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NON-WOVENS AS SOUND REDUCERS

D. Belakova[1], A. Seile[1], S. Kukle[1], T. Plamus[2]
[1] Institute of Design Technologies, Riga Technical University,
3/7 Paula Valdena Str., Riga, LV-1048, LATVIA
[2] Tallinn University of Technology, Department of Materials and Environmental Technology, Laboratory of Polymers and Textile Technology,
5 Ehitajate Str., Tallinn, 19086, ESTONIA

Within the present study, the effect of hemp (40 wt%) and polyactide (60 wt%), non-woven surface density, thickness and number of fibre web layers on the sound absorption coefficient and the sound transmission loss in the frequency range from 50 to 5000 Hz is analysed. The sound insulation properties of the experimental samples have been determined, compared to the ones in practical use, and the possible use of material has been defined. Non-woven materials are ideally suited for use in acoustic insulation products because the arrangement of fibres produces a porous material structure, which leads to a greater interaction between sound waves and fibre structure. Of all the tested samples (A, B and D), the non-woven variant B exceeded the surface density of sample A by 1.22 times and 1.15 times that of sample D. By placing non-wovens one above the other in 2 layers, it is possible to increase the absorption coefficient of the material, which depending on the frequency corresponds to C, D, and E sound absorption classes. Sample A demonstrates the best sound absorption of all the three samples in the frequency range from 250 to 2000 Hz. In the test frequency range from 50 to 5000 Hz, the sound transmission loss varies from 0.76 (Sample D at 63 Hz) to 3.90 (Sample B at 5000 Hz).

Keywords*: non-woven, sound absorption, sound transmission*

1. INTRODUCTION

1.1. Noise Control

A typical noise control application involves a combination of absorption of sound and transmission of sound energy by a variety of airborne and structure-borne paths [1].

There are two important noise-related quantities of a material: 1) the ability to absorb acoustic energy characterised by absorption coefficient α; 2) the ability to reflect or block sound energy characterised by sound transmission loss (STL) measured in decibels, or τ – the transmission coefficient, which is a frequency-dependent physical property of the material:

$$\tau = I_{transmitted} / I_{incident}. \quad (1)$$

Sound Transmission Loss:

$$STL = 10 \log 1/\tau. \quad (2)$$

Sound absorption is the incident sound that strikes a material and is not reflected back. Performance of sound absorbers is determined by their ability to dissipate sound energy at various sound frequencies. Fibre-based materials are the best sound absorbers. When a sound wave strikes an acoustic material, the sound wave causes the fibres of the absorbing material vibrate. This vibration causes tiny amounts of heat due to friction and, thus, sound absorption is accomplished by energy to heat conversion. The more fibrous a material is, the better the absorption; conversely less absorptive materials have a higher density. The sound absorbing characteristics of acoustic materials vary significantly with frequency. In general, low frequency sounds are very difficult to absorb because of their long wavelength. On the other hand, humans are less susceptible to the low frequency sounds, which can be beneficial in many cases. For a vast majority of conventional acoustic materials, the material thickness has the greatest impact on the sound absorption qualities. While the inherent composition of the acoustic material determines the material acoustic performance, other factors can be applied to bear, improve or influence the acoustic performance. For example, incorporation of air space behind an acoustic surface often serves to improve low frequency performance.

Good absorbing materials allow sound pressure fluctuations to enter their surface and dissipate energy by air friction. They are generally porous and lightweight, such as fibres, open-cell foam, or acoustic ceiling tiles. Good barrier materials reflect sound, and are dense and non-porous (concrete, lead, steel, brick, glass, and gypsum board). In general, a single homogeneous material will not be both a good absorber and a barrier. It is common to laminate an absorbing layer to a barrier material [2].

1.2. Noise Emission of Passenger Vehicles

The permissible noise emission of a passenger vehicle has decreased from 82 dB (1978) to 74 dB (1996). A new EU regulation was introduced in July 2016 [3], which would phase in stricter noise limits over 10 years, together with a revised, more representative test procedure. By 2026 the limit for most new passenger cars will be 68 dB [3].

