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Acoustic Performance of Natural Fiber Felts for the Automotive Industry

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Research Article

Abstract

Passenger comfort is an important parameter in the design process of the car. Noise caused by many factors in the vehicle significantly affects passenger comfort. Insulators are used to reduce noise and these insulators are usually made of fibrous or porous petrochemical-based materials. Recently, natural materials have begun to replace petrochemical-based materials due to environmental and health problems. Natural fiber materials offer alternatives such as felts made from recycled cotton, hemp, and kapok fibers. These materials have various acoustic performance properties depending on their density, thickness, and structural differences.

There are some tests performed to evaluate the performance of materials for specific uses. To evaluate the acoustic performance of the felt, parameters such as sound absorption coefficient and sound transmission loss are considered. In the tests performed using an impedance tube and a reverberation chamber, it was investigated how the properties of the material affected these parameters. The results were that at higher thickness and density, sound absorption generally increased, while sound transmission loss decreased. The findings of the study are an important example for the selection and optimization of acoustic insulation materials and will contribute to the development of more effective insulation solutions in the automotive industry.

Keywords: Felt; Sound Transmission Loss; Sound Absorption Coefficient; Reverberation Cabin; Impedance Tube; Recycled Cotton; Kapok Fibers; Hemp Fibers

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1. Introduction

Automotive companies are working to improve vibration and noise, which are factors affecting passenger comfort. There are two main causes of noise from vibration of solids and air, and these are vibrations from the engine or the ground [1]. Engine-borne noise in vehicles is caused by the dynamic behavior of the powertrain components and the vehicle itself [2]. Internal combustion engines produce broadband noise predominantly at medium frequencies. In electric motors, the tonal sounds they produce become stronger [3]. Automotive manufacturers' desire to produce lightweight vehicles, reduce emissions, save fuel and costs has a negative impact on vibration control and noise vibration harshness (NVH) performance [4]. This situation can be eliminated and the noise felt by passengers, which also has a negative impact on human health, can be reduced by various methods. Insulators, one of the main methods, are used in many parts throughout the vehicle [5]. Engine compartment insulator, dashboard insulator, carpet floor and many other parts are reserved for this purpose.

Fibrous or porous materials are generally preferred to provide insulation [6]. Expensive and petrochemical-based materials such as glass wool, polyurethane or polyester are generally used as porous materials. However, increasing awareness of the environmental impacts and health problems associated with materials based on petrochemicals has also increased interest in natural materials. Natural materials generally have characteristics such as the materials that make them up have natural and renewable resources and the environmental pollution that occurs during their production is low [7]. Fibrous materials consist mostly of natural materials and recycled fabrics and are also considered a strong option for insulation [6]. Natural fibers have become an alternative reinforcement option to polymer composites in recent years [8]. These materials can be manufactured in various densities, thicknesses and structures, and the versatility they provide provides a significant advantage in sound insulation applications for automotive manufacturers [9].

In this case, sound absorption coefficient and sound transmission loss are important parameters to evaluate the acoustic performance of the felt for various applications and make appropriate choices. Accurate understanding and evaluation of these acoustic properties in industrial and commercial areas can allow better optimization of sound insulation and acoustic control solutions. Therefore, studies on the acoustic properties of felts are important resources for improving and optimizing the acoustic performance of the material.

Sound absorption coefficient measures how effectively a material can absorb sound waves. This means that some of the sound waves falling on the surface of the material are absorbed and their energy is converted. When sound waves come into contact with acoustic insulators, their energy undergoes reflection, absorption and transmission, shown in Figure 1. The reflected energy returned to the original area where the sound wave came from. The absorbed energy is dispersed within the material. Conducted energy is the amount of energy remaining after reflection and absorption through the insulator. Acoustic isolators use sound absorption and sound transmission loss coefficients for their functions.

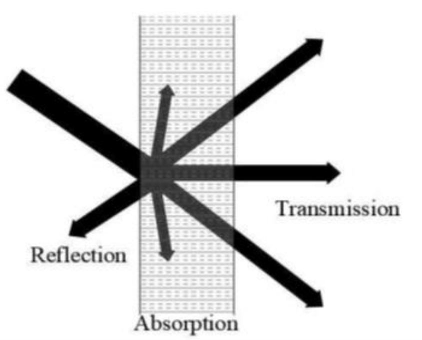

Figure 1. Sound transmission loss [10]

The sound absorption coefficient of the felt may vary depending on factors such as density, thickness, porosity degree and internal structure of the material [11]. In particular, the porous structure of the felt and the type and density of the fibers it contains affect its sound absorption properties. Tests and analyzes show that the sound absorption coefficient of felt can vary within a wide range depending on the structure and components of the material. Using these parameters, various models can calculate the sound absorption coefficient analytically. Also note that the sound absorption of porous and fibrous materials generally increases quasi-linearly from low to high frequencies [3]. In particular, if their thickness is above 1/4 of the wavelength of sound (Fabry-Pérot resonance), the absorber works very efficiently [12].

Sound transmission loss measures how much a material blocks the passage of sound and expresses the ratio of incoming sound energy to transmitted sound energy in decibels. This means reducing sound passing from one environment to another. Sound transmission loss is determined by the viscoelastic properties, structure and shape of the material and decreases sharply when the material reaches its resonance frequency [13-14].

Traditionally, materials with excellent performance in sound transmission loss usually consist of layered structures. If both sound transmission loss and sound absorption require high performance, materials with sound absorption properties are preferred [3]. The layers of such composites are usually formed as Absorber-Barrier-Absorber or Double Layer-Absorber. The double layer and barrier correspond to the pressed felt, and the absorbent corresponds to the uncompressed felt [15]. Recent developments have made possible pressed felts with satisfactory properties for both sound transmission loss and sound absorption. Additionally, these materials are inherently lighter than their viscoelastic alternatives [16].

