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Determining Sound Absorbing and Transmission Loss Properties of Rubbers Used in Automotive Industries

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Abstract: Sound is simply a kind energy which sprawls to environment as waves. Sound changes pressure at air, water etc. which this detected by ears as sound. At the other hand noise is a kind of sound which is unpleasant, and undesirable for humans. In automotive industry, noise effects drivers and passengers comfort directly. Because of that, automotive manufacturers consider noise insulation in automobiles as an important factor for quality. Ethylene Propylene Diene Monomer Rubber (EPDM), Natural Rubber (NR) and Nitrile Rubber (NBR) are one of the most used insulation materials in automotive industry. In this study, EPDM, NR and NBR materials sound absorption coefficient and sound transmission loss are measured with impedance tube for investigate these materials as insulation part placed between passenger cabin and engine side on shifter mechanisms. Measurements repeated three times and results showed at graphics. Results are which obtained from tests are presented systematically in this study. In conclusion, study results showed that EPDM is slightly better than NR and NBR as material of noise insulation part at shifter mechanisms.

Keywords: Sound absorption coefficient, Sound transmission loss, Sound insulation properties of rubbers

Introduction

Today, because of the competition in automotive industry and changes of the user needs cause constant development of insulation materials which are used in automotive industry. Automotive manufacturers want to eliminate noise based on engine, road or construction of the cars for provide better travel in automobiles (Batman & Aydın, 2012; Akaydın et al., 2013).

Sound is kind of an energy which is sprawling to environments at air, water etc. with waves and cause pressure changes and ears can detect this pressure changes as sound. Noise is a kind of sound which not pleasant and unwanted by humans. We considered some sounds as noise because of high sound level, sound kind, sharp changes at frequency and disturbing of it. Noise can cause some unwanted effects on human health. One of the most important effect for drivers is it can lower hearing capability. Besides this it can cause physiological effects like muscle spasms, stress, raises blood pressure, changes heart beat rhythm 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).

There are wide variety of insulation materials which are using for sound absorption. It is important to choose right material, thickness and amount for keeping cost/performance ratio. Choosing wrong material, thickness or using it at wrong places may result low noise insulation for high prices. So, it is important for automotive manufacturers to obtain best performance for cheaper solutions because of the high competition in automotive industry (Batmaz & Aydın, 2012).

When a source creates a sound, energy of sound pass through air molecules to other molecules and 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 the watt per square meter (W/m^2). There are two ways to insulate noise. Sound insulation which is basically lower sound level and 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 to heat energy. So simply if sound waves encounter to anything which has different density or elasticity, some part of the sound energy reflects and some part of it turn heat energy. The rest just pass through (Kaya & Dalgar, 2017).

Most of sound, vibration and noise contains various frequencies. Frequency is characterized as a periodic vibration whose frequency is audible to the average human. The SI unit of sound frequency is the hertz (Hz). Period is the times passes for one vibration of sound and SI unit is second (sec). And wave length is the spatial period of a periodic wave and SI unit is meter (m). Kind of the sound depends on frequencies and low frequency sounds called bass and high frequency sounds 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 need of small test specimens, impedance tube method widely using. With impedance tube both sound absorption coefficient and sound transmission loss can be measured. Diameter of impedance tube is important for measurement. For low frequency tests bigger diameter impedance tube needed and for high frequencies smaller diameter 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 automotive industries a wide range of insulating materials are used. Natural rubber (NR), nitrile rubber (NBR), ethylene propylene diene rubber (EPDM), hydrogenated nitrile butadiene rubber (HNBR), fluoroelastomer polymer rubber (FKM) and chloroprene rubber (CR) are the most used kind of rubbers in automotive. Especially EPDM, NR and NBR are widely using for door isolations, shifter mechanism isolations, engine etc.

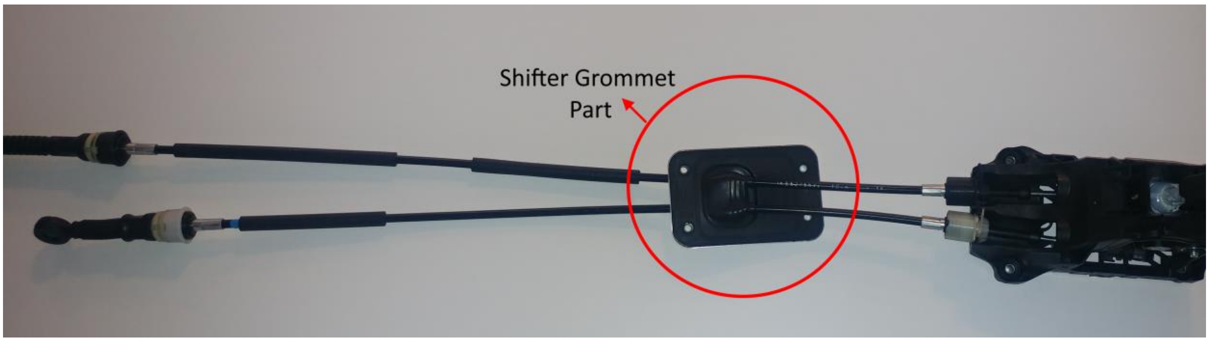

Figure 1. Shifter mechanism and insulation grommet part

There are various studies made about sound insulation capabilities of insulation materials. Batmaz and Aydın 2012, investigate insulation capabilities of EPDM+Mat and PU+Mat with different thickness and determined best solution for automobiles depend on different sound frequencies. 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. Xu et al. 2018, measured insulation capabilities of perforated high-density polyethylene, recycled rubber and fiberboard sawdust with 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 on how granular size of rubber insulation materials effects their sound absorption coefficients.