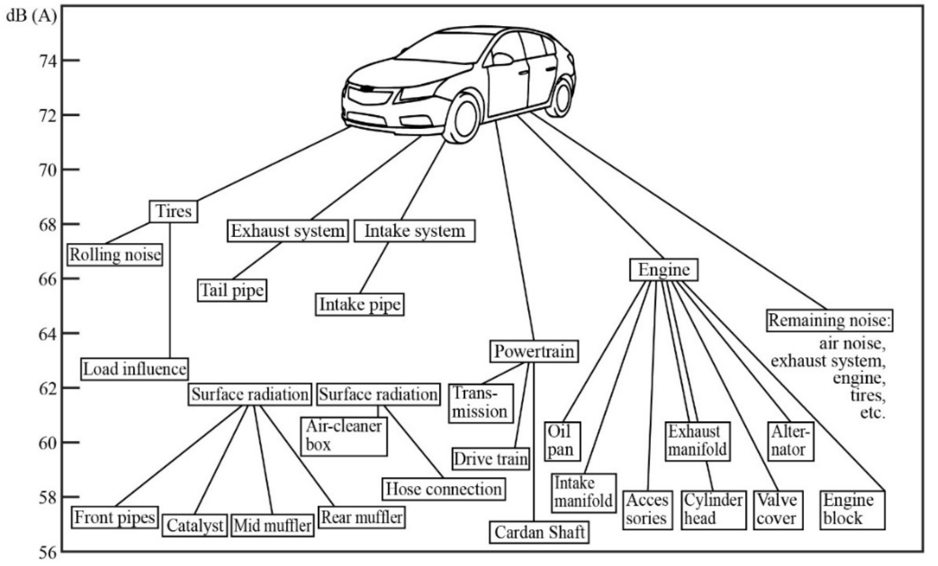

Fig. 1. Noise source ranking for a vehicle during the pass-by noise test [5].

The four major noise sources that contribute significantly to the noise level created by cars are the engine, the intake system, the exhaust system and the tyre/road system [4]. Pressure pulsations at the intake and exhaust valves of the engine are the main excitation source for the intake and the exhaust system noise. Gas flow in their piping systems is the source for flow noise, which occurs as broadband noise in the mid-frequency range. At the exhaust outlet, the mixing of hot exhaust gas and still ambient air is the cause of jet noise. Tyre/road interaction noise is caused by the impact, adhesion and air-displacement mechanisms between the tyre and the road [4].

Figure 1 [5] presents a ranking of the noise sources with the highest contributions to pass-by noise in the following order: tyres, exhaust system, intake system, and engine. Analysis of the frequency content of noise helps us to understand noise source characteristics. However, detailed testing of each major noise source is required in order to identify and reduce critical noise contributions. There are no specific resonance frequencies, but the increased amplitude components in the frequency range between 500 Hz and 2 kHz are caused by tyre/road noise. Dominant frequencies are around 1000 Hz. The frequency range below 500 Hz is dominated by the engine movement, which is related to the sound radiation of the engine, intake and exhaust system [4].

The so-called flow noise is caused by turbulence and vortices of the high speed mass flow around sharp edges, small bends and free jets [6]. Opinions about its characteristic vary. According to [6], flow noise is of a broadband character between 1 kHz and 3 kHz. In contrast, it is described in [7] as being a rather tonal character with low and high frequency components. Therefore, noise of frequency range from 125 Hz to 500 Hz and 500 Hz to 3 kHz needs to be reduced by car interior elements to ensure user comfort.

1.3. Noise Insulation Materials Used in Transport

In contrast to the sound insulation materials used in buildings, the soundproofing materials used in vehicles are relatively thin (< 50 mm). A material provides absorption best if its thickness is between ¼ to ½ of the sound wave length acting on the material.

Up until 2005, the weight of textiles built into the construction of passenger cars was, on average, 21 kg. Now the use of textiles is increasing, and by the end of 2020 textile-based materials are expected to weigh 35 kg [8].

The most common materials used in cars are closed-cell foam formed sound absorbing materials or fibre structure materials with open-cell air pockets. The latter includes non-wovens (NWM). In accordance with the EU regulation, the use of fibre-based materials in the automotive industry, including NWM, continues to increase.