For this reason, the reason why recycled cotton is considered suitable for sustainability in felt production is that it has good sound absorption properties compared to absorbers produced from raw materials [17]. The acoustic properties of natural fibers are generally considered to be better due to their better absorption of sound waves due to their porous structure and naturally more irregular surface texture [6]. For example, kapok fibers have thin cell walls and large lamella; With these properties, they become good sound absorbers as cavities fiber structures [18-19]. On the other hand, hemp fibers are fiber structures with good sound absorption in the frequency ranges of 300-600 Hz and the same ability to absorb sound at low frequencies with the ability to change their structure through different types of chemical processes and produce alternative types [20-21].

In this study, we will focus on the parameters that affect the performance of felts in acoustic applications. In order to investigate the composition parameters and felt density effects of various fibers, the effects of fiber thickness and density of felts composed of recycled cotton, hemp fiber and kapok fiber on acoustic performance were tested.

2. Experimental Details

2.1. Materials

Within the scope of this research, used 50% of recycled cotton fiber and 20% each of kapok and hemp fibers to create test samples with 10 mm and 25 mm thickness, 1200g/m² and 1400g/m² respectively. Microscope images of the fibers are as in Figure 2. Briefly, the felt production process[22] begins with mechanically combing and mixing the fibers. Then, the fibers are aligned with the air flow to form layers. Finally, the felt is compressed and cut to the desired dimensions by thermal bonding and needle punching methods.

Test samples were created by blending with low-melt polyester (PES), which has a low melting temperature, in high densities. In addition, felts were created by bonding 70% recycled cotton samples with PES at densities of 1200 g/m² and 1400 g/m² (Table 1).

Table 1. Material properties

Composition	Thickness (mm)	Density (g/m^2)	Samples
%50 Recycled Cotton, %20 Hemp Fibers %30 Low-melt PES	10 mm	1200 g/m2	H10-12
		1400 g/m2	H10-14
	25 mm	1200 g/m2	H25-12
		1400 g/m2	H25-14
%70 Recycled Cotton %30 Low-melt PES	10 mm	1200 g/m2	RC10-12
		1400 g/m2	RC10-14
	25 mm	1200 g/m2	RC25-12
		1400 g/m2	RC25-14
%50 Recycle Cotton %20 Kapok Fibers, %30 Low-melt PES	10 mm	1200 g/m2	K10-12
		1400 g/m2	K10-14
	25 mm	1200 g/m2	K25-12
		1400 g/m2	K25-14

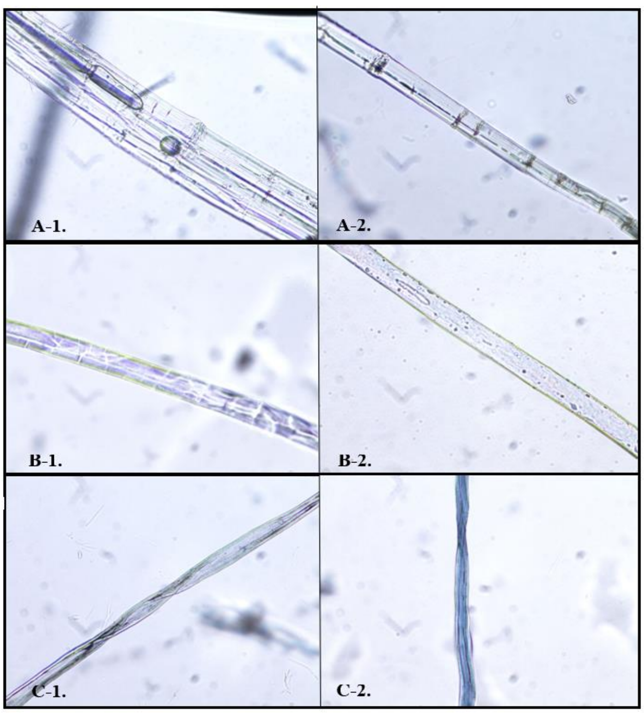

Figure 2. Microscope images of A-1 and A-2 hemp fiber; B-1 and B-2 kapok fiber; C-1 and C-2 recycled cotton fiber

2.2. Test Method and Parameter Calculation

2.2.1. Sound transmission loss measurement

Sound transmission loss can be measured by various methods. The main principle of these tests is to measure the transmission loss of sound passing through the material between the anechoic and reverberant medium [23]. As long as this principle exists, different types of surfaces can be tested. The impedance tube is an effective method for measuring sound transmission loss due to its small sample requirement and quick setup. However, using this method, the properties of a material for a single dimension can be obtained [24]. The sound transmission of a sample is measured by the amount of transmitted and reflected sound measured by microphones [25]. Figure 3 schematically shows the mechanics of sound transmission. Shortly, Microphone 1 and microphone 2 are mounted on the upstream tube. Another set of microphones, microphone 3 and microphone 4, are mounted in the downstream tube. Mounted microphones measure incident and reflected waves with this setup. The reference position (x = 0) is taken on the front surface of the sample, shown as "0" in Figure 2. x1, x2, x3 and x4 are the positions of the microphones. A and B correspond to the incident and reflected wave components in the upstream tube. C and D refer to the incident and reflected wave components in the downstream tube.

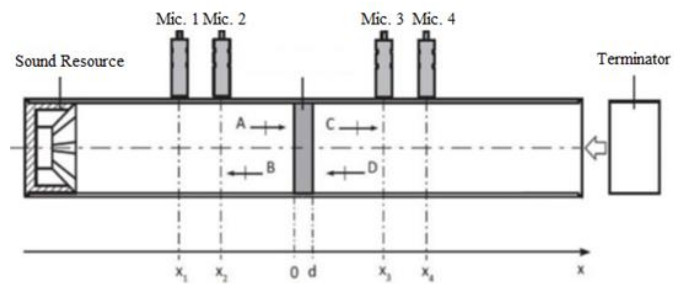

Figure 3. Impedance tube schematically

Pressure transmission loss (sound transmission loss) α which will be crucial for calculation sound transmission loss can be obtained with Eq. (1).

$$Sound\ Transmission\ Loss\ (STL) = -20\log(||\alpha||) \quad (1)$$

2.2.2. Sound absorption coefficient calculation with impedance tube

The impedance tube is used to find the sound absorption coefficient between 200-6400 Hz. The main principle of these tests is to measure the transmission loss of sound passing through the material between the anechoic and reverberant medium [23]. Figure 4 shows the impedance tube used.

