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Obtaining Sound Transmission Loss of Inner Dash Insulator via Numerical Methods

Mustafa CEYHAN[1], Tunahan DOĞRU[2], Halim SEVİM[3] , Merve Kafiye ÖĞÜTGEN[4] , İbrahim AYDIN[5]

[1] *Formfleks Otomotiv Yan Sanayi ve Ticaret A.Ş., Bursa, TURKEY, ORCID ID 0000-0001-5215-0383*
[2] *TOFAŞ Türk Otomobil Fabrikası A.Ş. Bursa, TURKEY, ORCID ID 0000-0002-3879-1421*
[3] *Formfleks Otomotiv Yan Sanayi ve Ticaret A.Ş., Bursa, TURKEY, ORCID ID 0000-0002-9892-6412*
[4] *Formfleks Otomotiv Yan Sanayi ve Ticaret A.Ş., Bursa, TURKEY, ORCID ID 0000-0002-6798-0619*
[5] *Formfleks Otomotiv Yan Sanayi ve Ticaret A.Ş., Bursa, TURKEY, ORCID ID 0000-0002-7902-5360*

Corresponding Author: Mustafa CEYHAN, mustafa.ceyhan@ff-rd.com

Abstract

In-cabin acoustic comfort has an important place in the brand preference of customers today. Automotive main and sub-industry companies plan their research and development investments taking into consideration acoustic comfort. The airborne and structure-borne noise of the engine is reduced by the inner dash insulators and the acoustic comfort in the cabin is improved. As a result of today's changing needs and the ongoing competition between automotive companies, continuous development studies are carried out for insulators. The purpose of this study is to calculate the sound transmission loss of the dashboard insulators in automobiles by numerical means and to evaluate the effect of different materials used on sound transmission loss. For this purpose, to model porous materials used in insulators in finite element acoustic analysis, the parameters of the JCAL Model were obtained by using an impedance tube with a reverse characterization method. Again, the modulus of elasticity and damping ratio of viscoelastic-based materials used in insulators were determined by sound transmission loss measurements and analysis with a reverse engineering approach. With the material parameters obtained, the transmission loss was calculated by performing finite element acoustic analysis of an inner dash insulator. The effect of different material configurations on sound transmission loss was evaluated.

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Impedance Tube

Ön Göğüs İzolatörünün Ses İletim Kaybının Nümerik Yöntemle Elde Edilmesi

Özet

Kabin içi akustik konfor günümüzde müşterilerin marka tercihinde önemli bir yer tutmaktadır. Otomotiv ana ve yan sanayi firmaları araştırma – geliştirme yatırımlarını akustik konforu da gözeterek planlamaktadır. Motorun hava veya yapısal kaynaklı gürültüsü ön göğüs izolatörleri vasıtasıyla azaltılmaktadır ve kabin içi akustik konforu iyileştirilmektedir. Günümüzün değişen ihtiyaçları ve otomotiv firmaları arasındaki süre gelen rekabet sonucu, izolatörler için de sürekli geliştirme çalışmaları yapılmaktadır. Bu çalışmanın amacı, otomobillerde ön göğüs izolatörlerinin, ses iletim kaybının nümerik yollar ile hesaplanması, kullanılan farklı malzemelerin ses iletim kaybına etkisinin değerlendirilmesidir. Bu amaçla izolatörlerde kullanılan gözenekli malzemelerin sonlu elemanlar akustik analizlerinde modellenebilmesi için tersine karakterizasyon yöntemi ile JCAL Modeli parametreleri empedans tüpü kullanılarak elde edilmiştir. Yine izolatörlerde kullanılan viskoelastik esaslı malzemelerin elastisite modülü ve sönüm oranları da tersine mühendislik yaklaşımı ile ses iletim kaybı ölçümleri ve analizleri ile belirlenmiştir. Elde edilen malzeme parametreleri ile bir ön göğüs izolatörünün sonlu elemanlar akustik analizi yapılarak iletim kaybı hesaplanmıştır. Farklı malzeme konfigürasyonlarının ses iletim kaybına etkisi değerlendirilmiştir.

Anahtar Kelimeler

Ses İletim Kaybı
Ön Göğüs İzolatörü
Akustik
Karakterizasyon

Öne Çıkanlar

Nümerik Hesaplama
Empedans Tüpü

1. Introduction

To provide acoustic comfort in the cabin in automobiles, design and Noise Vibration and Harshness (NVH) engineers carry out important development studies (Genuit, 2004). There are some specific products in these studies carried out to prevent the engine noise from coming into the cabin as noise. The main goal of these products, which are located on both sides of the firewall steel in the area between the engine and the cabin, is to dampen the sound acoustically and to lose it in the transmission path (Jain et al, 2011). The way the sound propagates can be airborne or structurally sourced (Vige, 2010). For these reasons, the insulation products used work according to the mass spring principle to prevent the noise coming from these sound sources with their layered structure (Seppi et al, 2012). In this study, the insulator called the inner dash insulator located inside the cabin was examined. The acoustic effect it creates according to different configurations has been investigated. In addition, vehicle manufacturers are faced with regulations to produce vehicles with low fuel consumption due to the reduction of carbon emissions

(Ravinath et al, 2009). Acoustic expectations can also be achieved with lower weights, but it is beneficial in terms of time and cost to examine in a virtual environment before the mold (Duval et al, 2009). Light weight studies are repeated at the beginning of the project according to the requirements of the vehicle manufacturers (Duval et al, 2009). In this study, changes in the acoustic properties caused by the weighted area localization change are also considered.