In this study, EPDM, NR and NBR materials sound absorption coefficient and sound transmission loss are measured with impedance tube at low and high frequency for determining best material to use as grommet insulation at gear shifter mechanism. For filtering engine noise from passenger area grommets are used at gear shifter mechanisms. In Figure 1, example of a shifter grommet can be seen. Sound absorption coefficient and sound transmission loss of EPDM, NR and NBR compared for determining most suitable material for shifter grommet. Study results showed that EPDM materials slightly better than NR and NBR as sound insulation materials at shifter mechanism parts.

Method

With impedance tubes both sound absorption coefficient and sound transmission loss can be 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). System using Gras's phase-compatible high precise 46BD model pressure-field microphone set, National Instrument's 4 ICP channel analyzer and its sample rate 102.4 kS/s. Three different rubber-based materials, which these are EPDM, NR and CNR, their transmission loss and sound absorption coefficients measured based on their thickness and frequencies. For this thickness of the test samples choose as 2.4, 4.8, 7.2, 9.6 and 12 mm. Samples named first material and second thickness of the sample. Measurements repeated 3 times and results processed for create curve graphics. Totally, 45 sound absorption coefficient measurement and 45 transmission loss measurement performed.

Test specimens firstly molded as a flat plate. Measurements of these plates 200*250 mm and 6 mm thickness. After that test specimens cut from these plates for low frequency Ø29mm and for high frequency Ø100mm.

Sound Absorption Measurement

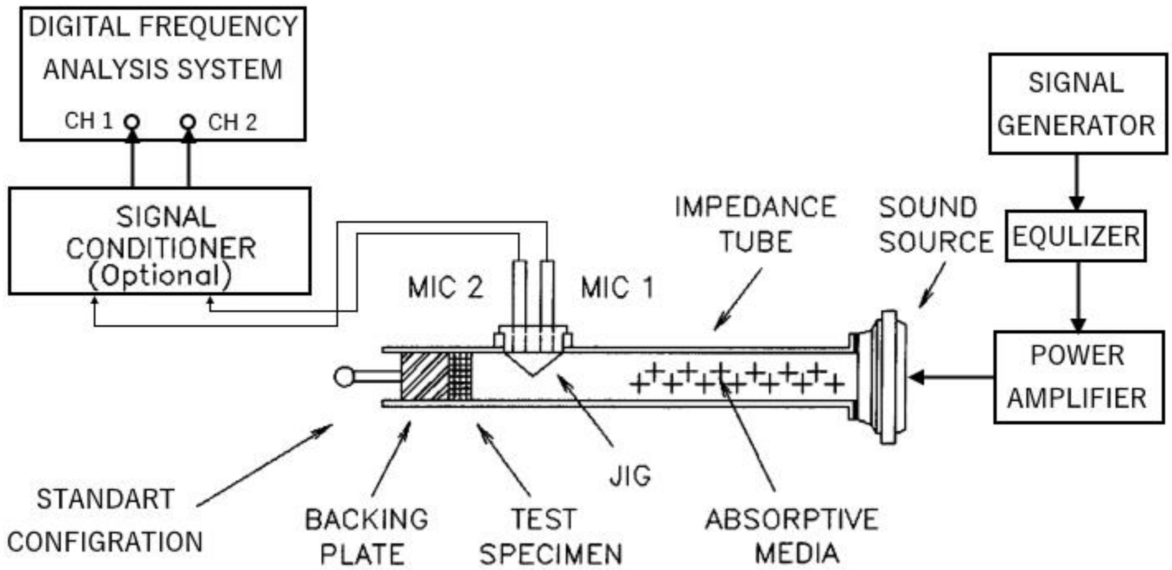

Figure 2. Diagram of sound absorption measurement system (ASTM-E 1050, 2006)

As mentioned before sound insulation properties of a material can be considered in two main topics and one of them is sound absorption coefficient. For measuring sound absorption of a material, firstly sound waves applied to material and sound waves reflected from material must be measured and with this surface impedance of material can be calculated. In Figure 2 you can see general diagram of measurement system. In system there is a speaker which generates white noise and microphones measures pressure of sound waves and using transfer function method sound absorption coefficient calculates (ASTM-E 1050, 2006; ASTM-E 2611, 2006; TS EN ISO 10534-1, 2004; TS EN ISO 10534-2, 2003).