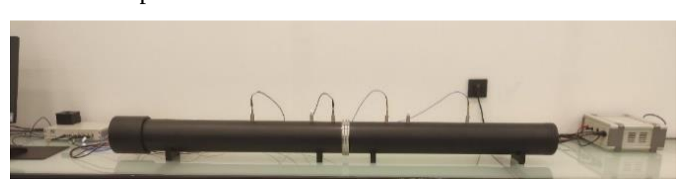

Figure 4. BSWA MPA416 impedance tube used for this study

The downstream tube is either removed during the sound absorption test or reset with a plunger for this test. Therefore, only the upstream part of the impedance tube is used for sound absorption [26]. Two microphones were placed upstream of the impedance tube. C and D wave components are eliminated without the downstream tube’s effect [26]. Incident and reflected wave components of H_A and H_B are obtained with the equation 2 and 3.

$$H_A = e^{-jk(x_1-x_2)} \quad (2)$$

$$H_B = e^{jk(x_1-x_2)} \quad (3)$$

Where k is wave number. x_1 and x_2 correspond to distance of first and second microphone to the specimen. Transfer function calculated from measurements taken from microphones at equation 4.

$$H_{12} = \frac{S_{12}}{S_{11}} \quad (4)$$

S are the sound wave pressures measured by microphones. S_{12} is the cross spectrum between microphones 1 and 2, and S_{11} is the spectrum of microphone 1. Then resistivity is obtained using equation 5.

$$r = \frac{H_{12}-H_A}{H_B-H_{12}} e^{2jkx_1} \quad (5)$$

Finally, sound absorption is calculated using resistivity obtained from previous equations in equation 6.

$$\alpha = 1 - |r|^2 \quad (6)$$

2.2.3. Sound absorption coefficient measurement with reverberation cabin

The reverberation chamber is the most common acoustic laboratory device for defining the sound absorption coefficient for materials [27]. In this study, the reverberation cabin will also be considered as its model, the alpha cabin [28]. In Figure 5, the reverberation cabin used in the test is schematized; The sound absorption coefficient is 400-10000 Hz and the Brüel&Kjaer 4189 model has a microphone with a measurement range of 10-10000 kHz / ± 2 dB. Sound absorption values can be measured for multiple dimensions in the reverberation cabin, making it very effective for obtaining the sound absorption coefficient of complex parts.

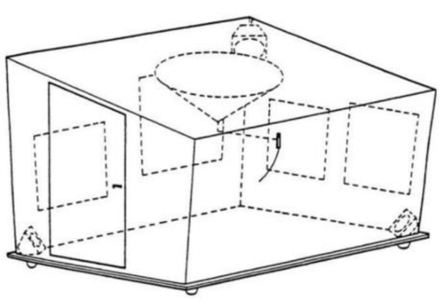

Figure 5. Schematic illustration of reverberation cabin [31]

In short, a reverberation booth consists of a closed enclosure, fixture, a movable microphone, and several sound sources. The losed enclosure has asymmetric walls to minimize overlapping of sound waves [29]. The sample with dimensions of 1000x1200xh mm is placed in the fixture where the various heights of the felts are h. Sound waves propagate through sound sources and reflected noise recorded by a microphone. The testing and recording process is repeated with varying microphone positions. Repetition can be eliminated with additional microphones. Finally, the time taken for a certain amount of absorption is used to calculate the sound absorption coefficient [30]. The sound absorption coefficient is calculated from the difference of reverberation time between cabin with part placed in it and cabin without the part. Reverberation time is determined using the equation shown at Equation (7).

$$T_{60} = 0{,}049 \frac{V}{S\bar{\alpha}} \quad (7)$$

In this equation, T_{60} corresponds to time required for 60 dB absorption from the emitted sound by the source. S is the total area of surrounding surfaces. $\bar{\alpha}$ is the mean of sound absorption coefficient.

3. Experimental Results

3.1. Sound Transmission Loss

The standardized method of ASTM E261 is used while sound transmission loss is being measured at impedance tube [32]. The BSWA brand impedance tube used in the Şiteks laboratory is shown in Figure 4. 30 and 100 diameter tubes are used for this study. For higher frequencies, 100 mm sample is used. For barrier purposes, high sound transmission loss is needed for material. Measurements are made within 400-2500Hz.

Sound transmission loss signals from four microphones were used to calculate the transfer matrix using BSWA VA-Lab 4 software. The results obtained are given in Figure 6 and Figure 7. Full results are given in Appendix A1.

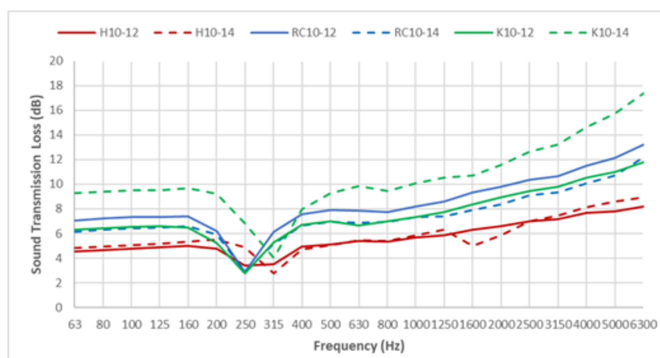

Figure 6. Graph of sound transmission loss values obtained with impedance tube when the thickness is 10 mm.

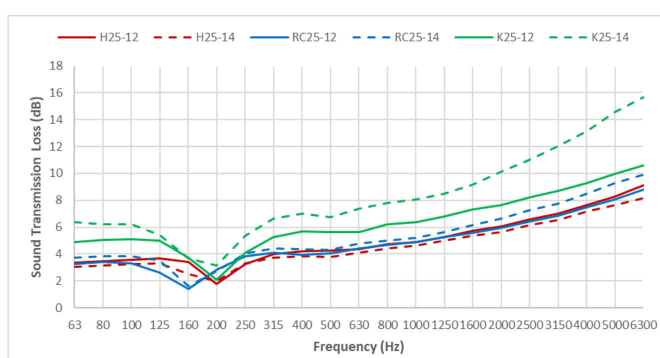

Figure 7. Graph of sound transmission loss values obtained with impedance tube when the thickness is 25mm.