There are some studies in the literature to determine the acoustic properties of insulators using Statistical Energy Analysis (SEA), Finite Element Method (FEM), or Finite Transfer Matrix Method (FTMM) methods (Reynders et al, 2014). Zhang et al. (2015) developed a lightweight design of dash insulator with a SEA simulation, and in their study PE film was used between two soft layers (felt) to reduce weight, and effects on NVH performance observed. Dejaeger et al. (2012) studied both airborne and structure-borne noise excitation and optimized the weight localization to better noise reduction in middle frequencies, and in their study, they made reverberation room tests and Finite Element (FE) simulations. Tests and FE simulation results showed that; the multilayered insulator with localized heavy layer has better acoustic performance. Shao et al. (2015) studied about vehicle dash and floor sound package systems, and in their study, SEA was used as methodology. In the results they shown that, the lightweight design has better noise absorption performance. Ravinath et al. (2009) studied about porous materials characterization and optimize sound package of vehicle. They modelled materials from the results of acoustic tests and these models was included in analytical and Finite Element Analysis (FEA) solutions, and their study shown that the CAE tools are helpful in NVH development studies.

In this study, product-based material properties and sound transmission loss of the inner dash insulator will be emphasized. To describe porous and viscoelastic materials in an acoustic environment, the characteristic properties of the materials must be obtained. In this study, first, the acoustic properties of the materials were obtained through impedance tube and Actran software. Then, modeling was made in the virtual environment according to the condition of the dashboard insulator in the cabin. In this virtual model created with two-dimensional and three-dimensional elements, approaches are used to model the firewall steel and the interior of the cabin. Afterward, improvements were made for the use of regional and completely viscoelastic as an alternative over the obtained model. By means of these defined values, the sound transmission losses in the inner dash insulator with different sizes and different materials were analyzed parametrically and the results obtained formed an input to the acoustic design stage of the inner dash insulators. Designers or NVH engineers in the constantly evolving automotive industry will be able to decide which material to use and how much with this study. Because this study aims to provide fast and logical results with the finite element method without creating separate prototypes. While the project processes are getting shorter and the costs are trying to be reduced, this method will contribute to the projects that progress in this way.

2. Material and Method

To calculate the loss of sound transmission in the inner dash insulator numerically, it is necessary to obtain the acoustic and structural properties of the materials. The method to obtain these values for porous and viscoelastic materials is described below. Then, information about modeling technique will be given. But first, sound transmission loss should be examined in detail.

2.1. Sound Transmission Loss Method

As sound waves pass from one medium to another, some of the acoustic energy is reflected on itself and some are transmitted. Discussion of this phenomenon is greatly simplified when it is assumed that both the incident wave and the boundary between the media are planar and that all media are fluid (Doğru and Pulat, 2020). The complex pressure amplitude of the incoming wave between two media with characteristic impedances $z_1 = \rho_1 c_1$ and $z_2 = \rho_2 c_2$, the complex pressure amplitude of the incoming wave P_i, the complex pressure amplitude of the reflected wave P_r, the complex pressure amplitude of the transmitted wave P_t the transmission coefficient can be written as follows (Kinsler et al, 1982).

$$T_I = \frac{\mathrm{I}_t}{I_i} = \frac{\mathrm{z}_1}{z_2}|T|^2 \tag{1}$$

$$R_I = \mathrm{I}_r/\mathrm{I}_i|R|^2 \tag{2}$$

TL specified in Equation 3 is the sound transmission loss. W_s is the sound power on the input surface and W_t is the sound power on the transmitted surface. Sound power can be obtained over sound pressure in the low-frequency region where planar waves are dominant since the sound pressure and particle velocity are in the same phase (URL 1: Brüel&Kjær, 2019).

$$TL = 10\log_{10}\left(\frac{W_t}{W_s}\right) = 10\log_{10}\left(\frac{p_t}{p_s}\right) \quad [dB] \tag{3}$$

The following empirical statements should be made to understand the working principle of the impedance tube. Equation 4 shows the sound transmission loss calculation algorithm used in TestSens software according to ASTM-E-2611-17. (Çavuş and Kara, 2020) Firstly, calculated Frequency Response Function (FRF) data should be decomposed.

$$\begin{aligned} A &= \mathrm{j}\frac{H_{1,ref}e^{-jkl_1} - H_{2,ref}e^{-jk(l_1-s_1)}}{2sinks_1} \\ \mathrm{B} &= \mathrm{j}\frac{H_{2,ref}e^{+jk(l_1+s_1)} - H_{1,ref}e^{+jkl_1}}{2sinks_1} \end{aligned} \tag{4}$$

$$\mathrm{C} = \mathrm{j}\frac{H_{3,ref}e^{+jk(l_2+s_2)} - H_{4,ref}e^{+jkl_2}}{2sinks_2}$$

$$\mathrm{D} = \mathrm{j}\frac{H_{4,ref}e^{-jkl_2} - H_{3,ref}e^{-jk(l_2+s_2)}}{2sinks_2}$$

Sound pressure and particle velocity values at the inlet and outlet of the test piece placed in the impedance tube are shown in Equation 5. C is the sound velocity in here.

$$\begin{aligned} p_0 &= \mathrm{A} + \mathrm{B} \qquad & \mathrm{B} &= Ce^{-jkd} + De^{+jkd} \\ u_0 &= (\mathrm{A} - \mathrm{B})/\rho\mathrm{c} \qquad & u_d &= (Ce^{-jkd} - De^{+jkd})/\rho \end{aligned} \tag{5}$$

