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Araştırma Makalesi — Research Article

DETERMINING THE EFFECT OF AIR CHAMBERS ON RUBBER INSULATION IN AUTOMOTIVE PARTS FOR SOUND ABSORPTION COEFFICIENT AND TRANSMISSION LOSS

Murat KORU[1*], Orhan SERÇE[2], Osman İPEK[3], Hüseyin KARABULUT[2], Mehtap HIDIROĞLU[2]

[1] Isparta University of Applied Sciences, Faculty of Technology, Department of Mechanical Engineering, Isparta, Türkiye
[2] ORAU Orhan Automotive, R&D Center, Bursa, Türkiye
[3] Suleyman Demirel University, Faculty of Engineering, Department of Mechanical Engineering, Isparta, Türkiye

Keywords

Sound Absorption Coefficient, Sound Transmission Loss, Sound Insulation Properties of Rubbers.

Abstract

In automotive industry, noise from the road, engine and environment are undesirable sounds which impacts the driver and passengers. In automobiles, the connection between the gear shifter mechanism and the transmission is carried out through cables and these cables go through a passage between the engine and the passenger compartment and rubber-based grommet parts are using for insulation. In this study, a phenomenon is investigated for shifter grommet parts. For using low sound transmission speed of air, air chambers are positioned perpendicular to the sound direction in insulation materials and tested with impedance tube of samples transmission loss and sound absorption coefficient. At these tests EPDM samples were used. On these samples, 2 types of air chambers with 4 mm and 6 mm diameter were considered having either 2 or 3 whole body or blind holes. Results showed that in the air chamber with 3 blind holes, test sample results are best up till 8% void in the insulation material. On the other hand, most of the test samples with holes showed better results than the one's without the hole and the results showed that using low sound velocity of air can help to achieve better sound insulation properties in similar applications.

OTOMOTİV PARÇALARINDA KULLANILAN KAUÇUK YALITIM MALZEMELERDE HAVA ODACIKLARININ SES YUTMA KATSAYISI VE İLETİM KAYBINA ETKİSİNİN BELİRLENMESİ

Anahtar Kelimeler

Ses Yutma Katsayısı, Ses İletim Kaybı, Kauçukların Ses Yalıtım Özellikleri.

Öz

Otomotiv endüstrisinde yoldan, motordan ve çevreden gelen sesler kabin içi için istenmeyen sesler olup sürücü ve yolcuları etkilemektedir. Araçlarda vites kumanda mekanizması ile şanzıman arasındaki iletişim vites kabloları ile sağlanmaktadır ve bu kablolar kabinden motor bölümü tarafına açılmış olan bir açıklıktan geçerek gider. Bu açıklığın yalıtımı için grommetler kullanılmaktadır. Bu çalışmada, yalıtım için kullanılan grommet parçalar üzerinde bir fenomen incelenmiştir. Havanın düşük ses iletim hızının kullanılması için numunelere sesin geçiş yönüne yatay hava odacıkları konumlandırılmış ve empedans tüpü ile hem ses yutma katsayısı hem de iletim kaybı ölçülmüştür. Testlerde EPDM numuneler kullanılmış olup, odacıklar numunelerde 2 farklı çap da (4 ve 6 mm) ve 2 veya 3 odacık olacak şekilde oluşturulmuştur. Odacık tipleri boydan boya ve kör delik olacak şekilde iki tipte hazırlanmıştır. Sonuçlar incelendiğinde 3 adet kör delik bulunan numune en iyi sonuçları vererek, numuneler içerisindeki odacığın hacminin %8'e kadar iyi sonuç verdiğini göstermektedir. Diğer yandan, çoğu içerisine odacık açılmış numuneler hiç odacık bulunmayan referans parçaya göre daha iyi yalıtım değerleri göstermiştir. Böylelikle havanın düşük ses iletim hızından faydalanılarak benzer uygulamalarda daha iyi yalıtım sonuçları elde edilebileceği görülmüştür.

[*] İlgili yazar / Corresponding author: muratkoru@isparta.edu.tr, +90-246-214-6771

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M. Hıdıroğlu, 0000-0002-3368-1696		

1. Introduction

Automotive industry is constantly changing because of the user needs and competition. This affects the insulation materials and techniques which are widely used in automobiles. For providing better driving comfort and environment for both the drivers and passengers, automotive manufacturers want to eliminate the noises which come from the road, engine and environment (Batman & Aydın, 2012; Akaydın et al., 2013).

Sound is a form of energy which is transmitted to the environment through waves which causes a pressure change and our ears detect this pressure changes as sound. Noise is a kind of sound which is unpleasant and disruptive to humans. We consider some sounds as noise because of their frequency, pitch and intensity which could be distressing. Some research shows that, noise can cause unwanted effects on human health. From the driver's perspective, unwanted noise could disrupt the driver's concentration which can cause great damage or could even lead to lower hearing capability. Besides this, it can also cause physiological effects like muscle spasms, stress, high blood pressure, change in heart rate and blood circulation, sleeplessness and some psychological effects like anger, fear, nervousness, slower mental activity and lower work efficiency (Batman & Aydın, 2012; Akaydın et al., 2013; Akaydın et al., 2013; Akaydın et al., 2013; Kılınçarslan et al., 2018).