Sound Transmission Loss Measurement

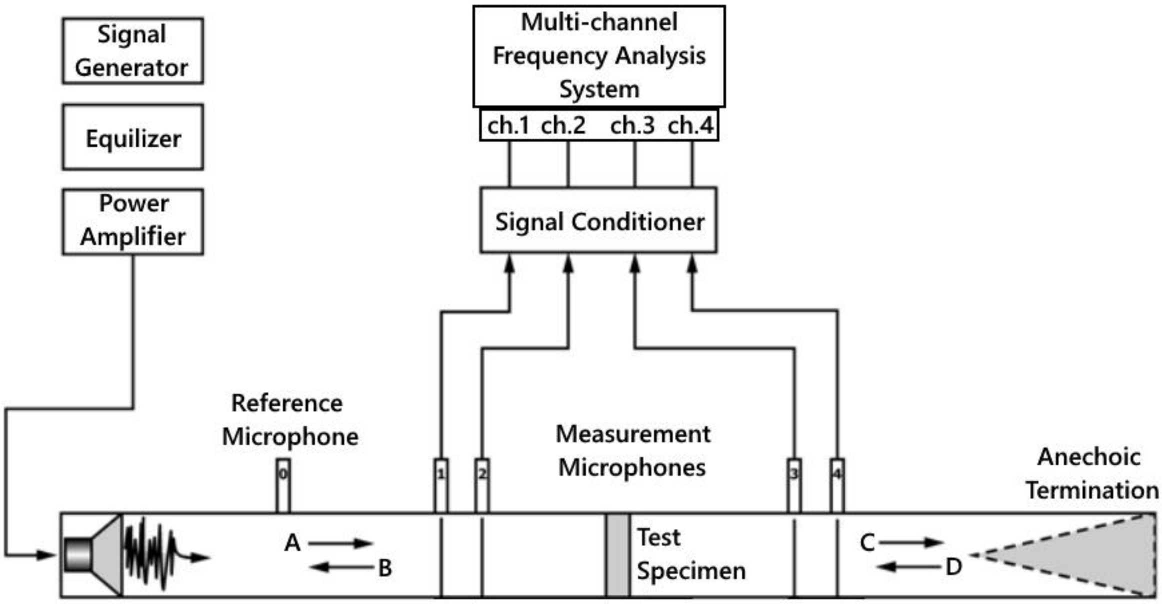

Figure 3. Sound transmission loss measurement system (ASTM-E 2611, 2006)

For measuring sound transmission loss with impedance tube, test sample placed middle of the impedance tube and this way, two chambers created in the impedance tube. Both chambers measured with different microphones and sound transmission loss calculated. For transmission loss can be calculated, reflected sound waves at chamber two must be removed from equations and for these measurements repeated with anechoic termination and without it. In Figure 3 you can see 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).

Theory

Sound transmission coefficient, τ (dimensionless) of a material in a specified frequency band, the fraction of airborne sound power incident on a material that is transmitted by the material and radiated on the other side.

$$\tau = \frac{W_t}{W_i} \tag{1}$$

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

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

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

$$c = 20.047\sqrt{273.15+T} \tag{3}$$

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

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

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

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

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

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

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

$$R = \frac{T_{11} - \rho c T_{21}}{T_{11} + \rho c T_{21}} \tag{7}$$

Where R is complex acoustic reflection coefficient. With this absorption coefficient with hard-backed impedance tubes can be calculated with;

$$\alpha = 1 - \left|R\right|^2 \tag{8}$$

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

$$z = \sqrt{T_{12}/T_{21}} \tag{9}$$

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

Results and Discussion

With impedance tube transmission loss and sound absorption coefficient measurements made and results turned to graphics. Measured transmission loss of EPDM material at low frequency can be seen in Figure 4. When we check the graphic, transmission loss increased with thickness. But when we considered results as whole, EPDM_9.6 results are better than EPDM_12 thickness.

High frequency transmission loss of EPDM results can be seen in Figure 5. Similar results to low frequencies observed at high frequencies too. When the thickness increased, transmission loss increased too. For EPDM_2.4 and EPDM_4.8 results are really close to each other. This situation valid for EPDM_7.2 and EPDM_9.6 too. At some frequencies EPDM_12 samples results are much higher than others.

In Figure 6 transmission loss of NBR at low frequencies can be seen. When the thickness increased, transmission loss of NBR increased too. When the frequency gets higher than 1100 Hz, transmission loss increased dramatically for high thickness samples especially NBR_9.6 and NBR_12. High frequency transmission loss results of NBR can be seen at Figure 7. Results of the NBR_12 and NBR_9.6 samples are really close to each other. This situation can be observed for NBR_7.2 and NBR_4.8 samples too.