The transfer matrix obtained from here appears as following Equation 6.

$$\begin{bmatrix} \dfrac{p_{0a}u_{db} - p_{0b}u_{da}}{p_{da}u_{db} - p_{db}u_{da}} & \dfrac{p_{0b}p_{da} - p_{0a}p_{db}}{p_{da}u_{db} - p_{db}u_{da}} \\ \dfrac{u_{0a}u_{db} - u_{0b}u_{da}}{p_{da}u_{db} - p_{db}u_{da}} & \dfrac{p_{da}u_{0b} - p_{db}u_{0a}}{p_{da}u_{db} - p_{db}u_{da}} \end{bmatrix} \tag{6}$$

The calculation of acoustic properties from the transfer matrix is shown in Equation 7.

$$\mathrm{t} = \frac{2e^{jkd}}{T_{11} + (T_{12}/\rho\mathrm{c}) + \rho\mathrm{c}T_{21} + T_{22}} \tag{7}$$

Equation 8 occurs when this transmission coefficient is used with normal incidence sound waves.

$$TL_n = 20\log_{10}\left|\frac{1}{t}\right| \tag{8}$$

The sound transmission loss is calculated by measuring the transfer matrices with the impedance tube according to ASTM E2611-09. The structure of the impedance tube is shown in Figure 1.

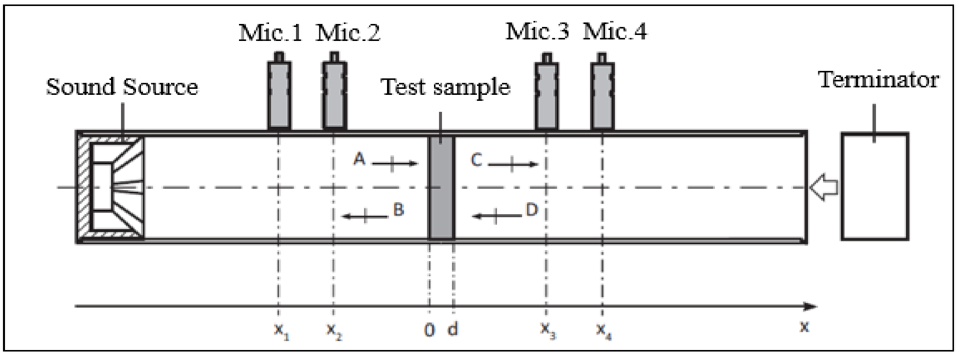

Figure 1. Schematic representation of sound transmission loss measurement (URL 1: Brüel&Kjær, 2019)

For sound transmission loss measurements of porous and viscoelastic materials used in the dash insulator, a system consisting of the Bias TestSens measurement software in the Erkurt R&D laboratory and the Brüel&Kjær impedance tube was used. Table 1 shows the devices in the study.

Table 1. Devices used in the study

Device Name	Device Brand	Device Model	Measuring Range
Impedance Tube	Brüel&Kjær	4206 type	100-6400 Hz
Impedance Tube	Brüel&Kjær	4206-A type	100-6400 Hz
Microphone	GRAS	46BL-S1 ¼”	10-10000 kHz / ± 2 dB
Calibrator	Brüel&Kjær	4231 type	1 kHz/94.0 dB ±0.2 dB
Data Acquisition	NI Instruments	USB-4431	0.8 Hz AC/DC 24 bit
Amplifier	SMSL	S 36-A PRO	20 Hz-20 kHz / 8Ω
Software	Bias	TestSens v2.7.7	-
Porosity Measurement	Bias	TestSens	-

According to the ASTM E2611 standard, sound transmission loss is tested with a small tube (29mm) for high-frequencies (1700-6400 Hz) and with a large tube (100mm) for low frequencies (200-1700 Hz) (ASTM E2611, 2019). After the tests, low frequency and high frequency measurements are combined discontinuously by interpolation. In these measurements, the frequency resolution is 4 Hz, the average number is 48 and the measurement time is 12 s. large and small tube mounted impedance tubes are shown in Figure 2.

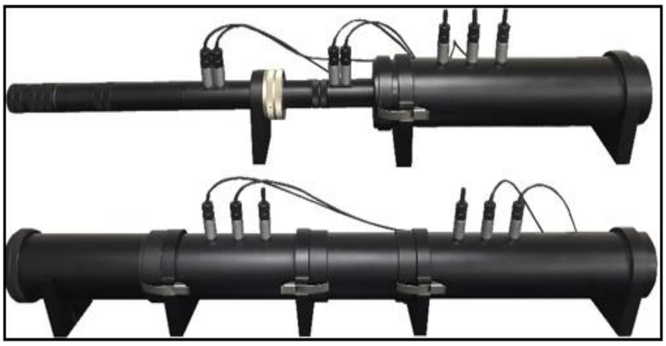

Figure 2. Impedance tube of 29 mm and 100 mm diameter

The measurements were repeated 5 times for each sample and the acoustic parameters were calculated according to the average measurements.

2.2. Material Characterization

Many methods have been developed to model acoustic measurement results. The most important of these methods is to perform acoustic models by obtaining Biot parameters. All Biot parameters must be obtained to describe the acoustic behavior of the material (Biot, 1956). The properties of the material are examined in two different phases, solid and fluid. Here, the solid phase is the material itself and the fluid phase is the area confined as air. Fluid and solid phases are related to acoustic parameters. While the solid phase is alone, it is only related to structural parameters (Allard and Daigle, 1994). In porous materials, it is sufficient to obtain acoustic parameters. When defining the viscoelastic material, the structural parameters of the material should be obtained. (Doğru, 2020) The poro-mechanical parameters help to link the acoustic behavior to the finite element method (Johnson et al, 1987, Champoux and Allard, 1991, Garner, 2008). For this reason, the method developed is named JCAL (Johnson-Champoux-Allard-Lafarge).