When a source creates a sound, the energy of the sound produced propagates through the air molecules to other molecules and the sound intensity level is defined as the power carried by sound waves per unit area in a direction perpendicular to that area. The SI unit of intensity is watt per square meter (W/m^2). There are two ways to insulate noise. Sound insulation, which deals with basically lowering the sound level and the other being sound absorption. Often these two terms can be mixed with each other. In sound absorption, energy of sound waves rubs to insulation material and some part of the sound energy turns into heat energy. If sound waves encounter anything which has different density or elasticity, some part of the sound energy reflects and some part of it turns into heat energy while the rest just passes through (Kaya & Dalgar, 2017).

Most of the sound, vibration and noise contain various frequencies. Frequency is characterized as a periodic vibration whose frequency is audible to the average human. The SI unit of sound frequency is Hertz (Hz). Period, reciprocal of frequency, is the time to complete one oscillation which remains constant and its SI unit is second (sec). Wavelength is the spatial period of a periodic wave and its SI unit is meter (m). The type of the sound depends on its frequency and low frequency sounds are called bass and high frequency sounds are called sharp sounds. An automobile engine can generate both low frequency and high frequency sounds (ASTM-E 1050, 2006; ASTM-E 2611, 2006).

Best way to measure sound insulation of a material is reverberation room method. But because of the small test equipment and the need of small test specimens, impedance tube method is widely used. With impedance tube both sound absorption coefficient and sound transmission loss can be measured. Diameter of the impedance tube is important for measurement. For low frequency tests, bigger diameter impedance tube is needed and for high frequencies smaller diameter is needed (Batmaz & Aydın, 2012; Akaydın et al., 2013; Akaydın et al., 2013; Akaydın et al., 2013; ASTM-E 1050, 2006; ASTM-E 2611, 2006).

In automobiles, different insulation methods are used for different areas like windshields in car windows, insulation panels at engine compartment, door insulations etc. It is important to achieve good insulation with cheaper solutions for the automotive sector because of the high competition present (Batmaz & Aydın, 2012). In Figure 1 an example of shifter grommet part can be seen.

Rubber materials are widely used in automobiles because of their exemplary absorption properties. As a lot of research and development activities are laid by automotive companies to make their existing parts smaller but sometimes it results in lower insulation capacity which is not suitable enough. During such moments, sometimes manufacturers use another insulation layer or make thicker rubber insulations. But these solutions raise the cost of insulation solutions. On the other hand, in the literature, sound velocity in rubber materials is 6100 m/s and for air is 329 m/s (Holz rubber ve altındaki). Celerity phenomenon uses these properties and states that if air chambers placed in solid materials, low sound velocity of air helps to obtain better insulation properties.

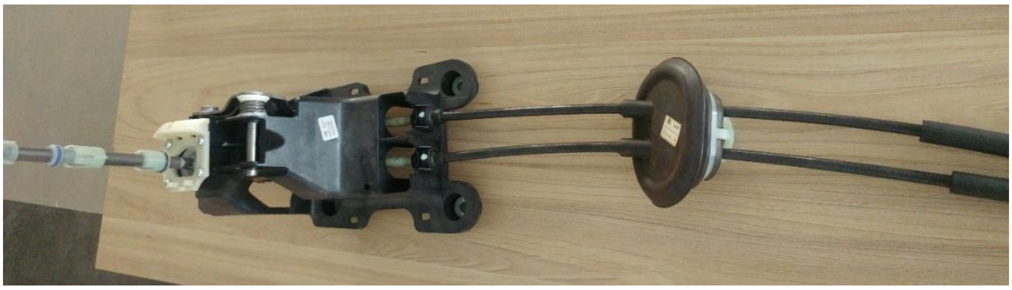

Figure 1. Shifter mechanism and insulation grommet part

There are various studies made about determining sound insulation capabilities of insulation materials with impedance tube. Akaydın et al. 2013, determined acoustic specifications of sound insulation materials with impedance tube. Kaya and Dalgar 2017, determined acoustic properties of natural fibers with impedance tube. Seçgin et al. 2017, determined acoustic properties of insulation materials depend on temperature with special conditioned impedance tube. Asdrubali et al. 2018, determined sound absorbing properties of materials made of rubber crumbs. Ersoy and El-Hafid 2013, determined sound absorption properties of high-density polyethylene and styrene butadiene rubber polymer composites. Hedayati and Arefazar 2009, determined fillers effect on acoustic absorption properties of EPDM based highly filled particulate composites. El-mansy et al. 2011, worked on in their study, sound absorption coefficient of different insulation materials with measuring at reverberation room. Harjana et al., 2014, worked on sound absorption and sound insulation properties of re-claimed waste tire rubbers. Sikora and Turkiewicz, 2010, study shows that how granular size of rubber insulation materials effects their sound absorption coefficients. And on the other side there are different studies for automotive insulation materials. Batmaz and Aydın 2012, investigate insulation capabilities of EPDM+Mat and PU+Mat with different thickness and determined best solution for automobiles depending on different sound frequencies. Beside these studies, Xu et al. 2018, measured insulation capabilities of perforated high-density polyethylene, recycled rubber and fiberboard sawdust with impedance tube. In this study they made, perforation direction to sound source like ceiling panels for rooms. But during our research in the literature we couldn't find any study directly linked to celerity phenomenon.