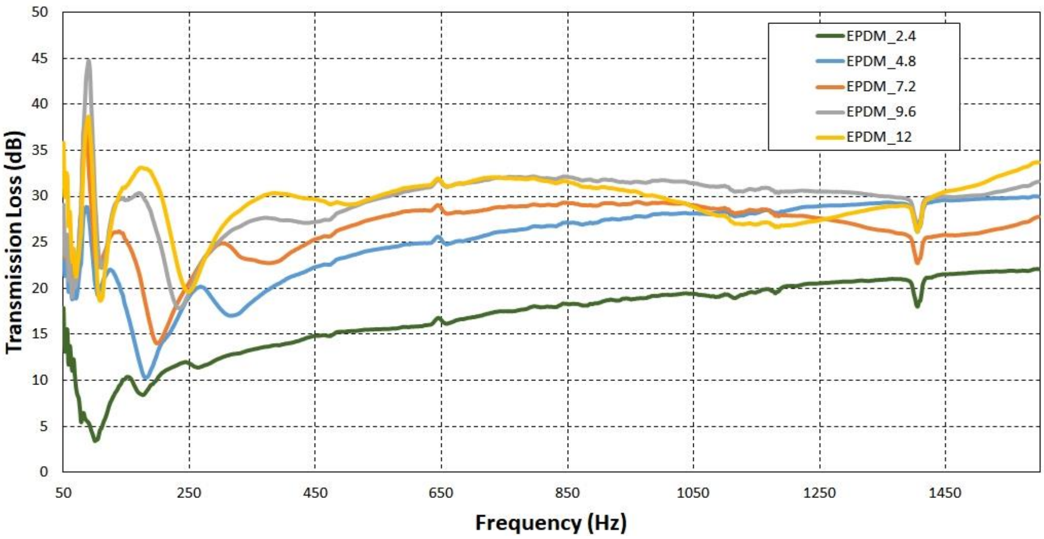

Figure 4. Low frequency transmission loss of EPDM

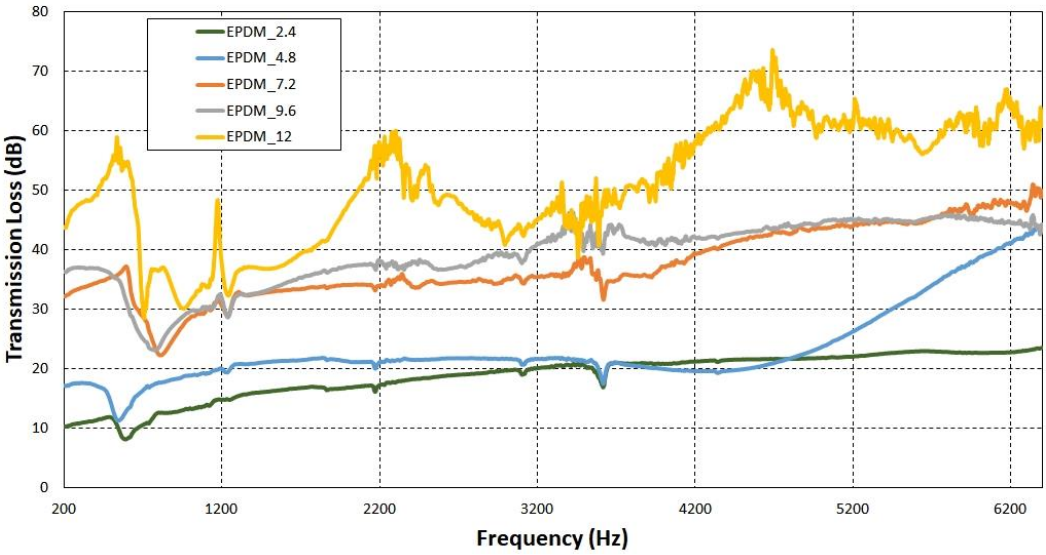

Figure 5. High frequency transmission loss of EPDM

In Figure 8, low frequency transmission lost for NR can be seen. Result is similar to others. When thickness increased, transmission loss increases too. For NR_9.6 and NR_12 thickness there is different situation. When the frequency reaches to 800 Hz, transmission loss of these samples getting decreases until 1100 Hz and after that it gets increases again. At the other hand results for NR_9.6 and NR_12 is really close to each other. In Figure 9, high frequency transmission lost for NR can be seen. Result for high frequency transmission loss for NR is wavy. There is different situation for NR_9.6 thickness sample. At the other results when thickness increased, transmission loss gets better. But in this best result is NR_9.6 thickness sample when we take average of the curves.

When results considered for all of the materials and samples thickness for transmission loss best results taken from EPDM materials NR_9.6 and NR_12 at low frequencies around 30 dB. When we looked for high frequencies, best results are taken from NBR_12 mm samples and varies from 40 dB to 70 dB. When we compared the test results with the literature information's, results are conforming to the literature (Sikora & Turkiewicz, 2010; Harjana et al., 2014; El-mansy et al., 2011).