The average sound transmission loss values of the results obtained for 1/3 octave are given in Table 2.

Table 2. Mean sound transmission values measured with impedance tube

Samples	Mean STL (dB)
H10-12	5,65
H25-12	5,23
H10-14	5,83
H25-14	4,61
RC10-12	8,40
RC25-12	4,82
RC10-14	7,42
RC25-14	5,36
K10-12	7,52
K25-12	6,35
K10-14	10,50
K25-14	8,30

According to the results shown in Figure 6 and 7, as density increased, STL also increased. The H10-12 sample showed lower transmission loss at higher frequencies. Therefore, the compression used during the manufacturing process to obtain denser felts had a significant impact on sound transmission loss performance.

Changes caused by compression affect various parameters of the felt, which alter its sound transmission loss performance. Higher density increases flow resistance and stiffness while reducing thickness and porosity. Higher hardness, density, flow resistance and lower porosity increase sound transmission loss. In terms of material, K10-12, K25-12 (1200 g/m2 density) samples and RC10-12, RC10-14 (10 mm thickness) samples showed the best performance in terms of sound transmission loss performance among other materials.

3.2. Sound Absorption Coefficient with Impedance Tube

Sound absorption coefficients were tested with an impedance tube using the ISO 10534-2 standard [33]. Signals measured from microphones were converted using BSWA VA-Lab 4 software. All results regarding the sound absorption coefficient in the impedance tube are given in Figure 8 and Figure 9. Full results are given in Appendix A1.

Mean sound absorption coefficients of obtained results for 1/3 octaves are given in Table 3 for overall performance comparison. When the average sound absorption coefficients and graphs are examined, it is seen that the thickness of the felt has a significant effect on sound absorption rather than its density. This situation was examined as the opposite in the STL results.

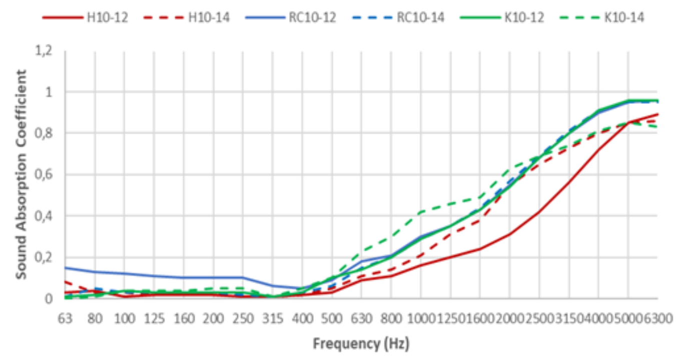

Figure 8. Graph of sound absorption coefficients (α) obtained with impedance tube when the thickness is 10 mm.

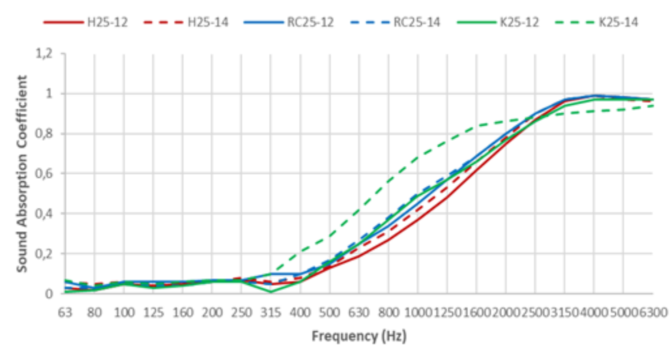

Figure 9. Graph of sound absorption coefficients (α) obtained with impedance tube when the thickness is 25 mm.

Table 3. Mean sound absorption coefficients (α) measured with impedance tube

Samples	Mean STL (dB)
H10-12	0,23
H25-12	0,38
H10-14	0,28
H25-14	0,40
RC10-12	0,35
RC25-12	0,41
RC10-14	0,31
RC25-14	0,41
K10-12	0,31
K25-12	0,40
K10-14	0,33
K25-14	0,46

3.3. Sound Absorption Coefficient with Alpha Cabin

The average sound absorption values are calculated by the average of the measured values. Average of the sound absorption values for third of octave frequencies are given in Table 4.

In terms of sound absorption coefficient data with Alpha cabin, the best efficiency was obtained from recycled felts with kapok additives. The values match the measurement with the impedance tube.

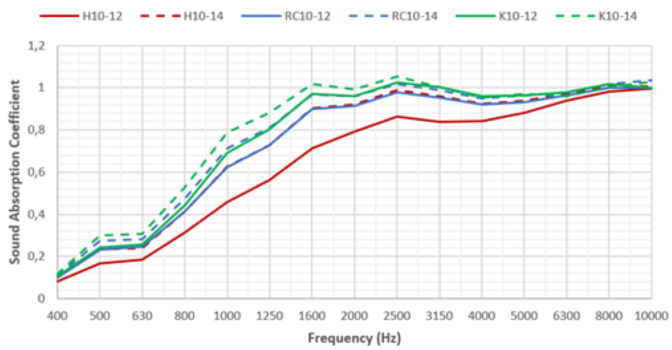

Figure 10. Graph of sound absorption coefficients (α) obtained with alpha cabin when the thickness is 10 mm.

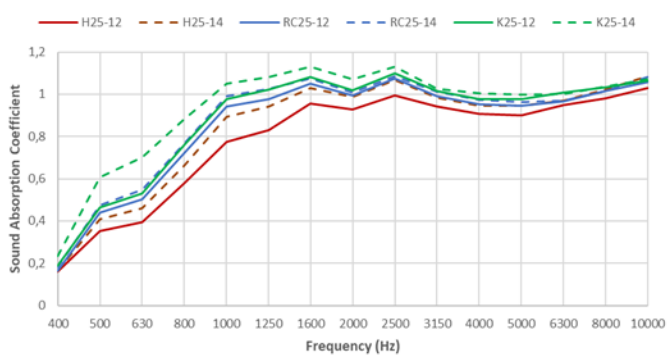

Figure 11. Graph of sound absorption coefficients (α) obtained with alpha cabin when the thickness is 25 mm.

