteristics of the foam samples. The results indicated that the foam sample taken from the middle region exhibited the highest acoustic performance. Specifically, it was observed that the sample taken from the middle region met the OEM (Original Equipment Manufacturer) requested sound absorption coefficient of 0.8 in the frequency range of 4000 Hz to 9000 Hz (Figure 5). This result indicates that different regions of the foam block have varying sound absorption performances, suggesting that the pore size and distribution in the sponge depend on the region from which it is taken. Upon examining the foam structure, it was observed that the middle region of the sponge has smaller pores and a more homogeneous pore size distribution compared to the bottom and top regions.

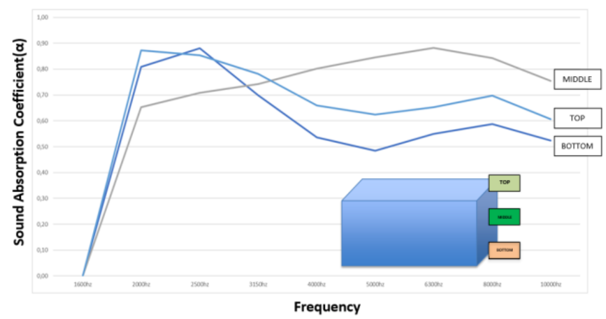

Figure 5. Sound absorption coefficient of the upper, middle, and lower regions of the sponge block.

To better understand the acoustic performance of foam samples, it is necessary to consider the material properties and structure of the foam. The acoustic behavior of porous materials like foam is influenced by factors such as porosity, pore size distribution, and material density. These properties affect the foam's ability to absorb sound energy within a specific frequency range.

In a study conducted by Cao and colleagues, the acoustic absorption of porous materials was investigated, emphasizing the importance of pore size and porosity in determining the sound absorption coefficient. The findings indicated that foam samples with medium-sized and homogeneously structured pores exhibited better results in terms of sound absorption capacity. In line with the findings of previous studies, including Cao and colleagues' research, our study further supports the notion that foam blocks with homogeneous pore structures offer superior sound absorption properties, thus establishing a clear correlation between foam pore structure and sound absorption [9].

3.2. Thickness of Foam

Within the scope of the study, the effect of foam thickness (7, 9, 9.5, 10, 10.5, and 11 mm) on the sound absorption of headliner composites was investigated. Based on the obtained information, the evaluation of sound absorption performance concerning sponge thickness indicates that 11 mm thickness provides the best performance, showing an improvement of approximately 5% compared to 10 mm thickness. The average sound absorption at 11 mm thickness was reported as 0.85 in the frequency range of 2000 Hz to 10000 Hz. Additionally, it was observed that the 9 mm thickness also exhibited satisfactory sound absorption by meeting the minimum requirement of 0.8, as shown in Figure 6.

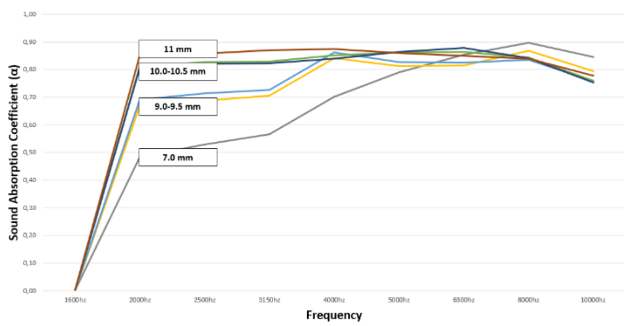

Figure 6. Sound absorption coefficient of sponges with thicknesses of 7, 9, 9.5, 10, 10.5, 11 mm.

In the context of sound absorption performance and foam thickness, various research studies in the literature have provided valuable insights into the acoustic behavior of materials and the impact of thickness variations. For instance, the study conducted by Farhad and Zahra investigated the influence of foam thickness on sound absorption properties, emphasizing the importance of thickness optimization to achieve the desired acoustic performance. This study laid the foundation for understanding the observed improvements between 25 mm and 50 mm thicknesses by highlighting the relationship between foam thickness and sound absorption coefficients. It was observed that increasing the thickness of the foam allowed it to absorb more sound, reaching an almost maximum absorption value of 0.98 [10].

The increase in foam thickness leading to an enhancement in sound absorption capability is evident both in our study and in various other studies in the literature. Considering the criteria of sound absorption capability, final product cost, and weight, the correct foam thickness was determined to be a minimum of 9 mm as the optimum thickness when all three criteria were taken into account.