In this study, in order to obtain better insulation properties for automobile gear shifter grommet parts, celerity phenomenon has been carried out. For this, air chambers were placed perpendicular to the sound direction in insulation materials. For testing this phenomenon, impedance tube was used to measure both transmission loss and sound absorption coefficient. 29 mm diameter Ethylene Propylene Diene Monomer (EPDM) samples were prepared and their insulation properties were measured between 200Hz to 6400Hz. On these samples 4 mm and 6 mm diameter air chambers place 2 or 3-chambers whole body and as blind holes. At the end 6 different types of air chamber were tried. Results which were obtained from the tests are presented systematically in this study.

2. Material and Method

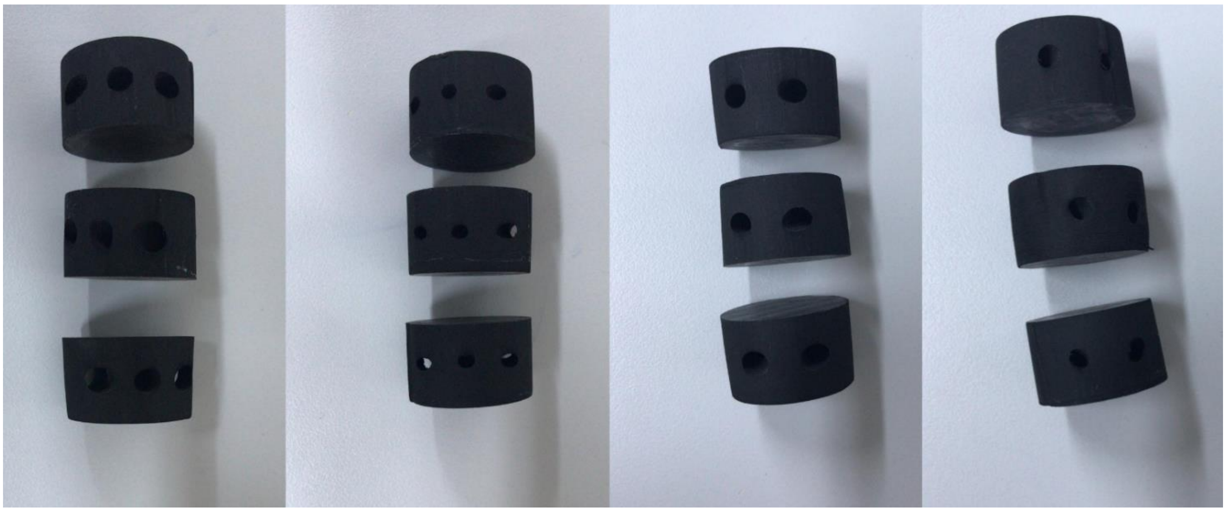

Figure 2. Photos of test samples

With impedance tubes, both sound absorption coefficient and sound transmission loss can be readily measured. There are some application differences for measuring these properties. In this study we used TestSens's impedance tube. This impedance tube can measure low frequencies at 50-1600 Hz with big diameter tube (100 mm) and high frequencies at 200-6400 Hz with small diameter tube (29 mm). The test setup consists of Gras's phase-compatible high precise 46BD model pressure-field microphone set, National Instrument's 4 ICP channel analyzer and its sample rate at 102.4 kS/s. 6 different air chamber shapes were used and 3 pieces of without the air chamber samples for every shape were prepared. Totally 21 test samples were measured with impedance tube to determine their sound absorption coefficient and transmission loss.

Cylindrical, molded EPDM test sample parts were prepared with 29 mm diameter and 18 mm thickness. Subsequently, 6 different chamber shaped samples were prepared by drilling holes. In Figure 2, sample pictures can be seen. In Figure 3, air chamber shapes of sample and sample numbers are illustrated. Sample without chamber is numbered as Sample 0.