In this study, different materials, porous and viscoelastic, will be evaluated as the input parameter for the dash insulator. Acoustic characterization parameters of porous and viscoelastic materials will be calculated by analytical methods. The values obtained will be selected as a material input parameter in Actran software. The materials are shown in Figure 3. These materials were chosen as they are generally used in inner dash insulators. One of them is the Light PU, which is 15kg/m^{3}density and 20mm thickness, the second material is PU, which is 75kg/m^3 and 20mm thickness, third material is Epoxy felt, it has 1800g/m^2 density and 20mm thickness. The fourth and last material is Heavy layer, it is a viscoelastic material and product from EVA.

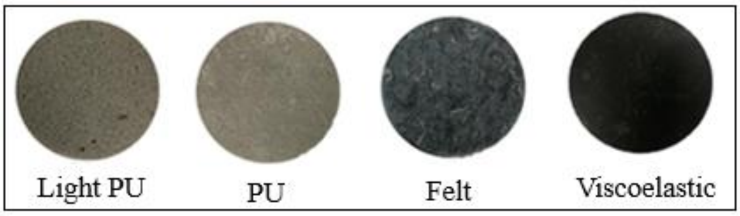

Figure 3. Alternative materials used in the study

Porosity is a parameter that indicates the volumetric ratio of the fluid phase in the material to the solid phase. The increase in material porosity is the most important feature that increases the sound absorption coefficient (Champoux et al, 1991). The porosity measuring schematic is shown in Figure 4. The precise weight and pressure obtained with and without sample in the device with using argon tube and pressure transducer. Obtained weight and pressure using in the processing of TestSens software.

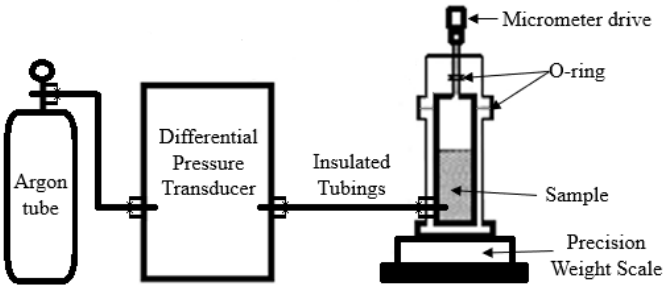

Figure 4. Porosity measurement schematic

The porosity measuring device, TestSens, used in this study is shown in Figure 5.

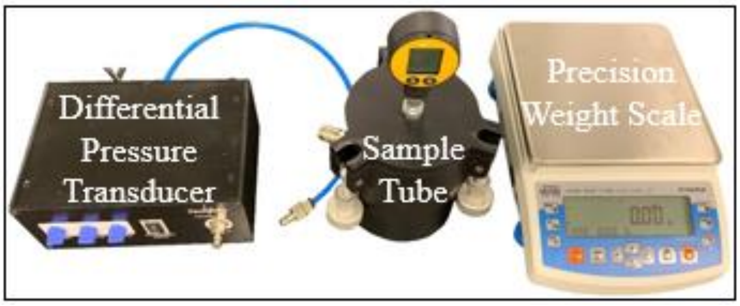

Figure 5. Porosity measurement device

According to the ISO 9053 standard, when air passes through a porous specimen placed in a tube, a pressure difference appears between the two sides of the specimen, and this difference is called airflow resistance (ISO 9053, 1991). When a steady stream of air passes through a flat sample of porous material, the complexity of the geometry of the pores forces the fluid particles to follow an uneven path, and this path determines the curvature parameter. (Johnson et al., 1987). The viscous length depends on the viscous friction dispersion mechanism in a porous material (Johnson et al, 1987). The thermal length depends on the thermal dissipation mechanism, that is, changes between the material frame and the fluid that saturates it (Lafarge et al, 1997).

Two methods are used to obtain the acoustic parameters of such porous materials. All the values described above can be measured directly or obtained by an analytical calculation method using the data obtained from sound transmission loss measurement and porosity measurement. In this study, the acoustic parameters were obtained from the measured sound transmission loss curve and porosity value by analytical calculation of TestSens software. Also, materials in porous class are prepared with a cutting press and porous materials to be used in the system are felt, polyurethane, and light polyurethane. Biot values, the thermal and viscous characteristic length unit is rayls and shown in Table 2.

Table 2. Acoustical parameters of porous materials

Acoustic Properties	**Light PU**	**PU**	**Felt**
Density	18 kg/m^3	75 kg/m^3	1800 g/m^2
Porosity (%)	0,97	0,94	0,9
Tortuosity (-)	1,677	1,1	1
Static airflow resistivity (Ns/m^4)	6,307x10^3	73,709x10^3	35,538x10^3
Viscous length (µm)	68,914	13,860	20,409
Thermal length (µm)	99,612	58,298	224,494

To calculate the sound transmission loss in non-porous materials, the structural properties of the material should be determined. EVA-based viscoelastic materials used in insulators can be modeled with a complex modulus of elasticity, Poisson's ratio, and density. It is not possible to talk about a single modulus of elasticity and damping ratio for viscoelastic materials (Saf et al, 2016). The modulus of elasticity and damping ratio of viscoelastic materials vary depending on the frequency, the amplitude of the drive, and the temperature under the dynamic drive. Dynamic mechanical analyzers are used for the measurement of the relevant parameters, which unfortunately cannot be measured up to acoustic frequencies. In this direction, the structural properties of the materials were determined by reverse engineering using sound transmission loss measurements made with high-frequency impedance tubes.