3.3. Density of Foams

One of the most important foam properties affecting acoustic performance is known to be foam density. Foam density has a significant impact on the efficiency of sound absorption. Gwon demonstrated that numerous well-dispersed small cells in flexible polyurethane foams could enhance sound absorption even at low foam density [11]. Park also showed that cell openness in low-density polyurethane foam is a crucial factor in achieving satisfactory sound absorption [12].

In NVH tests conducted with polyurethane foams of two different densities, it was observed that the foams with a density of 22 kg/m^3 exhibited particularly 10% better sound absorption capability than the foam with a density of 26 kg/m^3, especially at sound wave lengths of 4000 Hz and above (Figure 7).

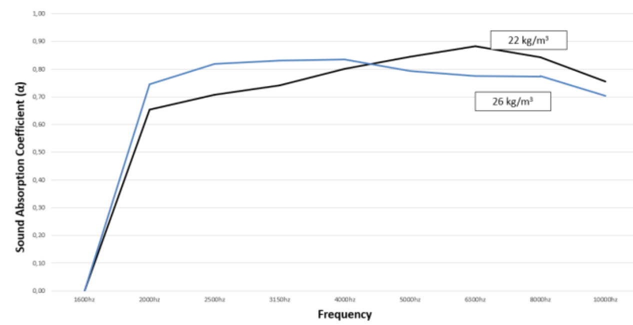

Figure 7. Sound absorption coefficient of foam with densities of 22 and 26 kg/m^2.

3.4. Type of Glass Fiber

Glass fiber materials can be used in schools, offices, private properties, and various other areas due to their high sound absorption capabilities. Glass fiber materials primarily used to provide strength in ceiling covering composites are also important components affecting the sound absorption ability in addition to their strength properties. Glass fiber materials have various structures such as chopped, fabric, felt, or mat.

In the study, when the sound absorption ability of glass fiber material with a weight of 150 g/m^2, in chopped and mat forms, used in headliner composites was examined, it was observed that chopped glass fiber material absorbs sound 10% better than mat glass fiber material (Figure 8).

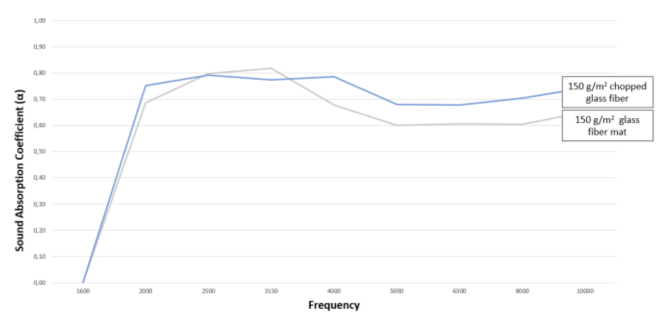

Figure 8. The sound absorption coefficient of chopped glass fiber and glass fiber mat.

3.5. Amount of Glass Fiber in Headliner Composite

In the study, the ratios of glass fiber used in headliner composite were altered, and their sound absorption capabilities were tested. Headliner composites reinforced with glass fiber amounts of 100, 150, and 200 g/m^2 were examined, revealing that the composite with 200 g/m^2 glass fiber reinforcement exhibited the best sound absorption capability. The headliner composite reinforced with 200 g/m^2 glass fiber was observed to absorb sound 10% better than the one with 100 g/m^2 glass fiber reinforcement and 5% better than the one with 150 g/m^2 glass fiber reinforcement (Figure 9).

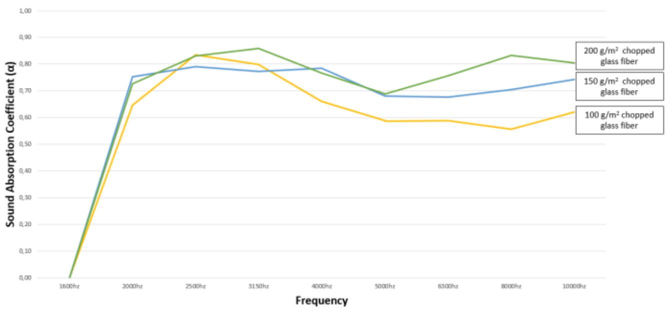

Figure 9. Sound absorption coefficient of different amounts of chopped glass fiber reinforced composites.