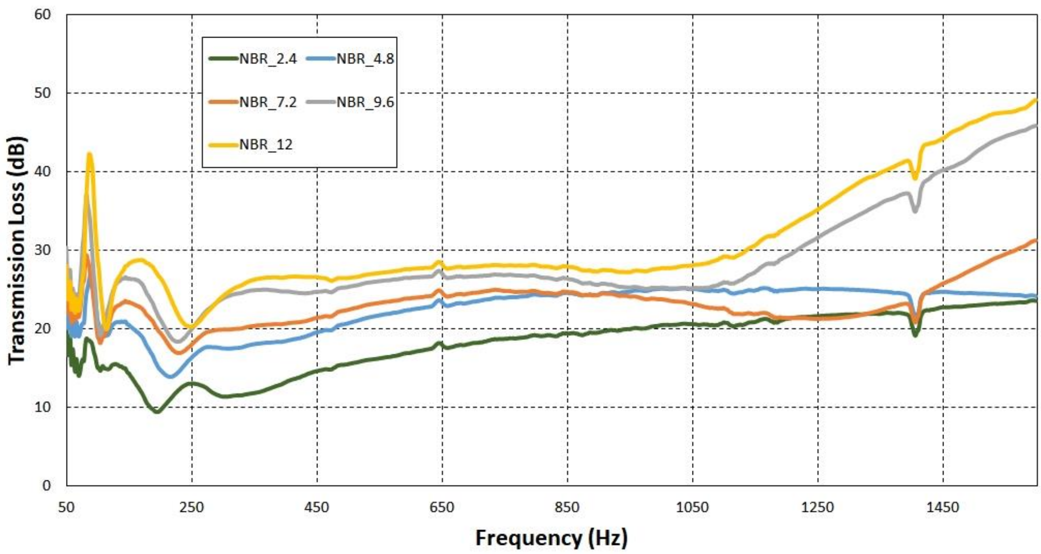

Figure 6. Low frequency transmission loss of NBR

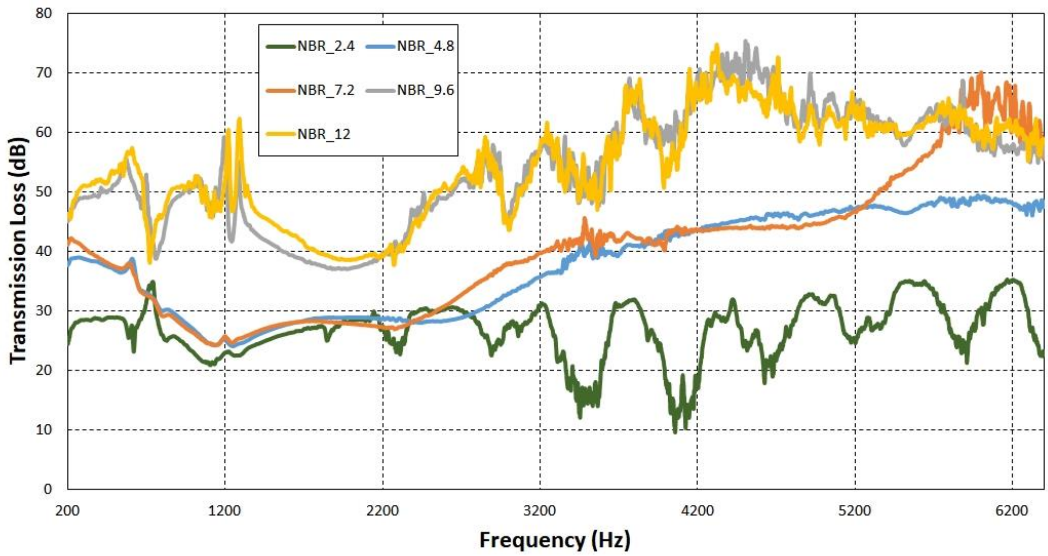

Figure 7. High frequency transmission loss of NBR

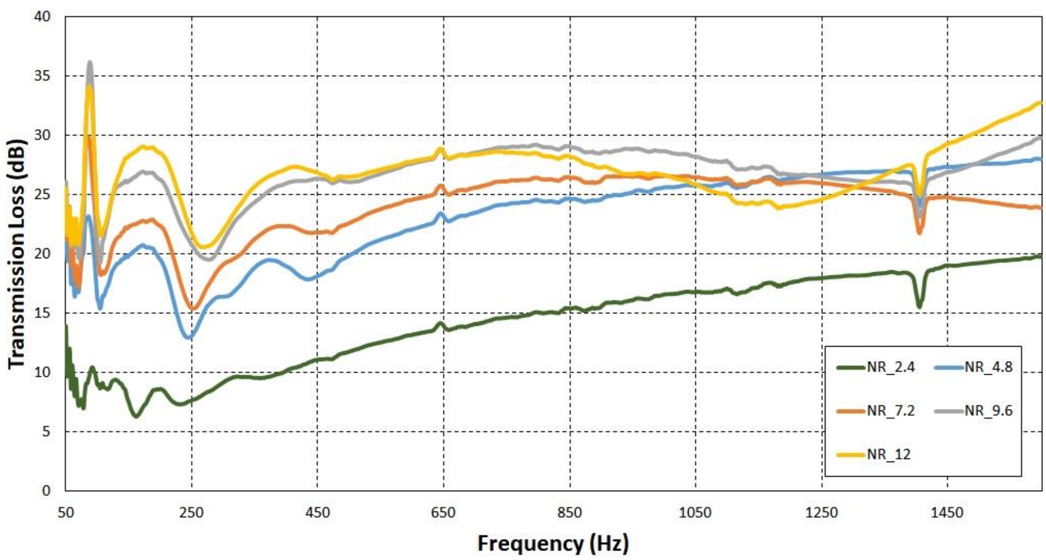

Figure 8. Low frequency transmission loss of NR

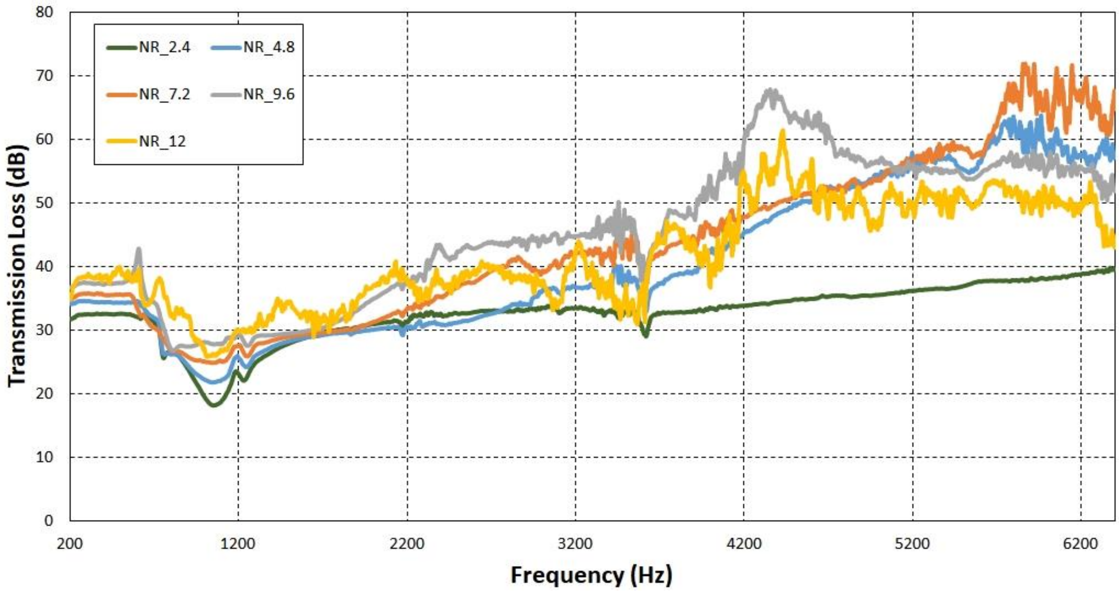

Figure 9. High frequency transmission loss of NR

Sound absorption coefficient test results of EPDM material at low frequencies can be seen at Figure 10. Results are really close to each other and at some frequencies they go to peaks and after goes low back. When we look at the results depend on thickness, there is reverse connection. At transmission loss results when thickness increased, transmission increases too but in sound absorption coefficient results when thickness decreased, sound transmission coefficient slightly gets better. When we look at the sound absorption coefficient results of EPDM at high frequencies which can be seen at Figure 11, again results are really close to each other. Sample of EPDM_12 thickness makes peak at around 1500 Hz. But results considered as average sound absorption coefficient sample of EPDM_7.2 result is better than others.