In this study, an EVA-based viscoelastic material mixture is considered, and samples were prepared by cutting with a water jet for precise measurement. The modulus of elasticity and damping ratio properties of such materials should be defined in the analysis software. These values will be found by comparing the sound transmission loss graphs obtained physically in the impedance tube and virtually obtained from the axially symmetrical impedance tube model created with finite elements in the Actran software.

The sound transmission loss is not only a material property, it also depends on the test method, part installation method, and boundary conditions. This should be considered in the interpretation of the results obtained with this test method. Boundary condition effects such as natural frequencies can be observed in sound transmission loss measurements made with impedance tubes (URL 1: Brüel&Kjær, 2019). For this reason, the adapter shown in Figure 6 can use viscoelastic material measurements to get repeatable and accurate results.

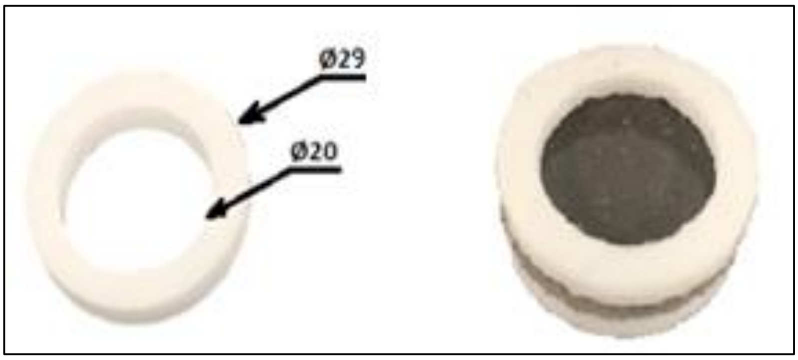

Figure 6. Adapter used in measurements

The finite element model of the impedance tube is shown in Figure 7 and made with Actran software. The material is defined in the region where the elements are concentrated and elements in this section have been removed to determine the effects of the adapter.

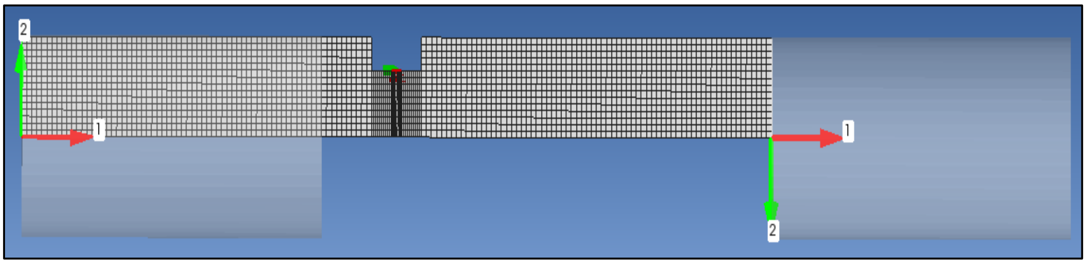

Figure 7 Finite element model of impedance tube.

In the finite element analysis, acoustic energy applied entrance of the system with normal wave propagation and free field boundary condition defined at the system output. The sound transmission loss is determined by the dependences of the sound forces of entrance and output surfaces. An axial symmetric model was used in this study, sound transmission loss calculated from 200Hz to 400Hz in 10Hz increments and shown in Figure 8.

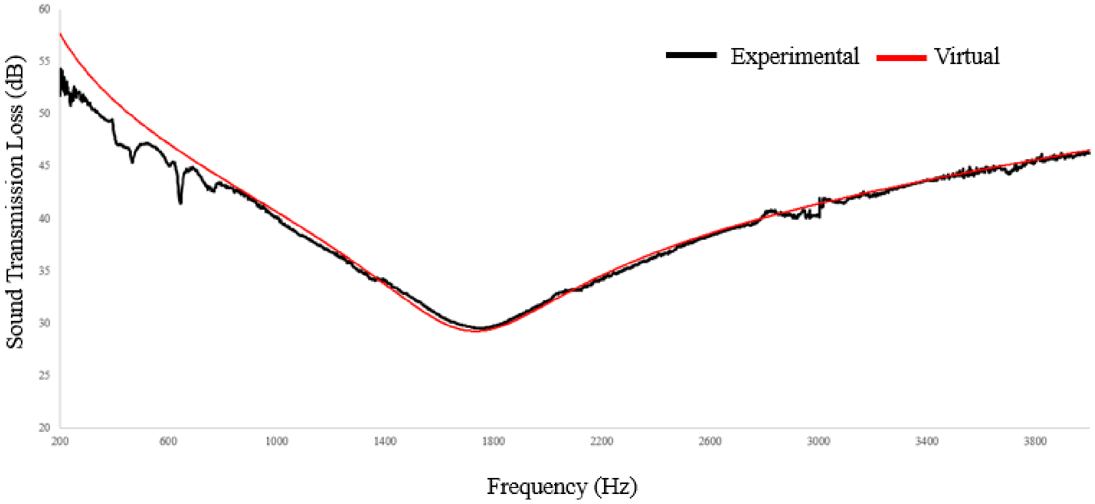

Figure 8. Comparison of experimental and virtual sound transmission loss values of viscoelastic material mixing

The values of the viscoelastic material obtained by the reverse characterization were shown as in Table 3 by intersecting the experimental and virtual sound transmission loss curves in Figure 8. When performing acoustic analyzes in Actran software, only elastic modulus, poisson ratio and solid density parameters are entered as input since it is known that viscoelastic materials have high sound transmission loss values and biot parameters can be simplified.