Table 4. Mean sound absorption coefficients measured with alpha cabin

Samples	**Mean STL (dB)**
H10-12	0,23
H25-12	0,38
H10-14	0,28
H25-14	0,40
RC10-12	0,35
RC25-12	0,41
RC10-14	0,31
RC25-14	0,41
K10-12	0,31
K25-12	0,40
K10-14	0,33
K25-14	0,46

4. Results

This study, which focuses on recycling industrial cotton waste and blending it with other natural fibers to enhance desired properties, underscores the complexity of the factors that influence felt performance. Overall results showed that significant performance differences could be seen below 4000 Hz. Then the difference becomes less steep. In order to better understand the parameters affecting performance, the test results are given again in groups in Table 5, and are detailed in APPENDIX tables A1, A2 and A3. Additionally, the Johnson-Champoux-Allard-Pride Lafarge (JCAPL) model [34] was used for sound absorption coefficient results.

Table 5. Average coefficients of samples between 400 - 6300 Hz.

Samples	Between 400 to 6300 Hz		
	$\bar{\alpha}$ (Alpha Cabin)	$\bar{\alpha}$ (Impedance T.)	Mean STL (dB)
H10-12	0,587	0,353	5,645
H25-12	0,774	0,587	4,986
H10-14	0,688	0,435	5,827
H25-14	0,805	0,610	4,611
RC10-12	0,684	0,496	8,403
RC25-12	0,824	0,627	4,817
RC10-14	0,730	0,492	7,419
RC25-14	0,851	0,639	5,360
K10-12	0,723	0,491	7,518
K25-12	0,855	0,618	6,350
K10-14	0,759	0,507	10,499
K25-14	0,917	0,705	8,304

Considering the sound absorption tests performed with Alpha cabin and impedance tube, as the thickness of the samples increased, the sound absorption coefficient also increased. This shows that although the amount of material used is the same, the compression effect and air density applied during production are important parameters in the test.

The main reasons for this are the decrease in porosity and the increase in static air flow resistance as the material compresses [35]. Porosity, one of the main factors of sound absorption, critically affected the sound absorption coefficients of felts with the same parameters except compression. In the tests, denser felt samples compressed at lower thickness; For example, it was observed that the hemp-added felt sample H25-14 shown in Figure 10 and 11 showed significantly higher sound absorption performance up to 8000 Hz compared to the H10-14 sample. This situation was significantly similar for RC25-14 and K25-14. The difference between the sound absorption coefficients continued in all sample types until it reached 3150 Hz, and then, since the semi-linear increase in sound absorption became effective, the difference in sound absorption decreased to a minimum level.

The average sound absorption coefficients of the samples in the common range between 400 Hz and 6300 Hz are given in Table 5. In the Alpha cabin test, samples with kapok additives (K10-12: 0.723; K10-14:0.759; K25-12:0.855; K25-14:0.917) gave the highest sound absorption coefficient, and samples with an areal density of 1400g/m2 in the impedance tube were K10-14 and K25-14 also showed good performance compared to other samples. In impedance tube tests, hemp blended felts showed poor performance in samples with an areal density of 1200 g/m2. In the Alpha cabin test, felts with kapok additives achieved the best sound absorption results at 1200 Hz frequency; In hemp-added felts, this value could be achieved at a frequency of 10000 Hz.

The general values given in the graphs highlight the sound absorption performance of the samples in a wide frequency range. Kapok additives felt samples performed better in all tests at lower frequencies, followed by un-added recycled cotton felt samples. In hemp felt samples, H10-12 and H10-14 had higher sound absorption, but the insignificant difference in the 25 mm samples (H25-12 and H25-14) can be ignored.

The semi-linear increase of sound absorption as the frequency increases reduces the initial advantage obtained by parameter change. The value from wavelength to absorber thickness played an important role here. The sound absorption of 25 mm wide felts was 1 in both sound absorption tests. The main reason for this is the ratio of the absorber height to the wavelength of the sound. For conventional absorbers, the wavelength of sound must be above 1 up to the absorber height for effective absorption [26]. The wave speed is calculated [36]; When the speed of sound in air is 343 m/s and the frequency of the sound is written in 3150 Hz, the wavelength becomes 0.108 m, which gives the wavelength to thickness ratio of 25 mm samples to be 0.23. As mentioned, with the Fabry-Pérot resonance, the absorption performance becomes extremely high as the ratio of the wavelength of the sound to the absorber thickness increases above ¼. For 10mm samples, the frequency that meets this ratio is 8575 Hz.

In general, the pure recycled cotton felt samples and the kapok felt samples performed much better at low frequencies. This increase indicated that the low-frequency and mid-frequency sound absorption coefficient of recycled cotton could be improved by the addition of kapok fibers. The good acoustic properties obtained due to the hollow structure of kapok fibers were compatible with the structure of recycled cotton. The use of hemp fiber reduced the sound absorption coefficient of recycled cotton. It was observed that hemp-added felts had a lower sound absorption coefficient than kapok-added felt samples.

Looking at the sound transmission loss (STL) results with the Impedance Tube, the compression used in the manufacturing process to obtain denser felts had a significant impact on the sound transmission loss performance. Changes caused by compression affect various parameters of the felt, which alter its sound transmission loss performance. Higher density increases flow resistance and stiffness while reducing thickness and porosity. Higher hardness, higher density, higher flow resistance and lower porosity increase sound transmission loss. According to the results shown in Figures 6 and 7, as density increased, sound transmission loss also increased. The H10-12 sample showed lower transmission loss at higher frequencies.