3.6. A Surface Fabric Type

The surface coatings of ceiling covering composites, particularly the A surface (the surface seen by passengers inside the cabin), are not only important aesthetically but also play an effective role in sound absorption due to being a layer of the composite structure. The study examined how the use of three different types of fabrics on the A surface could impact sound absorption. In the conducted research, Printex fabric, non-woven fabric, and chemical barrier non-woven fabrics were tested along with a foam block taken from the middle region of a foam with a density of 22 kg/m^2 and a thickness of 9 mm, and a composite structure with chopped glass fibers weighing 150 g/m^2. The composite structure utilizing Printex fabric demonstrated the best sound absorption capability. Compared to the non-woven fabric structure, the Printex structure absorbed sound 14% better and 46% better than the chemical barrier non-woven fabric structure (Figure 10).

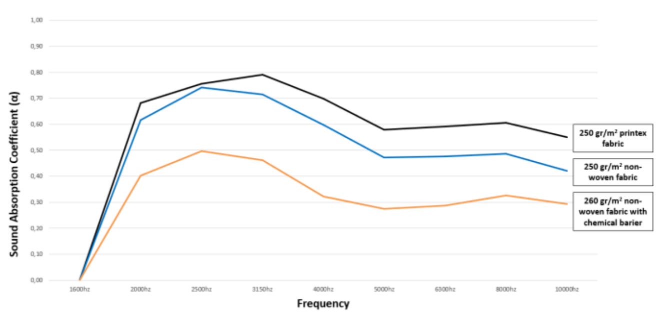

Figure 10. The sound absorption coefficient of composites using different A surface fabrics.

3.7. Density of A Surface Fabric

It was anticipated that fabric densities, similar to their impact on the sound absorption capabilities of glass fiber and sponge structures, could influence them. Therefore, two different densities of non-woven fabric were tested. The test results revealed that the fabric with a density of 250 g/m^2 absorbed sound 12% better than the fabric with a density of 200 g/m^2 (Figure 11).

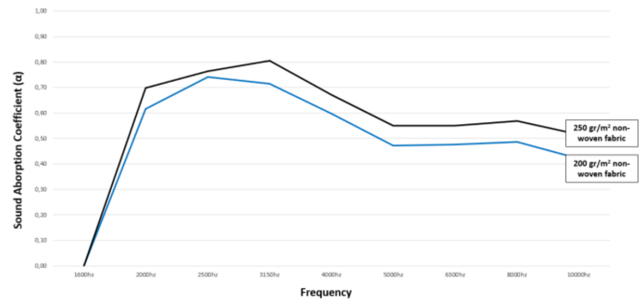

Figure 11. The sound absorption coefficient of non-woven fabric composites with a density of 200 and 250 gr/m^2.

4. CONCLUSION

Through detailed studies, specific criteria have been identified to ensure that headliner composites have the best sound absorption capability. These criteria form the basis of the 7-stages of the process:

1) In cases where foam material is used, it is recommended to prefer the middle part of the foam block. When three different foam block regions were tested in terms of sound absorption, the foam sample taken from the middle region showed 18% better sound insulation performance than the bottom region and 7,5% better than the top region. This is because the middle block of the foam sample allows for a more homogeneous pore structure, thereby increasing sound absorption.

2) Preferring low-density foam allows for obtaining a larger pore structure. This enables more effective damping of sound. This claim has been confirmed by the fact that low-density foam provides 10% better sound absorption performance than high-density foam.

3)Selecting the maximum thickness for the foam is recommended, which also increases sound absorption. Tests performed on foam thickness varying from 7 mm to 11 mm showed that the sound absorption coefficient increased by up to 16,5% from the thinnest sponge to the thickest sponge.

4) It is preferred that the glass fiber used within the composite be chopped glass fiber, which has a higher sound absorption capability. It has been observed that such a structural difference provides a significant improvement in the sound absorption coefficient, approximately 9%.

5) An increase in glass fiber density can enhance sound absorption capability. However, to maintain the flexibility of the composite and keep its weight under control, the optimum density should target 150 gr/m^2.

6) The A-surface fabric should have a printex fabric structure to ensure effective sound absorption.

7) The density of the A-surface fabric should be selected as high as possible for better sound absorption.

Developed by these criteria, the headliner composite has been successfully designed as a product that meets the 0.8 sound absorption coefficient demanded by many OEMs.

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