Table 3. Viscoelastic material structural parameters.

Structural	Viscoelastic
Density	1800 kg/m^3
Elastic Modulus	182 MPa
Damping Ratio	%31,86
Poisson Ratio	0,4

After obtaining the acoustic properties of porous and viscoelastic materials, these values will be used for calculations to be performed in Actran software.

2.3. Inner Dash Area and Finite Element Model

Inner dash insulator is located between engine and cabin space and as shown in Figure 9.

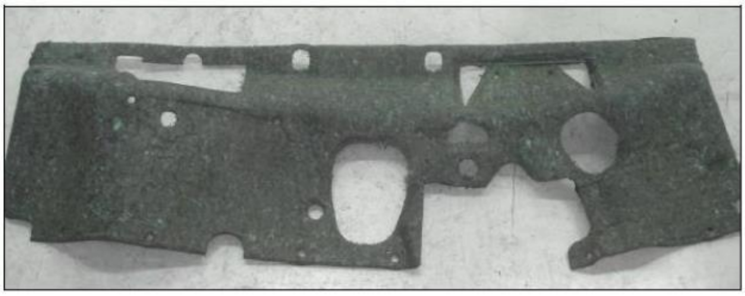

Figure 9. Sample of inner dah insulator (Aydın, 2008)

In the inner dash insulator, recycled fiber felt or polyurethane foam and heavy layer materials are frequently used, and Figure 10 shows an inner dash insulator.

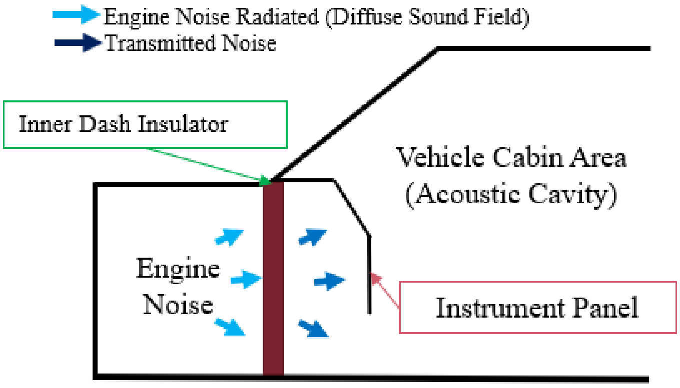

Figure 10. Location of inner dah insulator (Aydın and Batmaz, 2012)

Inner dash insulator is located between engine and cabin space and it is modeled as shown in Figure 10. The diffuse sound field has been defined as the inner dash insulator's engine side. The porous and viscoelastic materials were modeled by tetrahedral elements as shown in Figure 11. The acoustic cavity mesh was defined by using hexahedral and tetrahedral elements, to modeling the cabin side. On the upper side of the cavity, the receiving surface was determined with infinite elements by using a free-field boundary condition.

It will take a lot of time to model the situation on the vehicle exactly. The purpose here is to compare the materials with each other, so the processing time is shortened by using certain approaches for the cabin and the engine side. Actran software has been used for all these modeling processes.

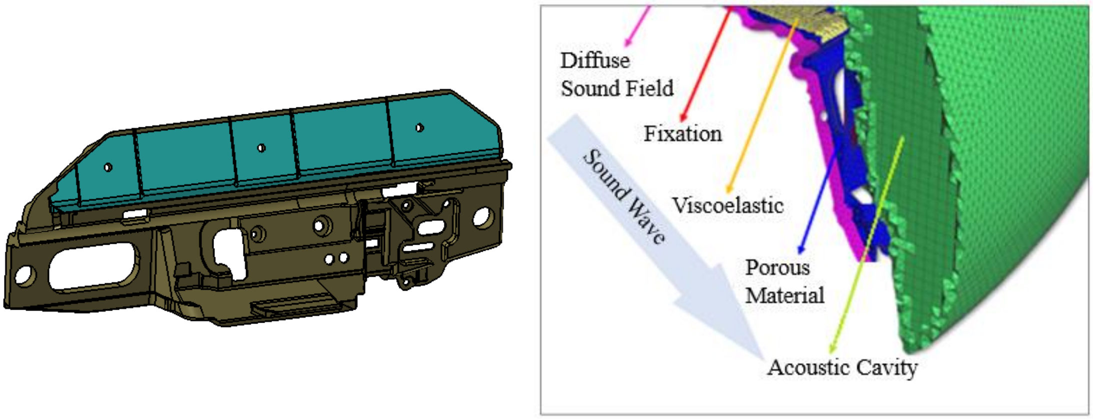

Figure 11. The finite element model of inner dah insulator

2.4 Inner Dash Insulator Variations

Alternative inner dash insulators modeled upon manufacturing methods are shown in Figure 12. A viscoelastic material is modeled with two-dimensional shell elements due to its constant thickness. The felt or polyurethane layers behind it are modeled in three dimensions due to their different thicknesses. 2-dimensional elements are used in the acoustic cavity simulating the cabin side.