Considering the sound transmission loss (STL) results with the Impedance Tube, the average sound transmission losses in the common range between 400 Hz and 6300 Hz are given in Table 5. The resonance frequency of the samples increased as the thickness decreased. The decrease in sound transmission loss values in the resonance region was much greater as the thickness decreased. This was caused by increased hardness and density as higher compression was introduced in the production process. Contrary to the expected increase, the effect of field intensity on the resonance frequency could not be determined because the changes were inconsistent. This is thought to be due to the resolution of the test equipment. Nevertheless, recycled cotton and kapok fibers also showed superior acoustic performance in sound transmission loss. Apart from the poor performance of RC25-12, the least sound transmission performance was obtained by hemp felt samples. As in the sound absorption tests, hemp fiber recycled cotton exhibited the worst sound transmission loss characteristics.

5. Conclusion

A careful material selection process is applied for acoustic insulation materials in the automotive industry, considering many factors. Sound absorption coefficient and sound transmission loss are of great importance in acoustic insulation, and these values are affected by various parameters of the material. In this study, the areal density of the felt, the thickness of the compressed felt and the material composition were evaluated using test methods and correlated with theoretical models. The sound absorption coefficient was evaluated using both the reverberation cabin and the impedance tube, while the sound transmission loss was measured using the impedance tube only.

In terms of composition, the effect of other added fibers was investigated and it was observed that the addition of kapok fibers significantly increased both sound absorption and sound transmission loss. The addition of hemp fibers caused this performance to decrease. The thickness to which the felt was compressed showed that higher thicknesses caused an increase in sound absorption values and a decrease in sound transmission values. Increasing field intensity resulted in higher sound absorption in reverberation cabin tests, while reduced sound absorption in impedance tube tests, with some exceptions (samples RC10-12 and RC10-14). High areal density generally increased sound transmission loss, except for H2512, H25-14 and RC10-12, RC10-14 samples. Most of the test results are consistent with the theoretical models used for felt performance, proving that areal density, compressed thickness and material composition are effective parameters in the acoustic insulation performance of felt. The relationships between these parameters and performance will be useful for future applications in the automotive industry.

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Nomenclature

NVH	:	Noise vibration harshness
PES	:	Low-melt polyester
STL	:	Sound transmission loss (α)
Hz	:	Frequency
dB	:	Decibel

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

Can Bilir: Conceptualization, Supervision
Bahadır Çetişli: Writing-original draft, Investigation, Validation, Data curation, Formal analysis
Nuray Kızıl: Writing - original draft, Review & Editing, Investigation, Validation, Data curation, Formal analysis
İnanç Karaduman: Investigation
Zeliha Çavuş: Investigation, Validation, Review
Ekin Sabuncu: Validation, Formal analysis

References

[1] Karabulut A, Şahman H, Korkmaz BŞ. Investigation of Vehicle Engine Driving Comfort Used in Vibration Dampers. IJASTECH. 2022;6(3):302-8. doi:10.30939/ijastech.1098514

[2] Crocker MJ, editor. Handbook of noise and vibration control. Cambridge (MA): John Wiley & Sons; 2007. ISBN: 978-0-471-39599-7

[3] Meriç C, Erol H, Özkan A. On the sound absorption performance of a felt sound absorber. Appl Acoust. 2016;114:275–80. doi: 10.1016/j.apacoust.2016.08.003

[4] Karagöz M, Tuncay B. An Engine Mount Design and Vibration Analysis. IJASTECH. 2020;4(3):164-70.

[5] Narang PP. Material parameter selection in polyester fibre insulation for sound transmission and absorption. Appl Acoust. 1995;45(4):335–58. doi:10.1016/0003-682X(95)00007-V

[6] Nick A, Becker U, Thoma W. Improved acoustic behavior of interior parts of renewable resources in the automotive industry. J Polym Environ. 2002;10(3). doi:10.1023/A:1021124214818

[7] Zhang D, Zhou X, Gao Y, Lyu L. Structural characteristics and sound absorption properties of waste hemp fiber. Coatings. 2022;12(12):1907. doi:10.3390/coatings12121907

[8] Çakmakkaya M, Kunt M, Terzi O. Investigation of polymer matrix composites in automotive consoles. Ijastech. 2019;3(3):51–6. doi:10.30939/ijastech.513332

[9] Fung W, Hardcastle M. Textiles in automotive engineering. Cambridge: Woodhead Publishing Limited; 2001. p. 212–5. ISBN: 9781855738973.

[10] Bujoreanu C, Nedeff F, Benchea M, Agop M. Experimental and theoretical considerations on sound absorption performance of waste materials including the effect of backing plates. Appl Acoust. 2017;119:88–93. doi: 10.1016/j.apacoust.2016.12.010

[11] Pompoli F, Bonfiglio P, Horoshenkov KV, Khan A, Jaouen L, Bécot FX, et al. How reproducible is the acoustical characterization of porous media? J. Acoustical society of America. 2017;141(2):945–55. doi:10.1121/1.4976087

[12] Ghorbani K, Hasani H, Zarrebini M, Saghafi R. An investigation into sound transmission loss by polypropylene needle-punched nonwovens. Alexandria Engi-neering J. 2016;55(2):907-914. doi: 10.1016/j.aej.2016.02.012

[13] Bonfiglio P, Pompoli F, Horoshenkov KV, Rahim MIBSA, Jaouen L, Rodenas J, et al. How reproducible are methods to measure the dynamic viscoelastic properties of poroelastic media? Sound and Vibration J. 2018;428:26–43. doi: 10.1016/j.jsv.2018.05.006

[14] Shravage P, de'Sa K. Effect of macroscopic parameters on sound absorption and sound transmission loss of porous materials. J. Acoustical Society of America. 2009;126(4_Supplement):2287. doi:10.1121/1.3249372

[15] dos Santos Pegoretti T. Environmental and sound analysis of the acoustic treatment of vehicle compartments [dissertation]. [sn]; 2014. doi:10.47749/T/UNICAMP.2014.942275

[16] Duval A, Crignon G, Goret M, Lemaire D, Prunet JB, Chanudet P. Ecofelt hybrid stiff NVH tunable insulator. SAE Tech Pap. 2018;2018-01-1494. doi:10.4271/2018-01-1494

[17] Yang M, Sheng P. Sound absorption structures: From porous media to acoustic metamaterials. Annu Rev Mater Res. 2017;47:83–114. doi:10.1146/annurev-matsci-070616-124032