The air trapped in the structure of NWM makes it an effective soundproofing and sound absorption material. The sound propagation speed through air is 331 m/s (at 0 °C), which is low compared to other media. The void volume in the structure of the material influences its geometrical form and is related to the fibre surface area. NWM total fibre surface area [9] depends on the denier and cross-sectional shape of fibres constituting the material. Finer fibres have to be arranged more densely and the surface area they form is larger. Apart from fibre denier, the surface area is influenced by the fibre cross-section. Comparing thermally bonded non-wovens manufactured from the same fibre denier, but three different cross-sectional shapes (round fibre, trilobal fibreangular and octalobal fibre), the materials from octalobal fibres have the largest surface area, which is up to three times the area of the round fibre NW. Non-wovens made from round fibres have the smallest surface area, if 3 denier and coarser fibres are used [9].

In addition to NWM, the automotive industry also uses woven and knitted textiles, laminated fabrics and surfaces, which are obtained by an electro-static flocking method [10].

Using a mechanical needle-punching method for manufacturing NWM polyester (PES), polyamide (PA) and polypropylene (PP) fibres are most commonly used [11].

In order to obtain a material with the highest possible absorption capacity and high transmission losses, a material with a multilayered structure where each layer has a specific task can be created.

2. EXPERIMENTAL PART

2.1. Materials

The samples of non-woven material with a multilayer structure are made from 6.5 ± 0.5 den fine and 64 ± 4 mm long polyactide (PLA) fibres (60 wt%) (fibre type SLN 2660D delivered from the company Ingeo) and hemp (40 wt%) technical fibres

(Vliesfähige Faser VF6 with fibre diameter between 16 and 50 µm, and average fibre length 50–80 mm delivered from the company BaFa Badische Naturfaseraufbereitung GmbH).

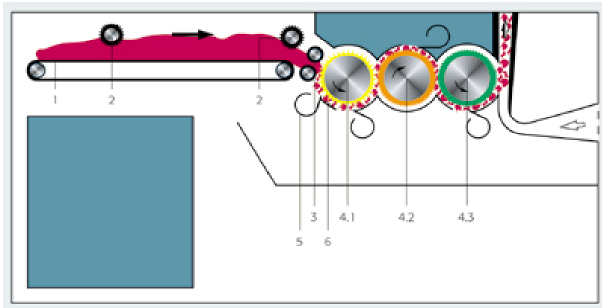

Fig. 2. Cleanomat Cleaner CVT3 by Trutzschler. 1 – Feed Lattice, 2 – Pressure Rollers, 3 – Feed Rolls. 4.1 – Fully-Spiked Rollers, 4.2 – Coarse Saw-Toothed Roller, 4.3 – Medium Saw-Toothed Roller, 5 – Mote Knives, 6 – Carding Segment [13].

Before incorporation into the non-woven material, the necessary amount of fibres is weighed and loosened. For each sample from the prepared fibres five web layers are formed initially: Layer 1 – PLA fibres, Layers 2, 3 and 4 – PLA fibres mixed with hemp technical fibres, Layer 5 – PLA fibres. Loosing of the fibres, mixing of the fibre types and preparation of the fibre web layers with the air-laid method [12] are performed on TRÜTZSCHLER CVT3 1200 (Fig. 2).

Bonding of the web layers, transformation of the five fibre web layers into three layers, and bonding of the three fibre web layers were performed by mechanical needle punching [14] using DILO LBM 6 laboratory type needle-punching equipment (see Fig. 3). DILO LBM 6 is equipped with the company GROZ-BECKERT needles produced for flax processing 15X18X25X3 ½ R333 G 3007.

Fig. 3. Laboratory needle loom with one needle board down stroke DILO LBM 6 (600 mm working width, 2000–3000 needles/m., 3000 strokes/min) [15], [16].

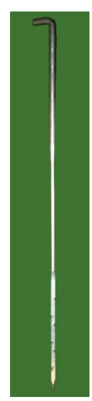

Fig. 4. GROZ-BECKERT punching needle (picture taken by the authors).

The NWM samples developed within the framework of the project were marked with the letters A, B, C, D and E. In the present article, Sample A, B and D characteristics were analysed. Samples for testing were taken from the two places of material – one piece was tested in the frequency up to 500 Hz, the second piece was tested in the frequency range from 500 to 5000 Hz.