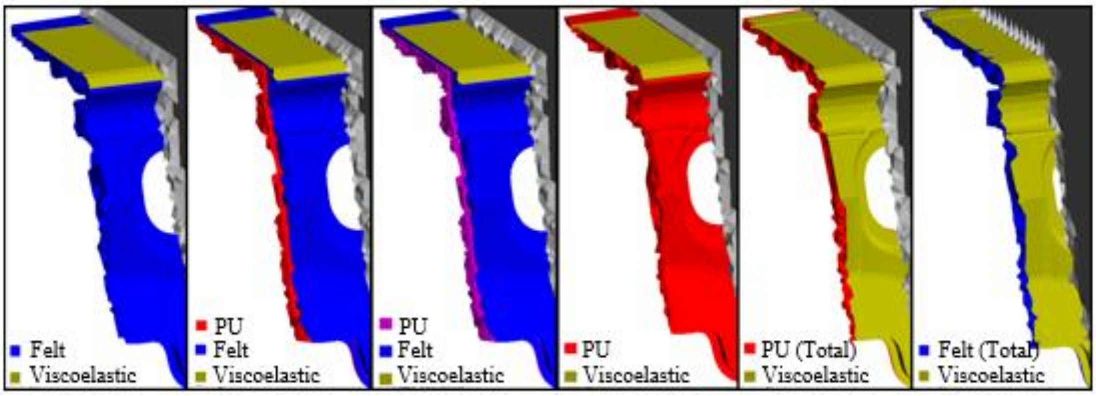

Figure 12. Alternative models with different materials of inner dah insulator

First, sound transmission loss curves will be obtained when a viscoelastic material is applied locally to the cabinet side of the insulator. Then, the sound transmission loss curves obtained by applying a viscoelastic material to the whole surface on the side of the cabin will be compared with the sound transmission loss curves obtained using the viscoelastic material locally.

3. Results and Discussion

In this part of the study, the sound transmission loss values of the models shown in figure 13 will be compared. The model was resolved from 20Hz to 4000Hz to consider alternative models. Results are shown separately for local use case and together for total area use case.

3.1 Local Viscoelastic material Application on Inner Dash Insulator

The transmission loss curves when applied local viscoelastic material are shown in Figure 13.

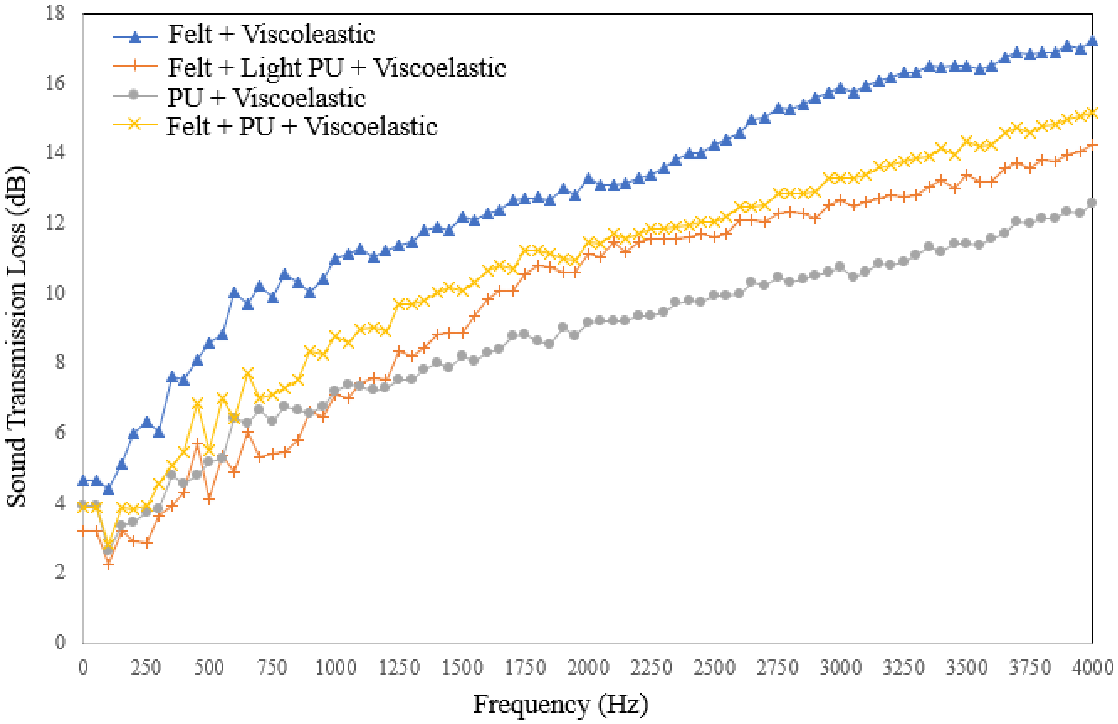

Figure 13: Models using local viscoelastic layer

It is seen that the use of felt increases the level of sound transmission loss. The sound transmission loss curve obtained because of forming the porous part of the insulator completely from felt is the curve shown in blue and the highest sound transmission loss was obtained with this material in the range of 0-4000 Hz.

By dividing the porous part in half, applying felt-light polyurethane versus felt-polyurethane, the resulting sound transmission loss curves are applied to a close behavior. From here, it is seen that 18 kg/m^3 polyurethane can be preferred to reduce the total material weight. In addition to its good acoustic values, its use in automotive will have a positive effect with the effect of its lightness. However, the cost of material should not be ignored here. The sound transmission loss obtained in the case of using only polyurethane remained at a very low level compared to other alternatives and it was observed that there was little sound transmission loss in the range of 0-600 Hz. When choosing between these alternatives, it can be interpreted that the use of felt material is necessary. Felts are low-cost solutions because they are recycled products. In addition, as can be seen from the figure, an improvement in acoustic values is achieved with its use.