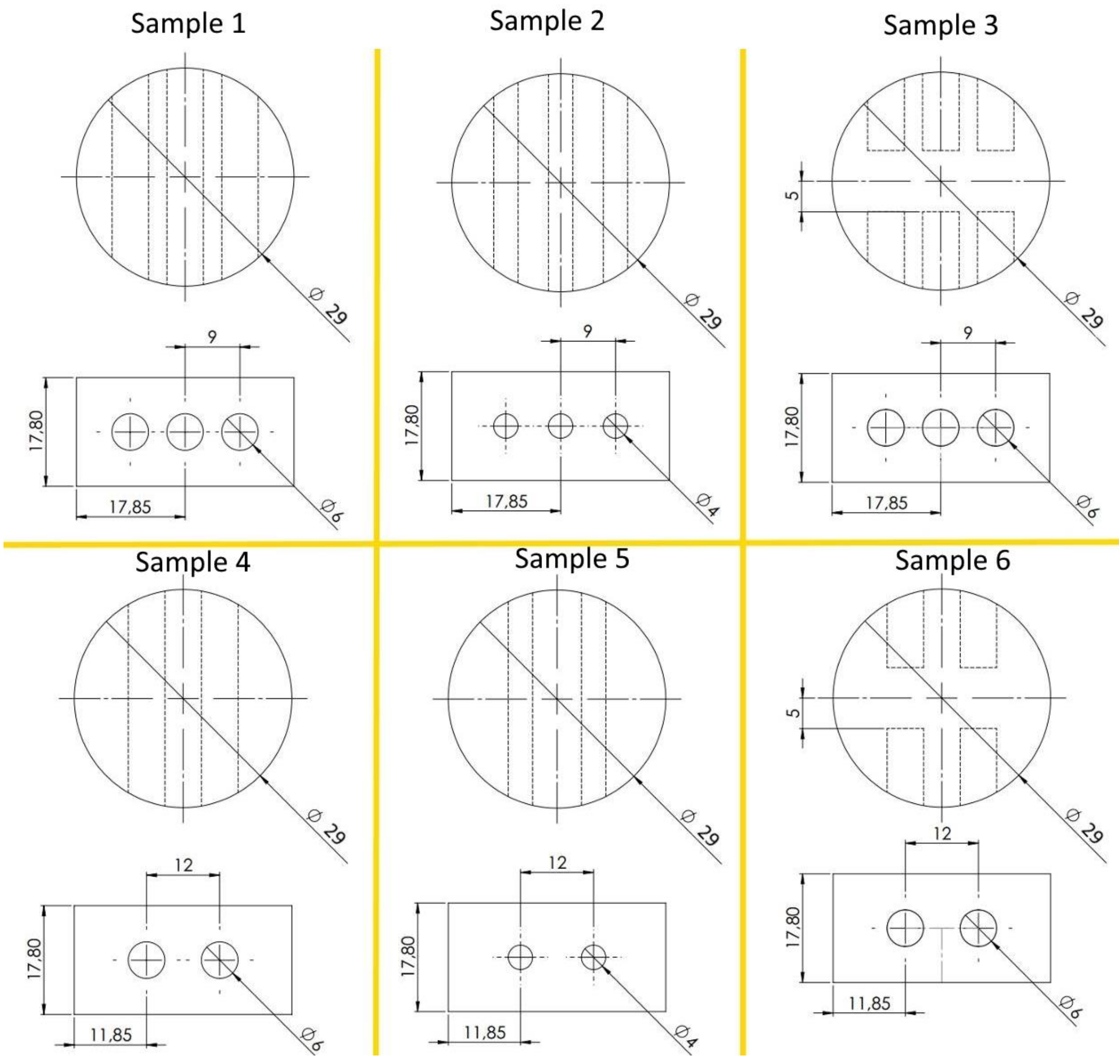

Figure 3. Measurements of air chamber shapes which used in test samples

2.1. Sound Absorption Coefficient Measurement

As mentioned before, sound absorption properties of a material can be considered into two main topics and one of them is sound absorption coefficient. For measuring the sound absorption coefficient of a material, firstly sound waves applied to the material and sound waves reflected from that material must be measured. With this method, the surface impedance of the material can be calculated. In Figure 4, general diagram of the measurement system used is illustrated. The system consists of a speaker which generates white noise and the microphones present measure the pressure of sound waves and using transfer function method, sound absorption coefficient is calculated (ASTM-E 1050, 2006; ASTM-E 2611, 2006; TS EN ISO 10534-1, 2004; TS EN ISO 10534-2, 2003).