The sample thickness was measured by textile thickness gauge SDL Atlas J100. To attain a higher insulation performance, the material was placed in two layers positioning the PLA fibre web layers on its outer sides, as they were needle punched more densely in the process being situated just above the needle board. Thus, the acoustic parameters were determined by placing the NWM in two layers.

2.2. Acoustic Testing

To determine the sound absorption of the materials, two test methods are most commonly used [9]: the Impedance Tube Method [17] and the Reverberation Room Test Method [18]. The dimensions of automotive textiles compared to the materials for soundproofing in buildings and premises are small. Due to this reason, it is more convenient to use the impedance tube method for testing the acoustic properties of the material. In this project, the absorption of all samples was tested by the impedance tube method. The main components of the impedance tube are speakers, tubes, two microphones and a material sample holder. The task of the loudspeaker is to generate a special sound called white noise. The white noise is composed of sound contributions from all frequency bands in the audible range. The sound moves straight down the tube and strikes the test material. Depending of the material, some of the sound is absorbed and some is reflected back. The two microphones measure the reflected sound and from the two microphone signals, the sound absorption can be calculated [19].

The sound insulation capacity of the experimental hemp and PLA NWM samples was evaluated by the sound absorption coefficient α, and transmission loss measurements in the impedance tube according to the standard [20]. The measured parameters: r – normal angle of incidence sound refractive index over the linear frequency scale; α_{linear} – normal angle of incidence sound absorption coefficient over the linear frequency scale; STL_{linear} – sound transmission loss over the linear frequency scale. The parameters to be calculated: α – normal angle of incidence sound absorption t 1/3 octave bands; STL– sound transmission loss at 1/3 octave bands.

Five samples were prepared for testing, of which three samples A, B and C were selected for testing acoustic properties. From these samples, three sample strips were cut with Ø99.5 mm (large samples) and three samples with Ø30 mm (small samples). The small sample strips were tested at frequencies over 1600 Hz, the large sample strips – at frequencies up to 1600 Hz.

3. RESULTS AND DISCUSSION

As seen in Figs. 4 and 5, although the thickness of NMW samples A and B is equal, the difference between their structures is meaningful as surface density of NWM variant B exceeds the surface density of Sample A by 1.22 times and 1.15 times that of Sample D.

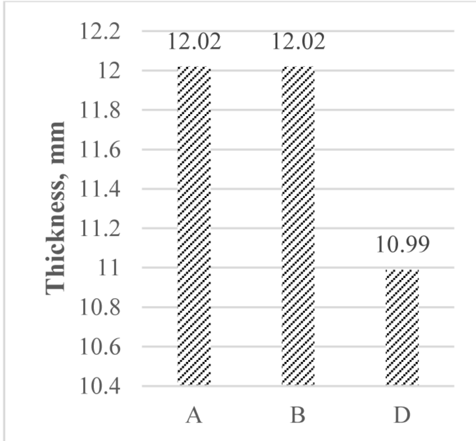

Fig. 5. Thickness of non-woven variants.

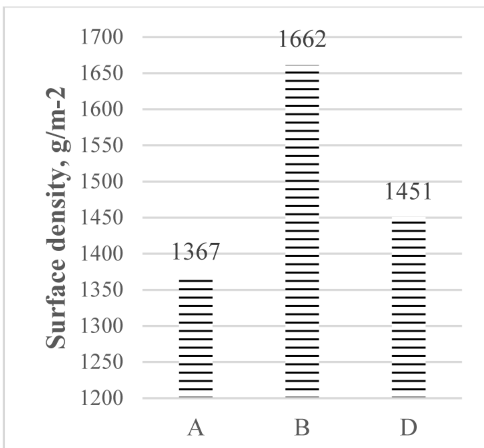

Fig. 6. Surface density of non-woven variants.

Within the present study, NWM samples A, B and D were tested in the frequency range from 50 to 5000 Hz. As mentioned above, an important factor for cars is the noise absorption at low frequencies up to 500 Hz related to the sound radiation of the engine, intake and exhaust system. The other common noise frequency band is from 500 Hz to 2000 Hz with a peak at 1000 Hz caused by tyre/road noise. The absorption coefficient value of NWM sample A exceeds the corresponding values of samples B and D for the entire low frequencies range, and at frequency 63 Hz corresponds to the sound absorption class E (Fig. 6, Table 1). At the same time, samples of variants B and D through almost the entire range of low frequencies demonstrate sound absorption coefficients below limits corresponding to class E.