By using viscoelastic material and porous material together, a system similar a mass-spring system is obtained in terms of acoustic. This mass-spring mechanism is a traditional technique commonly used in front chest insulators (Meric et al, 2016). In the studies in the literature, it has been observed that the absorption and barrier layers are generally used consecutively (Pegoretti, 2014). The reason for this is that while the absorption layer, which is the first layer, is expected to serve the sound absorption coefficient, the second layer, the barrier layer, prevents sound transmission. The materials that act as a high barrier to the sound transmission loss of viscoelastic material have been mentioned before. For this reason, the effect caused using the viscoelastic material should be examined.

In the design of the inner dash insulator, the felt thickness shows regional differences and these thickness limits determine the design volume of the felt. In the composition created with only felt and viscoelastic material, the upper surface of the felt is a formed felt. In other words, the piece is formed in a formed felt+felt+viscoelastic material composition. The formed felt here has a positive effect on the transmission loss performance. For this reason, it can be considered normal that the felt+viscoelastic material composition gives better results in sound transmission loss performance compared to the felt+pu+viscoelastic material composition.

3.2 Total Surface Viscoelastic material application on Inner Dash Insulator

The sound transmission loss curves obtained in the case of applying a viscoelastic material locally to the surface on the cabinet side and forming the entire surface with a viscoelastic material are as in Figure 14.

Viscoelastic materials have a negative impact on the automotive due to their weight. However, it is known from the literature that sound transmission loss values increase as their weight increases. Also, the cost rates change accordingly. For this reason, it should be examined completely in terms of weight, cost, and acoustics (Doğru, 2020). In this study, it has been shown how the use of heavy layers affects acoustic values when changed. These curves can be used as a criterion for choices.

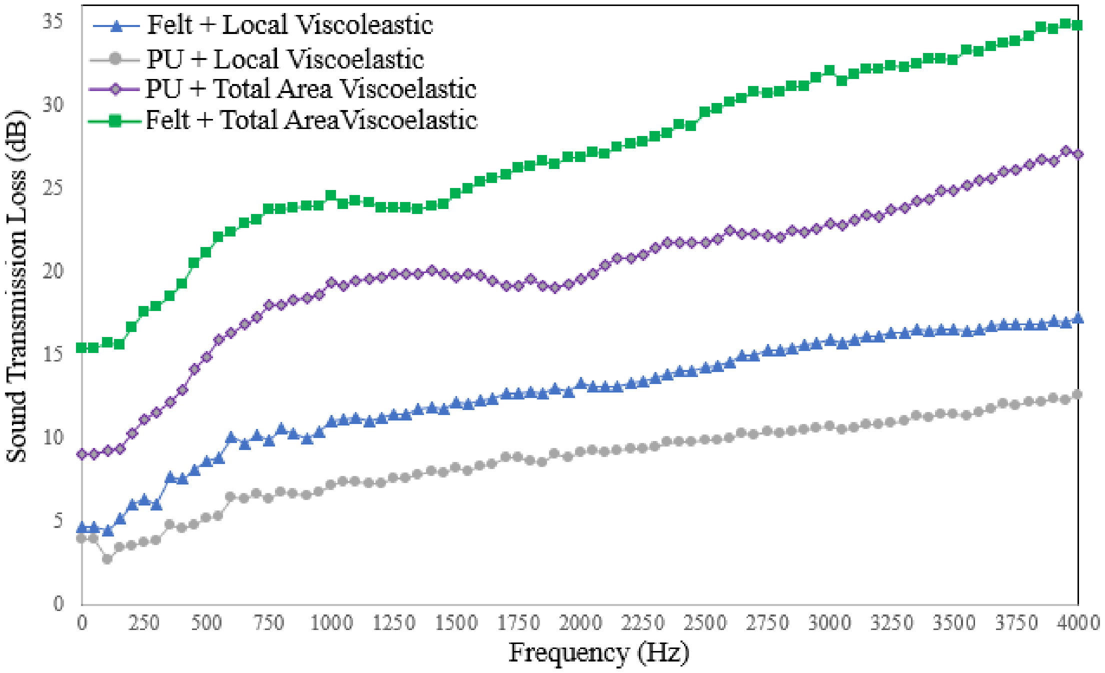

Figure 14: Sound transmission loss curves obtained by applying regional and all surfaces of cabin side viscoelastic materials

It is clear from Figure 13 that when using viscoelastic material, a very high increase in sound transmission loss is observed. The best results were obtained when the felt material was preferred as a porous material and the whole surface was covered with a viscoelastic material.

4. Conclusion

It is seen that using felt for the porous material side increases the sound transmission loss. By applying the viscoelastic material to the entire surface, a better sound transmission loss result was obtained as expected. Here, while the material properties are developed by the geometry, weight and cost issues should not be ignored. Felts are low-cost solutions, but viscoelastic materials are more costly solutions as their weight increases. Better acoustic values are provided in the dash insulator to be obtained by using these two materials. However, the usage rates of these two materials should be determined carefully. For this reason, after trying different materials, a selection should be made by considering the weight and cost of the product.

This work was carried out without the need to create separate prototypes for each material. Impedance tube was used for ease of sample production. The resulting final values also provide information about the material usage. If a separate prototype was created for each material, impossible results would occur in terms of project time and cost. These benefits have been achieved by using the finite element approach.

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Conflict of Interest

There is no conflict of interest.

Author Contribution

Each participant has an equal share.

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