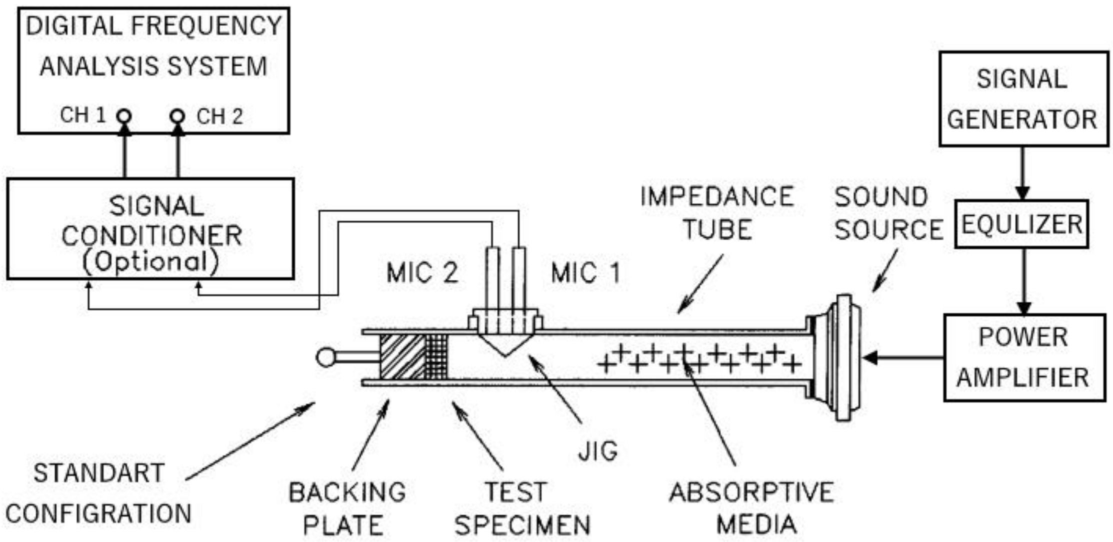

Figure 4. Diagram of sound absorption coefficient measurement system (ASTM-E 1050, 2006)

2.2. Sound Transmission Loss Measurement

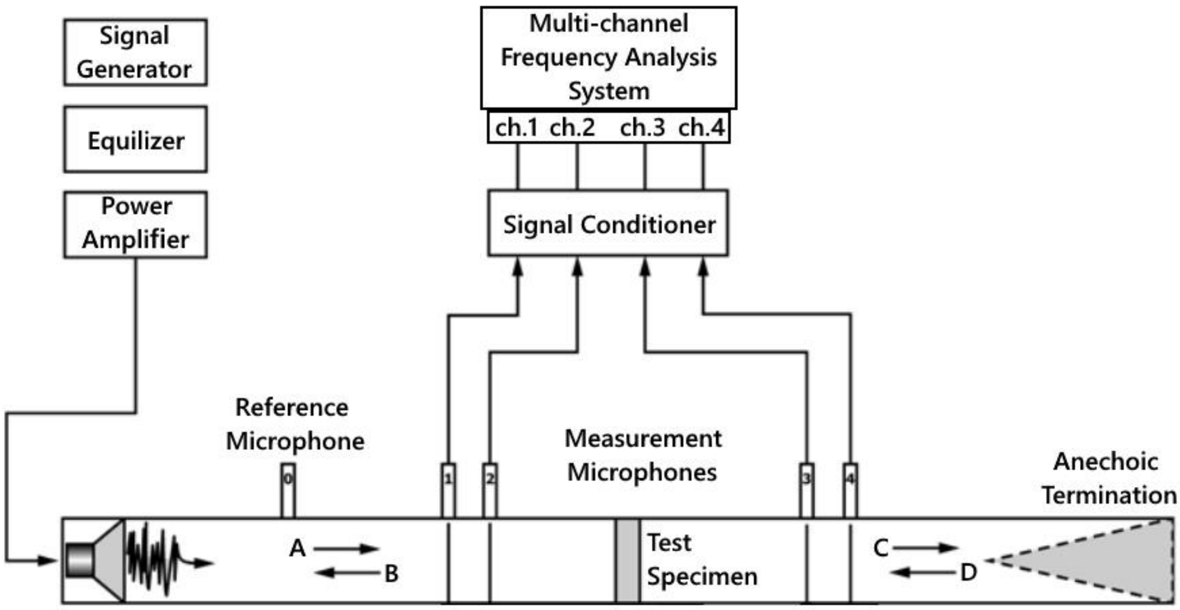

Figure 5. Sound transmission loss measurement system (ASTM-E 2611, 2006)

For measuring sound transmission loss with impedance tube, test sample were placed in the middle of the impedance tube and this way, two chambers were created in the impedance tube. Both chambers were measured with different microphones and their sound transmission loss were calculated. In order to calculate the transmission loss, reflected sound waves at chamber two must be removed from the equations and for this the measurements are repeated with anechoic termination and without it as well. Figure 5 represents the general diagram of measurement system (ASTM-E 1050, 2006; ASTM-E 2611, 2006; TS EN ISO 10534-1, 2004; TS EN ISO 10534-2, 2003).

2.3. Theory

Measuring both sound absorption coefficient and transmission loss lean on same theoretical method. Sound transmission coefficient, τ (dimensionless) of a material in a specified frequency band is the fraction of airborne sound power incident on a material that is transmitted by the material and radiated on the other side of the test specimen.

$$\tau = \frac{W_t}{W_i} \quad (1)$$

Where Wt. is the transmitted sound power and Wi is the incident sound power. Sound transmission loss, TL, of a material in a specified frequency band is ten times the common logarithm of the reciprocal of the sound transmission coefficient. The quantity so obtained is expressed in decibels.

$$TL = 10\log_{10}\left(\frac{W_i}{W_t}\right) = 10\log_{10}\left(\frac{1}{\tau}\right) \quad (2)$$