NWM of variant in the sound frequency range from 500 to 1000 Hz A will absorb more efficiently since throughout the entire frequency range **α** corresponds to the class E (Fig. 7, Table 1). Sound absorption coefficients of the B and D NWM samples for this frequency band only partly correspond to the class E. In the frequency band from 1250 to 2500 Hz, the sound absorption capacity of the sample A improves, over the entire frequency range **α** corresponds to the class D and at the frequency of 3150 Hz even to the class C. The absorption capacity of variants B and D is slightly worse.

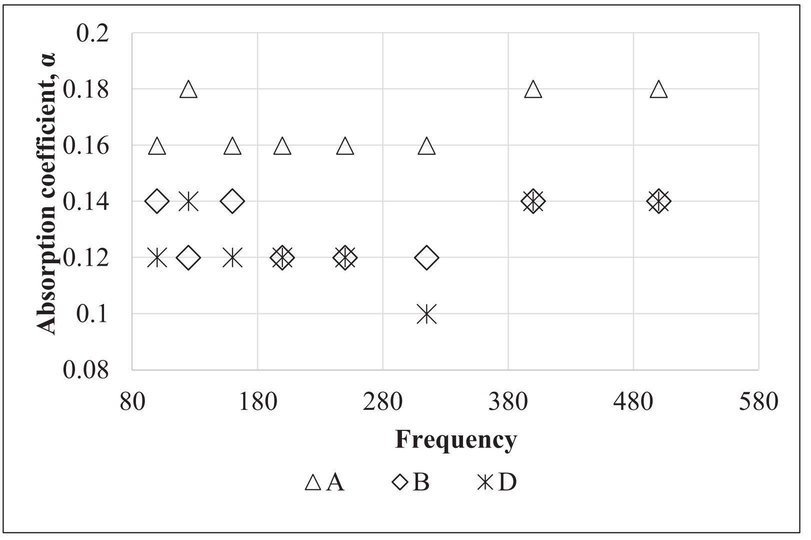

Fig. 7. Absorption coefficients corresponding to the range of low frequencies.

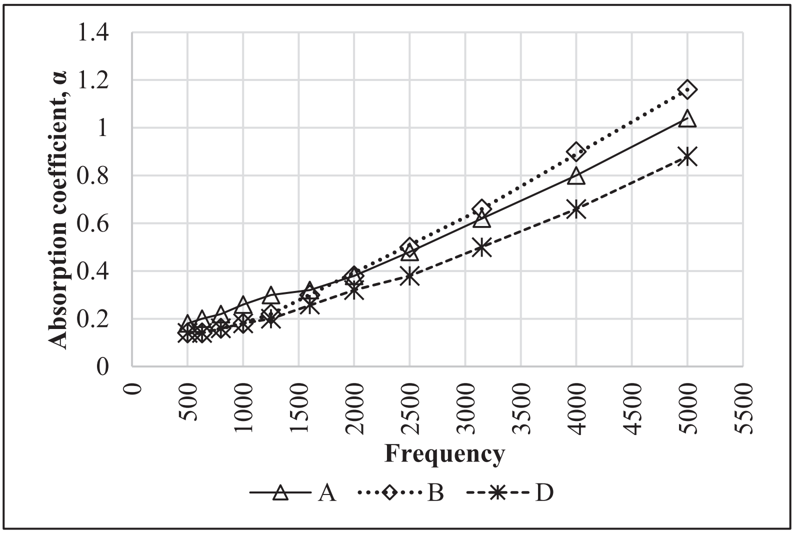

Fig. 8. Absorption coefficients corresponding to the range of middle frequencies.

Absorption coefficient values summarised in Table 1 show that all the test samples depending on frequency correspond to sound absorption classes C, D and E. The material demonstrates the trend that absorption class becomes higher with an increase in the sound frequency.