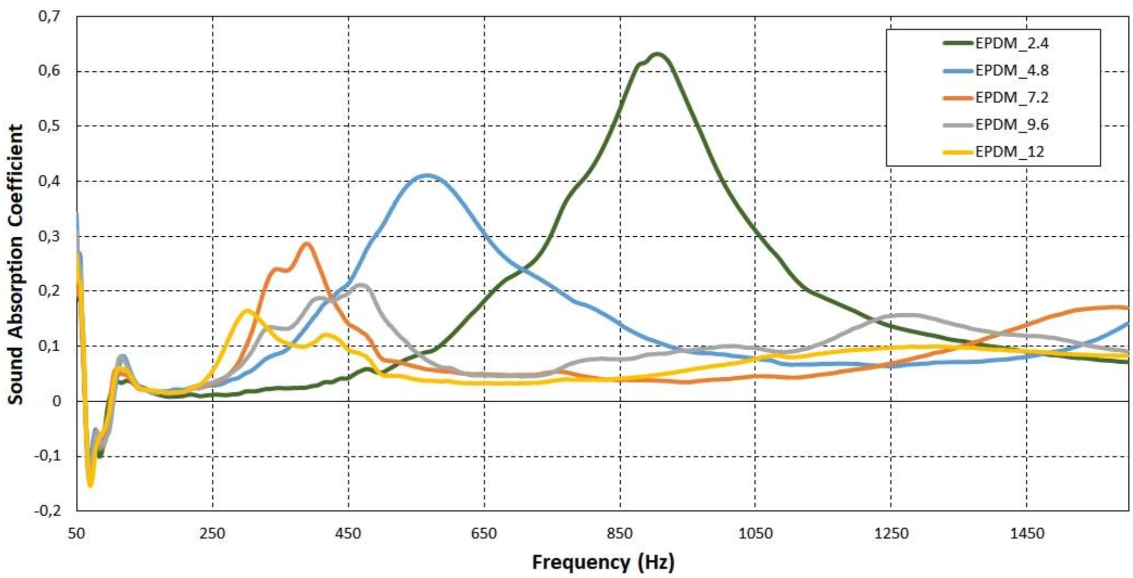

Figure 10. Low frequency sound absorption coefficient of EPDM

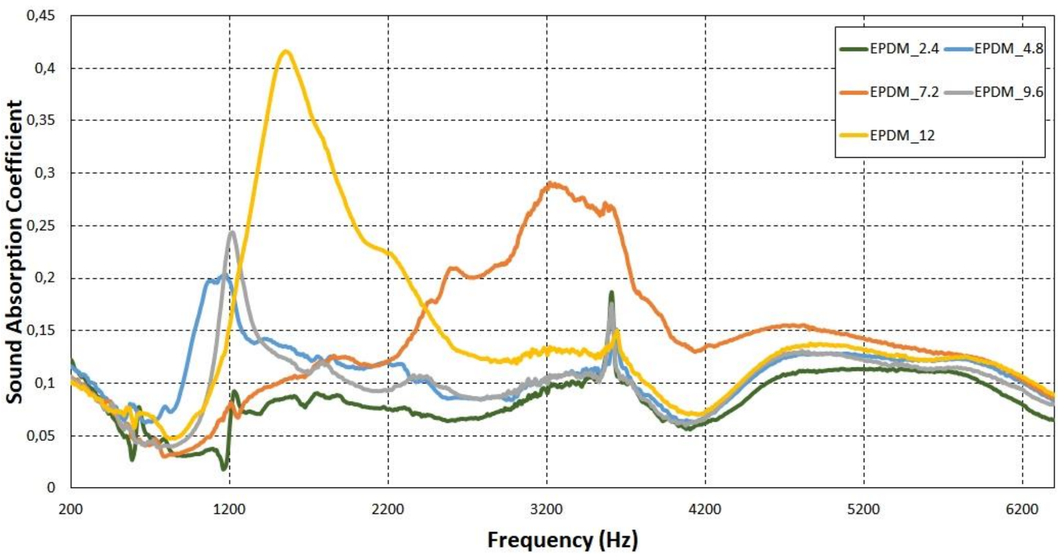

Figure 11. High frequency sound absorption coefficient of EPDM

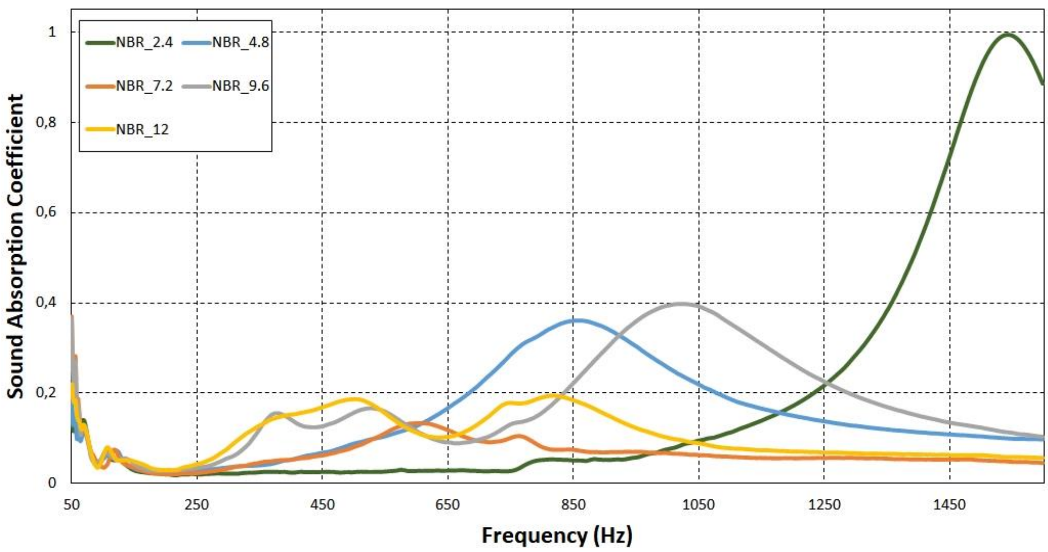

Figure 12. Low frequency sound absorption coefficient of NBR

Measurement results of sound absorption coefficient of NBR at low frequencies can be seen at Figure 12. As can be seen, test results are close to each other. Coefficient of NBR_2.4 sample gets high around 1500 Hz, but result isn't logical and probably there is a measurement anomaly. At Figure 13, sound absorption coefficient of NBR at high frequencies can be seen. As can be seen in the graphic, when thickness decrease, sound absorption coefficient increases. For NBR_2.4 samples peak is around 1600 Hz. But at the other hand for NBR_4.8 samples it is around 4400 Hz.

Sound absorption coefficient results for NR can be seen at Figure 14 at low frequencies and Figure 15 at high frequencies. The graphics show that, when the thickness decreases, sound absorption coefficient slightly gets better but results are really close to each other.

When we compared the result of the materials at low frequencies EPDM_2.4 and NR_2.4 results better than others depends on average sound absorption coefficient. When we look at the results for high frequencies, EPDM_7.2 mm sample results better than others.