The speed of sound in air changes with air temperature and can be calculated with,

$$c = 20.047\sqrt{273.15+T} \quad (3)$$

Where c is the speed of sound (m/s) and T is room temperature (C°). Air density, the characteristic impedance of air denoted by ρc, can be found using equation 4.

$$\rho = 1.290\left(\frac{P}{101.325}\right)\left(\frac{273.15}{273.15+T}\right) \quad (4)$$

Where ρ, air density (kg/m3), P, atmospheric pressure (kPa). For/In order to measure measuring transmission coefficient with anechoic-backed impedance tube equation 5 can be used.

$$t = \frac{2e^{jkd}}{T_{11} + \left(T_{12}/\rho c\right) + \rho c T_{21} + T_{22}} \quad (5)$$

Where, t is the transmission coefficient, k is the wave number (m-1), j which equals to -1-1. While T11, T12, T21 and T22 are terms taken from the transfer matrix. Normal incidence transmission loss can be calculated with;

$$TL_n = 20\log_{10}\left|\frac{1}{t}\right| \quad (6)$$

Where TLn is the normal incidence transmission loss. Hard-backed impedance tubes reflection coefficient can be calculated with;

$$R = \frac{T_{11} - \rho c T_{21}}{T_{11} + \rho c T_{21}} \quad (7)$$

Where R is the complex acoustic reflection coefficient. Thus, the absorption coefficient with hard-backed impedance tubes can be calculated with;

$$\alpha = 1 - \left|R\right|^2 \quad (8)$$

Characteristic impedance in test specimens can be calculated with equation 9.

$$z = \sqrt{T_{12}/T_{21}} \quad (9)$$

Where, z is the characteristic impedance of propagation in the materials (rayls).

3. Results and Discussion

Sound absorption coefficient measurement results are illustrated in Figure 6. When we look at the figure, results depict the confirmation of the celerity phenomenon. On comparing the measured results of the samples without chambers, we concluded that their sound absorption level is lower than the samples with chambers. When we considered automobiles, we can divide the results like for low frequency from 1 KHz to 2.5 KHz and for high frequency 2.5 KHz to 4 KHz. Engine sound mostly varies around these frequencies. For the low frequencies sample 3, 4 and 5 resulted almost same around at the peak 0.27. At the other hand sample 1,2 and 6 resulted closed to each other too around 0.2. All of the samples resulted better then samples without chamber for the low frequencies. For the high frequencies results closed to each other except for the sample 6 is better than others from 2.2 KHz to 3.5 KHz. When we took all the frequencies, the best results were demonstrated by sample 5 and 6.