Table 1

Values of Absorption Coefficients and Sound Transmission Loss

Variant	A		B		D	
Frequencies, Hz	**α**	**STL [dB]**	**α**	**STL [dB]**	**α**	**STL [dB]**
50	0.14	1.20	0.14	1.90	0.14	0.79
63	0.18	1.20	0.18	2.00	0.10	0.76
80	0.22	1.30	0.18	2.10	0.12	0.84
100	0.16	1.40	0.14	2.20	0.12	0.96
125	0.18	1.40	0.12	2.30	0.14	1.10
160	0.16	1.50	0.14	2.40	0.12	1.15
200	0.16	1.50	0.12	2.50	0.12	1.18
250	0.16	1.50	0.12	2.50	0.12	1.25
315	0.16	1.50	0.12	2.50	0.10	1.31
400	0.18	1.60	0.14	2.60	0.14	1.36
500	0.18	1.70	0.14	2.60	0.14	1.43
630	0.20	1.70	0.14	2.70	0.14	1.51
800	0.22	1.80	0.16	2.80	0.16	1.57
1000	0.26	1.70	0.18	2.80	0.18	1.58
1250	0.30	1.80	0.22	2.80	0.20	1.63
1600	0.32	2.00	0.30	2.90	0.26	1.75
2000	0.38	2.10	0.38	3.10	0.32	1.86
2500	0.48	2.20	0.50	3.20	0.38	1.97
3150	0.62	2.40	0.66	3.30	0.50	2.10
4000	0.80	2.50	0.90	3.50	0.66	2.25
5000	1.04	2.80	1.16	3.90	0.88	2.52

Absorption Class α-value

A 0.90; 0.95; 1.00

B 0.80; 0.85

C 0.60; 0.65; 0.70; 0.75

D 0.30; 0.35; 0.40; 0.45; 0.50; 0.55

E 0.15; 0.20; 0.25

not classified 0.00; 0.05; 0.10

Not classified

E

D

C

The American standard ASTM 423 provides similar test criteria to EN ISO 354 as well as provides a method for calculating Noise Reduction Coefficient (NRC) using the following equation that gives a single figure result:

$$NRC = (\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000})/4 \quad (2)$$

Table 2

Values of Noise Reduction Coefficient of Non-woven Variants

	α_{250}	α_{500}	α_{1000}	α_{2000}	NRC
A	0.16	0.18	0.26	0.38	**0.25**
B	0.12	0.14	0.18	0.38	**0.21**
D	0.12	0.14	0.18	0.32	

According to the estimated NRC values in Table 2, the Sample A demonstrates the best sound absorption of all the three samples in the frequency range from 250 to 2000 Hz. The sound absorption performance can be increased by increasing the structure thickness of sample A.

Sound transmission loss characterises the material capacity to reduce undesirable sound penetration – the higher the STL, the better a material reduces sound. In the frequency range from 50 to 5000 Hz, STL varies from 0.76 (Sample D at 63 Hz) to 3.90 (Sample B at 5000 Hz) dB (see Table 1). Figure 8 shows a tendency of STL to increase with an increase in sound frequency for all samples. STL Sample B has the highest values, which could be expected considering greater surface density of the sample. In order to additionally increase the STL in the range of low frequencies, the surface density of the material has to be increased. The porous structure of hemp PLA non-wovens is suitable for sound absorption and upon laminating the PLA located at the outer sides of the material both the STL and dimensional stability of the material would increase.

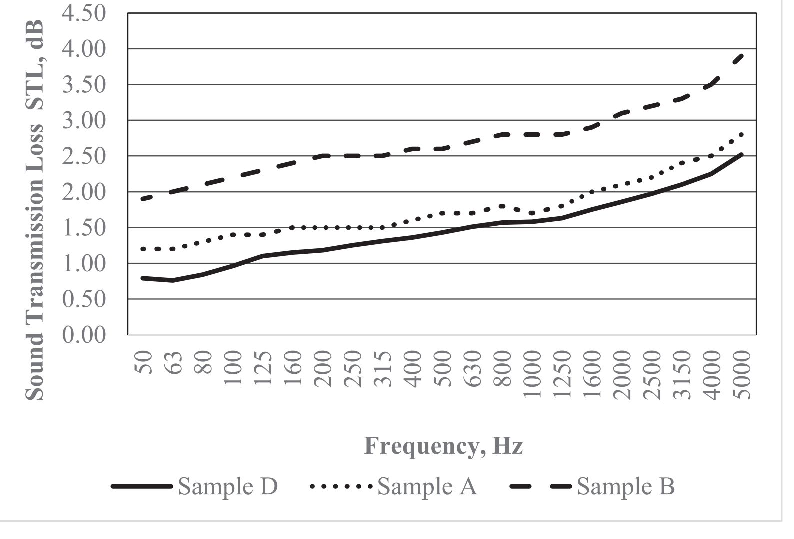

Fig. 9. Sound transmission loss corresponding to the tested range of frequencies.