[18] Ganesan P, Karthik T. Development of acoustic nonwoven materials from kapok and milkweed fibres. J Text Inst. 2016;107:477–82. doi:10.1080/00405000.2015.1045251

[19] Kabir MM, Wang H, Lau KT, Cardona F. Tensile properties of chemically treated hemp fibers as reinforcements for composites. Compos Part B Eng. 2013;53:362–8. doi: 10.1016/j.compositesb.2013.05.048

[20] Yilmaz ND, Powell NB, Banks-Lee P, Michielsen S. Hemp-fiber based nonwoven composites: Effects of alkalization on sound absorption performance. Fibers Polym. 2012;13:915–22. doi:10.1007/s12221-012-0915-0

[21] Balčiūnas G, Žvironaitė J, Vėjelis S, Jagniatinskis A, Gaidučis S. Ecological, thermal and acoustical insulating composite from hemp shives and sapropel binder. Ind Crops Prod. 2016;91:286-94. doi: 10.1016/j.indcrop.2016.06.034

[22] Prömper E. Natural fibre-reinforced polymers in automotive interior applications. In: Wiley, editor. 2010. p. 423-36.

[23] Yousefzadeh B, Mahjoob M, Mohammadi N, Shahsavari A. An experimental study of sound transmission loss (STL) measurement techniques using an impedance tube. J. Acoustical Society of America. 2008;123(5):3119. doi:10.1121/1.2933032

[24] Kierzkowski M, Law H, Cotterill J. Benefits of reduced-size reverberation room testing. In: Proceedings of Acoustics 2017; 2017 Nov 19-22; Perth, Australia.

[25] Gelen M. Acoustic materials used in the automotive industry and

examination of the effect of material properties on acoustic parameters [master's thesis]. Institute of Science and Technology; 2016. p. 978 625 7367 028.

[26]Labašová E, Ďuriš R. Measurement of the acoustic absorption coefficient by impedance tube. Research Papers Faculty of Materials Science and Technology Slovak University of Tech. 2019;27(45):94-101. doi:10.2478/rput-2019-0031

[27]Rey Tormos RM, Alba Fernández J, Bertó Carbó L, Gregori A. Small-sized reverberation chamber for the measurement of sound absorption. Mater Construcc. 2017;67(328):1-9. doi:10.3989/mc.2017.07316

[28]Santoni A, Bonfiglio P, Fausti P, Pompoli F. Computation of the Alpha Cabin sound absorption coefficient by using the finite transfer matrix method (FTMM): inter-laboratory test on porous media. J.Vibration and Acoustics. 2021;143(2):021012. doi:10.1115/1.4048395

[29]ASTM C423. Standard test method for sound absorption and sound absorption coefficients by the reverberation room method. ASTM International; 2019. West Conshohocken, PA. doi: 10.1520/C0423-22

[30]Kierzkowski M, Law H, Cotterill J. Benefits of reduced-size reverberation room testing. In: Proceedings of ACOUSTICS 2017; 2017 Nov 19-22; Perth, Australia.

[31]Duval A, Rondeau JF, Dejaeger L, Sgard F, Atalla N. Diffuse field absorption coefficient simulation of porous materials in small reverberant rooms: finite size and diffusivity. In: 10th French Congress on Acoustics; 2010 Apr 12-16; Lyon, France.

[32]ASTM E261. Standard test method for measurement of normal incidence sound transmission of acoustical materials based on the transfer matrix method. ASTM International. doi: 10.1520/C0423-22

[33]ISO 10534-2. Acoustics — Determination of sound absorption coefficient and impedance in impedance tubes — Part 2: Transfer-function method. International Organization for Standardization; 1998. Switzerland.

[34]Wang Y, Li C, Chen X, Zhang C, Jin Q, Zhou G, et al. Sound absorption performance based on auxetic microstructure model: A parametric study. Mater Des. 2023;232:112130. doi: 10.1016/j.matdes.2023.112130

[35]Zent A, Long JT. Automotive sound absorbing material survey results. SAE Technical Paper. 2007;(No. 2007-01-2186). doi:10.4271/2007-01-2186

[36]Fan TY, Fan L. New dispersion formula and wave speed. Trans Beijing Inst Technol. 2010;(7):757-8.

Appendix A1. Tables of Obtained Results

Table A1. All Sound Transmission Loss Values Obtained in Impedance Tube

Frequency	H10-12	H10-14	RC10-12	RC10-14	K10-12	K10-14	H25-12	H25-14	RC25-12	RC25-14	K25-12	K25-14
63	4,53	4,81	7,08	6,15	6,3	9,27	3,36	3,07	3,27	3,72	4,92	6,4
80	4,64	4,93	7,22	6,33	6,42	9,39	3,49	3,17	3,39	3,82	5,08	6,24
100	4,77	5,07	7,32	6,45	6,53	9,49	3,6	3,27	3,3	3,82	5,12	6,24
125	4,86	5,17	7,36	6,51	6,57	9,51	3,67	3,29	2,62	3,53	4,98	5,44
160	4,99	5,37	7,38	6,59	6,49	9,66	3,4	2,5	1,42	1,62	3,72	3,67
200	4,78	5,49	6,21	5,9	5,24	9,24	1,8	2	2,84	2,71	2,08	3,16
250	3,38	4,9	2,88	2,9	2,76	6,8	3,26	3,3	3,84	4,06	4,08	5,36
315	3,52	2,76	6,16	5,17	5,28	4,04	3,98	3,71	4,08	4,41	5,28	6,62
400	4,94	4,72	7,59	6,64	6,72	7,96	4,19	3,85	3,94	4,37	5,69	7,02
500	5,12	5,07	7,91	6,95	6,97	9,29	4,24	3,8	4,04	4,34	5,66	6,77
630	5,41	5,45	7,83	6,86	6,64	9,86	4,36	4,12	4,43	4,79	5,64	7,4
800	5,35	5,42	7,72	6,93	6,98	9,43	4,74	4,4	4,68	5	6,2	7,78
1000	5,67	5,85	8,19	7,33	7,36	10,08	4,9	4,62	4,9	5,22	6,36	8,06
1250	5,86	6,33	8,59	7,38	7,75	10,55	5,29	5	5,26	5,63	6,82	8,5
1600	6,34	5	9,34	7,92	8,34	10,72	5,74	5,39	5,58	6,19	7,33	9,18
2000	6,57	5,86	9,81	8,39	8,92	11,57	6,07	5,66	5,93	6,65	7,65	10,13
2500	7,01	7,02	10,37	9,11	9,47	12,67	6,6	6,15	6,44	7,27	8,2	11,02
3150	7,19	7,47	10,67	9,35	9,79	13,22	7,02	6,53	6,86	7,74	8,68	12,03
4000	7,66	8,14	11,51	10,06	10,54	14,64	7,64	7,15	7,46	8,48	9,29	13,12
5000	7,79	8,62	12,12	10,71	11	15,71	8,27	7,67	8,09	9,29	9,97	14,56
6300	8,18	8,93	13,22	12,17	11,81	17,38	9,1	8,19	8,79	9,92	10,61	15,7