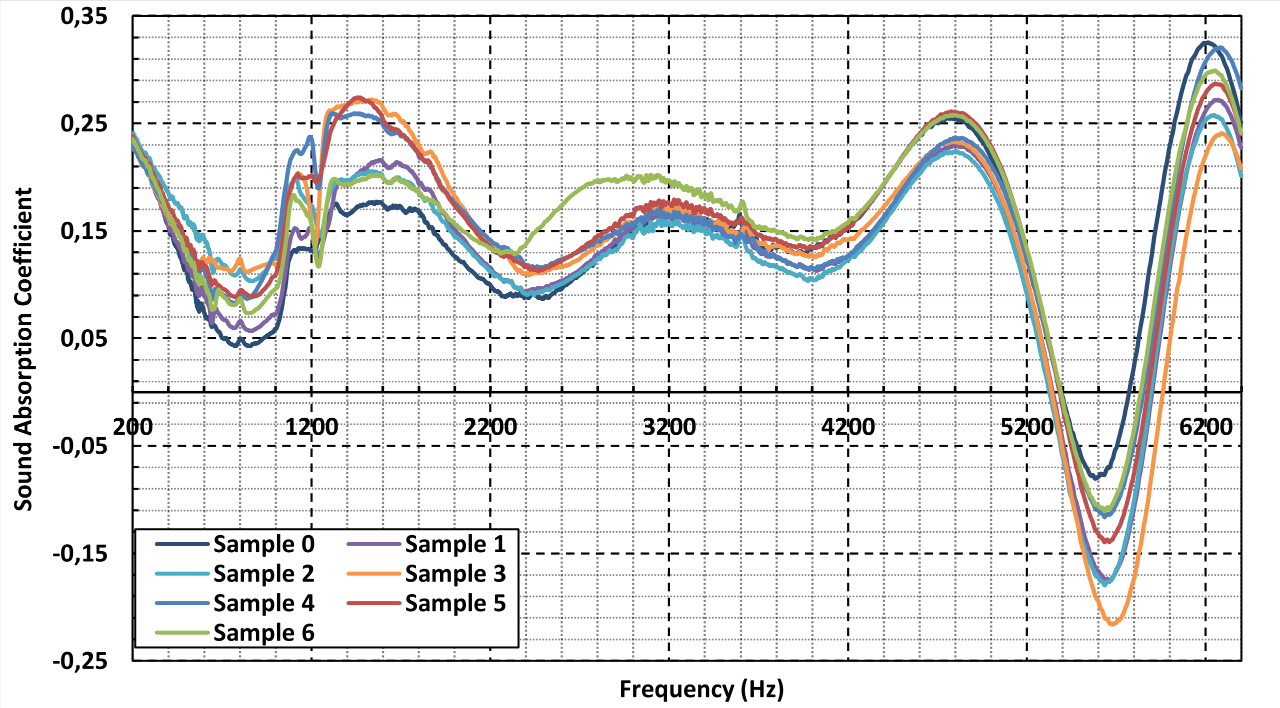

Figure 6. Sound absorption coefficient measurement results

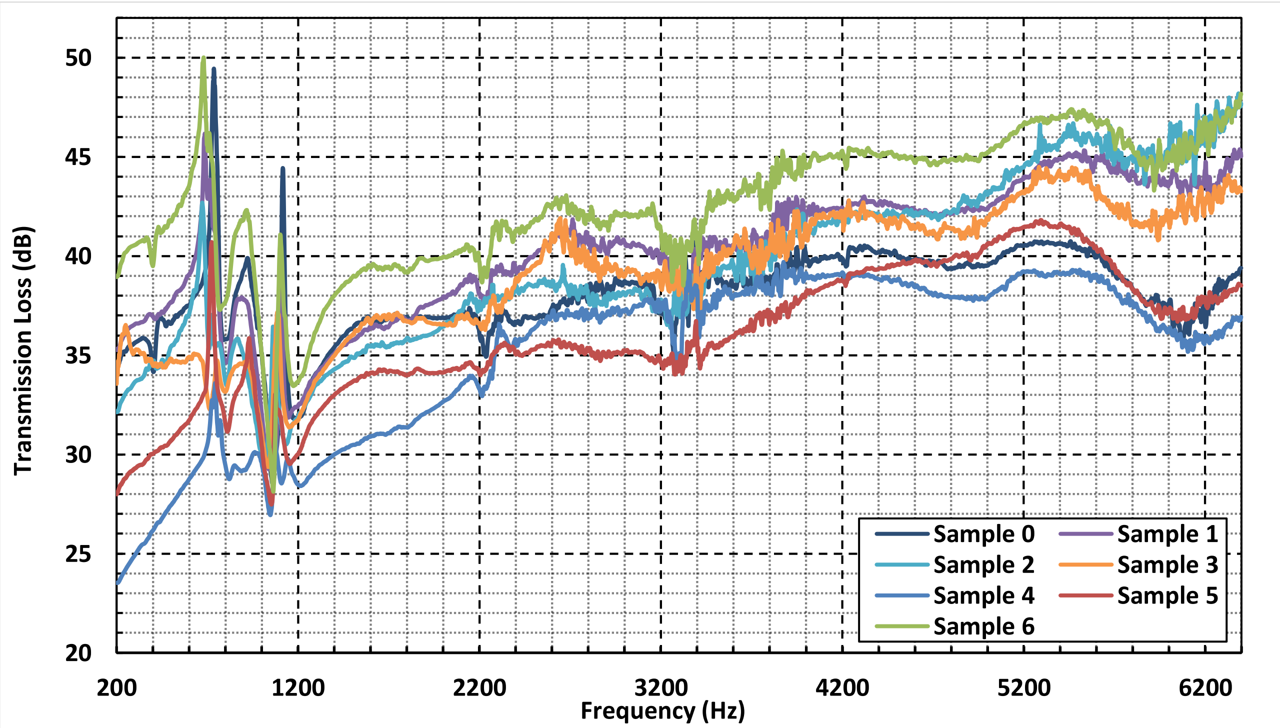

Figure 7. Transmission loss measurement results

On the other hand, transmission loss result of the samples are displayed in Figure 7. When we look at Figure 7, sample 6 shows the best result while sample 1, 2 and 3's transmission loss is better than sample 0. According to this, we can say that the best results for sound absorption coefficient and transmission loss measurements are represented by all samples except sample 6. But both sound absorption coefficient and transmission loss showed that holes in the solid sound absorption materials can enhance the materials sound absorption properties.

Table 1. depicts the material volume of the samples. When we compare the void volume in the samples to sound absorption properties, we can say that when the void in the samples taken gets higher than 10%, absorption properties gets worsen. The best results were illustrated by sample 6 and percentage of the void in that sample is 8%. But on the other hand, the percentage of sample 2 is almost same as sample 6 but results of sample 6 are much better than the one's from sample 2. So, this shows that blind holes with bigger diameter show better result than through-whole body holes with smaller diameter.

In literature we can't find any study which was focused on this phenomenon, but literature shows that speed of sound is lower in the air than solid materials. And there are also some research which show that porosity in the insulation properties make insulation materials properties better (Liu, 2015). There is a patent EP2857264A1 which is using this property to achieve better insulation properties in rubber-based automobile insulation parts. With this research we obtained similar results and results show that until at some point holes in the solid insulation materials can help to achieve better insulation properties.