4. CONCLUSIONS

The multilayer structure of the material contributes to sound wave propagation attenuation in the material. The mechanical needle-punching method used in the manufacture of the non-woven material provides air pockets in the material structure acting as a contributing factor to the soundproofing capacity of the material.

Upon determining the acoustic properties of hemp PLA non-woven material when comparing the frequency ranges where the material demonstrates the best performance of the measured and calculated parameters, 50–2000 Hz has been found to be the frequency range that best characterises the NWM acoustic performance. According to the obtained data, the sample A demonstrates the greatest porosity because it has the highest sound absorption coefficient in the range of low frequencies, the second highest absorption coefficient is in the remaining range of test frequencies. Low frequency sounds have long wave lengths. Because of wave length, low frequency sounds pass through material much easier than high frequency sounds. To improve better sound absorption of material at low frequencies without increasing the thickness of the material, film (from aluminium polyester or analogue material) layer of one side of the material is considered. Placing a film layer to the direction of sound, the film will act as a spring-mass resonator for the low frequency peak. It should be taken into account that increasing the sound absorption of the material by the film layer, absorption decreases at high frequencies. In order to increase STL in the range of low frequencies and in general, either the outer sides of the material should be additionally reinforced or the existing PLA webs should be processed thermally.

The hemp PLA non-woven material tested during the research, according to its sound absorption coefficient range in 1/3 octave frequency band, is close to such materials used in building construction as a cut pile carpet (fringe length from 3.13 to 6.25 mm) and a carpet with a combined cut pile (fringe length 4.69 mm) – foam structure [21].

The fibres used in the manufacture of the non-woven material are obtained from renewable resources. The results obtained for the acoustic properties of the hemp/PLA non-woven material justify the use of the fibres and the method of manufacture of the material.

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NEAUSTIE SKAŅAS IZOLĀCIJAS MATERIĀLI

D. Belakova, A. Seile, S. Kukle, T. Plamus

K o p s a v i l k u m s

Pētījumā analizēta kaņepju (40 wt%) un polilaktīda (60 wt%) neaustā materiāla virsmas blīvuma, biezuma un šķiedru klājuma kārtu skaita ietekme uz skaņas absorbcijas koeficientu un skaņas pārvades zudumiem frekvenču amplitūdā no 50 – 5000 Hz. Noteiktas eksperimentālo paraugu skaņas izolācijas īpašības, salīdzinātas ar praksē lietotajām, definēts iespējamais materiālu lietojums. Neaustie materiāli ir ideāli piemēroti lietošanai akustiskās izolācijas produktos, jo šķiedru kārtojums rada porainu materiāla struktūru, kas rada lielāku mijiedarbību starp skaņas vilni un šķiedru struktūru. Lielāks virsmas blīvums nodrošina lielāku skaņas izolāciju. No visiem pārbaudītajiem paraugiem (A, B un D), visaugstākais virsmas blīvums ir paraugam B un ir 1.22 reizes lielāks par parauga A un 1.15 reizes par parauga D virsmas blīvumu. Saliekot neausto materiālu vienu virs otra 2 kārtās – iespējams palielināt materiāla absorbcijas koeficientu, kas atkarībā no frekvences, atbilst C, D un E akustikas klasēm. No visiem trim neausto materiālu paraugiem, paraugam A ir novērtēta vislabākā skaņas absorbcija frekvenču diapazonā no 250 līdz 2000 Hz. Frekvenču amplitūdā no 50 līdz 5000 Hz skaņas pārvades zudumi variē no 0.76 (paraugs D pie 63 Hz) līdz 3.90 (paraugs B pie 5000 Hz).

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