Table A2. All Sound Transmission Coefficients Obtained in Impedance Tube

Frequency	H10-12	H10-14	RC10-12	RC10-14	K10-12	K10-14	H25-12	H25-14	RC25-12	RC25-14	K25-12	K25-14
63	0,03	0,08	0,15	0,01	0,01	0	0,03	0,06	0,06	0,03	0,01	0,07
80	0,04	0,03	0,13	0,05	0,02	0,01	0,02	0,05	0,03	0,03	0,02	0,04
100	0,01	0,03	0,12	0,03	0,04	0,04	0,05	0,06	0,06	0,05	0,05	0,06
125	0,02	0,02	0,11	0,03	0,03	0,04	0,04	0,05	0,06	0,04	0,03	0,05
160	0,02	0,02	0,1	0,03	0,03	0,04	0,05	0,05	0,06	0,04	0,04	0,06
200	0,02	0,03	0,1	0,03	0,03	0,05	0,06	0,06	0,07	0,06	0,06	0,07
250	0,01	0,01	0,1	0,02	0,03	0,05	0,07	0,08	0,07	0,06	0,06	0,07
315	0,01	0,01	0,06	0,01	0,01	0,01	0,05	0,06	0,1	0,05	0,01	0,1
400	0,02	0,02	0,05	0,03	0,03	0,05	0,06	0,08	0,1	0,1	0,06	0,21
500	0,03	0,05	0,09	0,06	0,1	0,1	0,13	0,14	0,15	0,17	0,16	0,29
630	0,09	0,11	0,18	0,15	0,14	0,23	0,19	0,23	0,25	0,27	0,25	0,42
800	0,11	0,14	0,21	0,2	0,2	0,3	0,27	0,31	0,34	0,38	0,37	0,56
1000	0,16	0,21	0,3	0,29	0,29	0,42	0,37	0,42	0,45	0,5	0,49	0,68
1250	0,2	0,31	0,35	0,35	0,35	0,46	0,48	0,53	0,57	0,59	0,57	0,76
1600	0,24	0,38	0,43	0,44	0,43	0,49	0,62	0,66	0,69	0,69	0,66	0,84
2000	0,31	0,55	0,55	0,57	0,54	0,63	0,75	0,78	0,8	0,8	0,77	0,86
2500	0,42	0,65	0,68	0,69	0,68	0,69	0,87	0,9	0,9	0,9	0,86	0,88
3150	0,56	0,73	0,8	0,81	0,8	0,74	0,96	0,97	0,97	0,97	0,94	0,9
4000	0,72	0,8	0,9	0,91	0,91	0,81	0,99	0,99	0,99	0,99	0,97	0,91
5000	0,85	0,85	0,95	0,95	0,96	0,85	0,98	0,97	0,98	0,98	0,97	0,92
6300	0,89	0,86	0,96	0,95	0,96	0,83	0,97	0,96	0,97	0,97	0,97	0,94

Table A3. All Sound Transmission Coefficients Obtained in Reverberation Cabin

Frequency	H10-12	H10-14	RC10-12	RC10-14	K10-12	K10-14	H25-12	H25-14	RC25-12	RC25-14	K25-12	K25-14
400	0,08	0,102	0,1	0,11	0,107	0,116	0,162	0,163	0,164	0,181	0,188	0,233
500	0,167	0,234	0,23	0,273	0,243	0,3	0,351	0,41	0,44	0,474	0,465	0,607
630	0,185	0,24	0,245	0,283	0,255	0,308	0,395	0,461	0,504	0,547	0,529	0,701
800	0,315	0,413	0,413	0,476	0,443	0,53	0,581	0,663	0,721	0,769	0,761	0,882
1000	0,458	0,625	0,622	0,712	0,692	0,789	0,776	0,894	0,941	0,99	0,977	1,052
1250	0,561	0,727	0,727	0,809	0,801	0,88	0,83	0,942	0,978	1,026	1,021	1,081
1600	0,714	0,902	0,898	0,966	0,971	1,016	0,955	1,031	1,052	1,073	1,083	1,131
2000	0,79	0,919	0,915	0,962	0,961	0,991	0,929	0,989	0,996	1,009	1,02	1,07
2500	0,864	0,989	0,979	1,018	1,026	1,054	0,996	1,067	1,074	1,084	1,1	1,132
3150	0,837	0,961	0,952	0,988	1,003	1,002	0,943	0,983	0,992	1,011	1,015	1,026
4000	0,842	0,924	0,922	0,951	0,96	0,952	0,908	0,947	0,951	0,972	0,976	1,006
5000	0,881	0,94	0,93	0,964	0,965	0,972	0,899	0,946	0,944	0,964	0,976	0,999
6300	0,938	0,971	0,964	0,978	0,977	0,959	0,948	0,971	0,967	0,97	1,01	1,003
8000	0,982	1,007	0,998	1,016	1,019	1,003	0,979	1,021	1,017	1,016	1,034	1,036
10000	0,996	1,007	1	1,037	1	1,028	1,03	1,085	1,056	1,083	1,063	1,071