Table 1. Solid volume percentage of the test samples

Sample (#)	Volume of Solid Part (mm^3)	Percentage of Rubber Part (%)
0	11757,25	100
1	9674,76	82,29
2	10826	92,08
3	10523,15	89,50
4	10276,34	87,40
5	11096,13	94,38
6	10841,77	92,21

4. Conclusion

In this study, we investigated how holes in insulation materials effects sound absorption coefficient and transmission loss of rubber-based insulation materials. Accordingly, different hole shapes and diameters were used. And the study showed that at some point of the void in the rubber-based insulation, the material achieves better insulation properties like up till 8% void. If void in the insulation increases, the properties of insulation get worse. Hence, the whole shape blind holes show better results. With this study we showed that using low sound velocity in the air can help to achieve better sound absorption properties in insulation materials. At the other hand in this study wide range of frequency band studied which in normally engine sound have smaller range. Focusing on smaller frequency range can help to acquire better sound insulation especially for insulating specific noise sources which is can be useful for further studies about this topic.

Conflict of Interest

No conflict of interest was declared by the authors.

References

Akaydın, O., Akgül, A., Orhon, E., Belek, H. T., 2013. Gürültü Kontrol Elemanlarının Akustik Özelliklerinin Empedans Tüpü ile Belirlenmesi. 10. Ulusal Akustik Kongresi, 1-10.

Asdrubali, F., D'Alessandro, F., Schiavoni, S., 2008. Sound Absorbing Properties of Materials Made of Rubber Crumbs. Acoustic'08 Paris, 35-40.

ASTM-E 1050, 2016. International Standard: Standard Test Method for Impedance and Absorption of Acoustical Materials Using A Tube, Two Microphones and A Digital Frequency Analysis System, 1-11.

ASTM-E 2611, 2006. Standard Test Method for Measurement of Normal Incidence Sound Transmission of Acoustical Materials Based on the Transfer Matrix Method, 1-14.

Batman, İ., Aydın, İ., 2012. Taşıtlarda Kullanılan Yalıtım Malzemelerinin Ses Yutma Katsayılarının Belirlenmesi. Journal of the Faculty of Engineering and Architecture of Gazi University, 27 (4), 687-693.

El-mansy, M. K., Abd-elfattah, Mahmoud, A., Abd-elbaseer, M., Youssif, R. S. 2011. Standart uncertainity of material size effect on sound absorption coefficient in reverberation room. Journal of Applied Sciences Research, 7 (2), 166-173.

Ersoy, S., El-Hafid, A., 2013. Investigation of Sound Properties of High Density Polyethylene/Styrene Butadiene Rubber Polymer Composites. Vibroengineering Procedia, 1, 77-80.

Harjana, H., Sabino, U., Yahya, I., Kristiani, R., 2014. Sound insulation and absorption properties of re-claimed waste tire rubber. ICAMST2014, 1-5.

Hedayati, A., Arefazar A., 2009. Effects of Filler Characteristics on the Acoustic Absorption of EPDM-based Highly Filled Particulate Composite. Journal of Reinforced Plastics and Composites, 28 (18), 2241-2249.

Kaya, A. İ., Dalgarno, T., 2017. Ses Yalıtımı Açısından Doğal Liflerin Akustik Özellikleri. 4. Ulusal Meslek Yüksekokulları Sosyal ve Teknik Bilimler Kongresi, 813-827.

Kılınçarslan, Ş., Davraz, M., Akça, M., 2018. Pomza Agregalı Köpük Betonların Özelliklerinin Araştırılması. Journal of Engineering Sciences and Design, 6(1), 148-153.

Liu, Y., 2015. Sound Transmission Through Triple-Panel Structures Lined with Poroelastic Materials. Journal of Sound and Vibration, 339; 376-395.

Seçgin, A., İhtiyaroğlu, Y., Kara, M., Ozankan, A., 2017. Akustik Yalıtım Malzemelerinin Ses Yutma Katsayılarının Farklı Sıcaklık Koşulları Altındaki Değişiminin Deneysel Olarak İncelenmesi. 18. Ulusal Makina Teorisi Sempozyumu, 317- 324.

Sikora, J., Turkiewicz, J., 2010. Sound absorption coefficients of granular materials. Mechanics and Control, 29 (3), 149-157.

TS EN ISO 10534-1, 2004. Akustik-Empedans borularında ses absorplama katsayısı ve empedansın tayini – Bölüm 1: Duran dalga oranını kullanma metodu, 1-24.

TS EN ISO 10534-2, 2003. Akustik-Empedans borularındaki ses absorpsiyon katsayısının ve empedansın tayini – Bölüm 2: Aktarım fonksiyonu metodu, 1-25.

Xu, X., Wang, H., Sun, Y., Han, J., Huang, R., 2018. Sound Absorbing Properties of Perforated Composite Panels of Recycled Rubber, Fiberboard Sawdust, and High-Density Polyethylene. Journal of Cleaner Production, 187, 215-221.