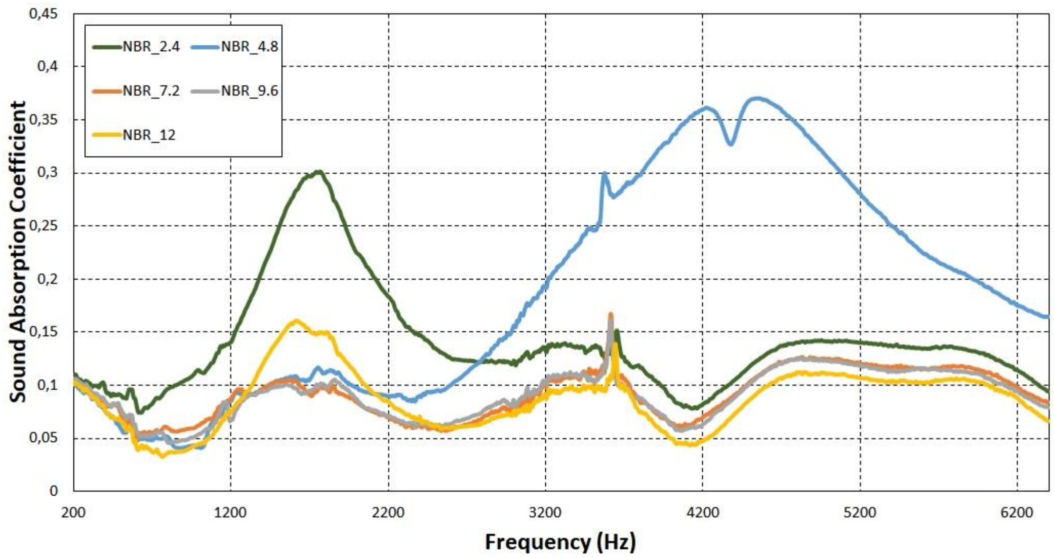

Figure 13. High frequency sound absorption coefficient of NBR

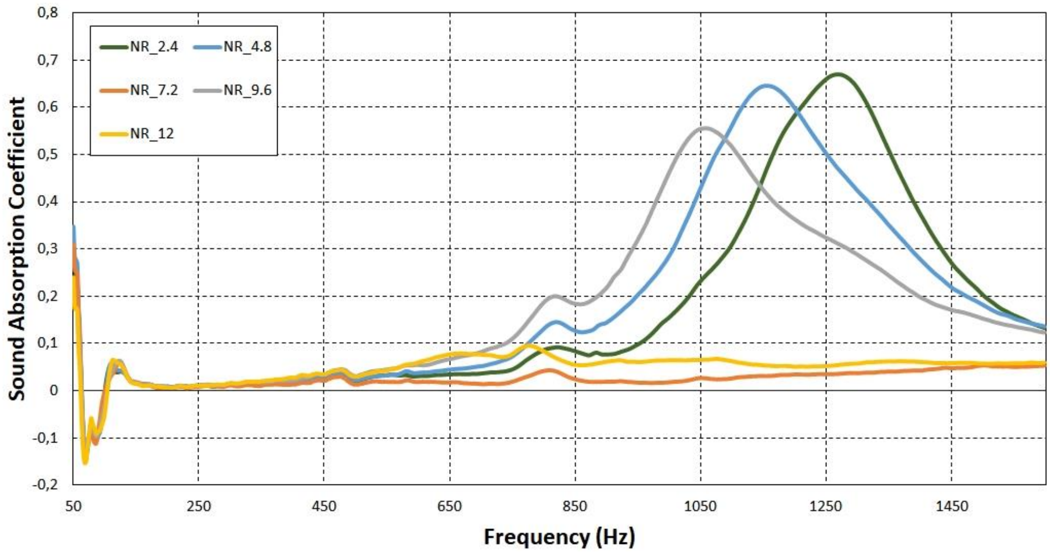

Figure 14. Low frequency sound absorption coefficient of NR

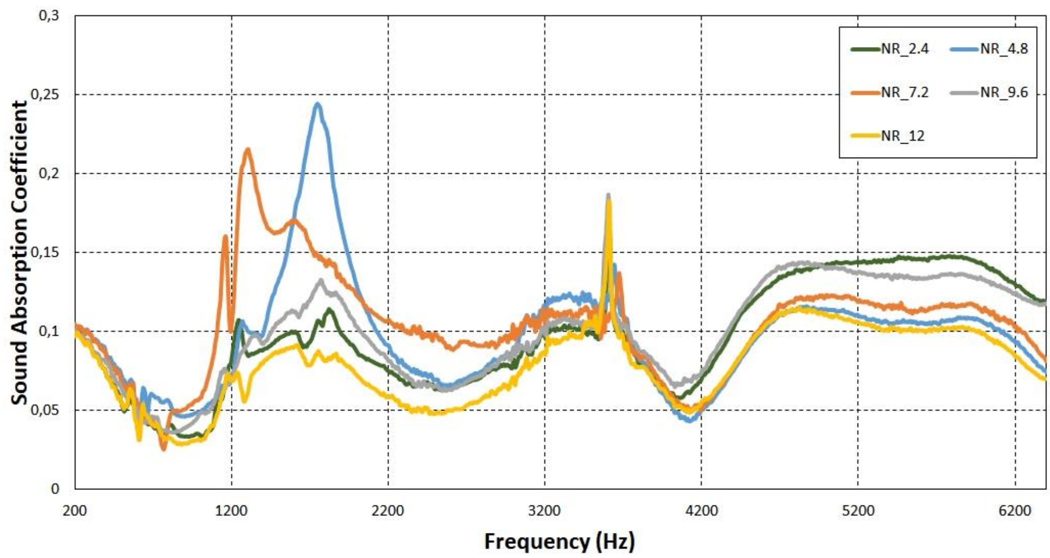

Figure 15. High frequency sound absorption coefficient of NR

Conclusion

In this study, transmission loss and sound absorption coefficient of EPDM, NBR and NR materials measured depends on five different thickness and frequencies. There can be seen at the transmission loss results that, when thickness of the materials increased, transmission loss increases too. Best results for transmission loss taken from EPDM materials 9.6 and 12 mm at low frequencies around 30 dB. When we looked for high frequencies, best results are taken from NBR 12 mm samples and varies from 40 dB to 70 dB. If we look at the sound absorption coefficient results, the results acting opposite to the transmission loss results. In the results, generally, when thickness of the material increased, sound absorption coefficient decreases. But there are some exceptions at the results. When we compared the result of the materials at low frequencies 2.4 mm EPDM and 2.4 mm NR results better than others depends on average sound absorption coefficient. When we look at the results for high frequencies, EPDM 7.2 mm sample results better than others. In automotive sector, while trying to choose right materials, there are other specification must be considered like material costs, usability, moisture resistance, heat resistance etc. If we ignore other parameters, study results showed that EPDM materials slightly better than NR and NBR as sound insulation materials at shifter mechanism parts.

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