[1.]Miroslav BADIDA, [2.]Anna BADIDOVÁ, [3.]Tibor DZURO, [4.]Lýdia SOBOTOVÁ

ACOUSTIC PROPERTIES OF SANDWICH ABSORBERS MADE ON THE BASIS OF COMPONENTS FROM VEHICLES AFTER THEIR LIFETIME

[1,2,3,4.]Technical University of Košice, Faculty of Mechanical Engineering, Department of Process and Environmental Engineering, Park Komenského 5, 042 00, Košice, SLOVAKIA

Abstract: In spite of existing European and national legislation aimed at noise abatement, public interest and concern about noise are high. The EU Directive 70/157/EEC [4] for setting and controlling environmental noise is aimed at creating less noisy and more pleasant environment for European residents within "Sustainable Development in Europe". The authors are presenting a methodology for measuring selected acoustic descriptors (sound absorption coefficient and sound transmission loss) for acoustic materials, which are currently in process of development. Emphasis is put on sandwich structures of absorbers. Verification results of the proposed methodology are presented.
Keywords: sound absorption coefficient, sound transmission loss, absorber, sandwich absorber

1. INTRODUCTION
The man in the environment is exposed of a multi-physics factors (as noise [3, 6], vibrations [5], non - ionizing radiation [10, 18], light [2, 4], thermo – humidity microclimate [8, 9] and chemical factors (as solid aerosols [7, 19, 20]). The noise is a factor that effects on large percentage of the population of the planet Earth. In spite of existing European and national legislation, aimed at noise abatement, public interest and concern about noise are high. Directive of EU 70/157/EEC [13] for setting and controlling environmental noise is aimed at creating less noisy and more pleasant environment for European residents within "Sustainable Development in Europe". Harmful effects of environmental noise are various and they can be produced in various ways. They can be categorized into three main categories: effects influencing health, impacts on quality of life and financial implications on affected persons. In the European Union, about 80 million persons are exposed to high noise levels, which are unacceptable or result in sleep disorders and other undesirable influences. There are approximately 170 million people living in the so-called "grey regions", where noise is very annoying. Transportation causes the main problem in the sphere of noise. In Europe, the first limits of protection against noise were specified for transportation. In this respect, the most important directive is 70/157/EEC [13], limiting noise for vehicles. The EU has only recently started to regulate noise emissions from railway transportation (2002). Limits for air transport are specified mainly at international levels ICAO (International Civil Aviation Organization). Noise protection measures for reducing the effect of noise caused by transportation (road, railway and air transport) can be passive and active. Active measures try to prevent the origination of noise, while passive measures are adopted only then, when noise arises. Passive noise protection measures can be divided into two groups, namely: measures preventing acoustic noise propagation (noise barriers and/or walls, noise protection embankments and the like) [11]. Attention is paid to the design process and materials used for construction of noise walls and to their properties. The authors have focused their attention on the research of new acoustic materials made on the basis of recycled raw materials and applicable for the structures of sandwich absorbers (two-layer and multiple-layer absorbers). The paper presents a proposed methodology for measuring selected acoustic descriptors (the sound absorption coefficient α and the sound transmission loss TL) [1, 14].

2. PROPOSAL OF METHODOLOGY MEASURING SELECTED ACOUSTIC DESCRIPTORS OF ACOUSTIC MATERIALS, WHICH ARE CURRENTLY IN PROCESS OF DEVELOPMENT
Out of several possible acoustic descriptors, the authors have focused their attention on the two following descriptors:
- ≡ sound absorption coefficient (α),
- ≡ transmission loss (TL).

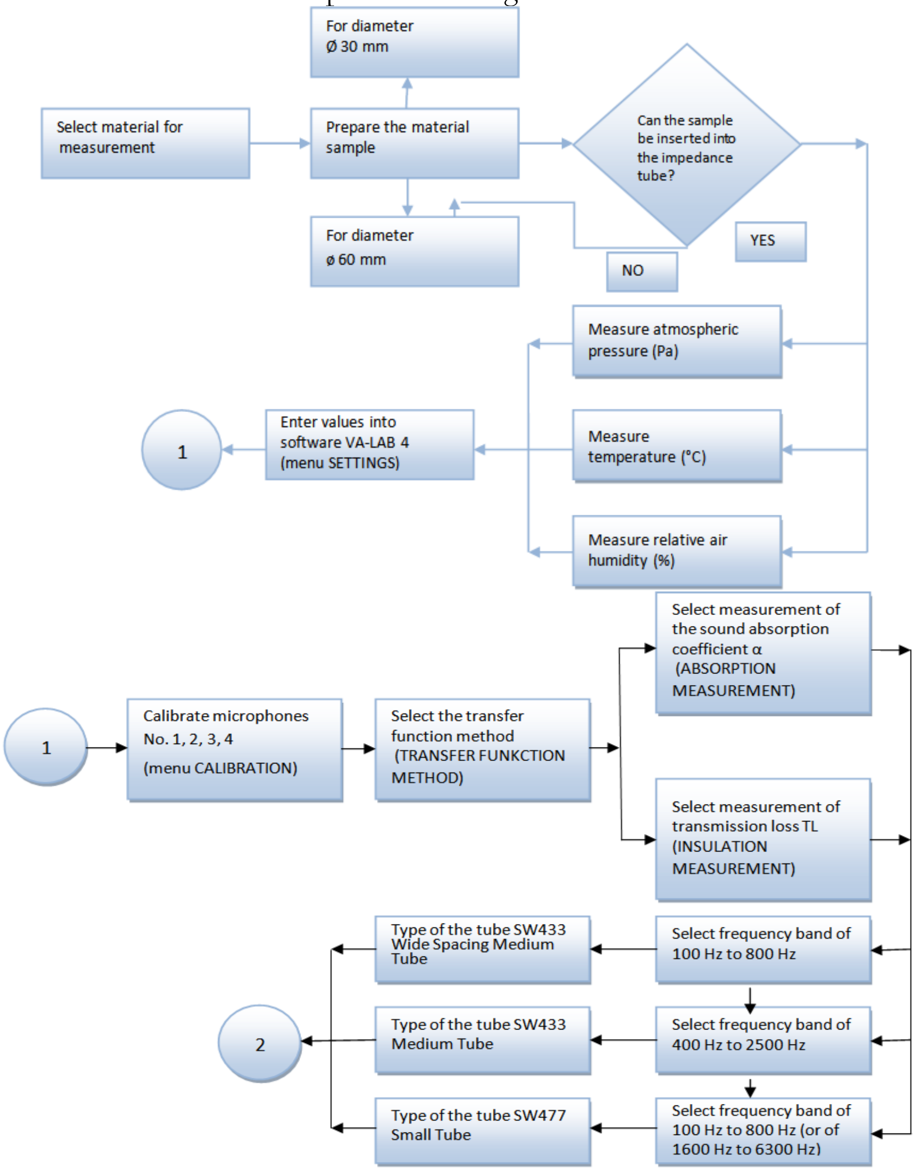
For measuring the sound absorption coefficient (α) and the transmission loss (TL) there are two theoretically available methods, namely: the method of standing wave ratio and the method of transfer function. The authors have used in their work the method of transfer function. This method can be used for measuring the sound absorption coefficient, the reflection factor, the normal impedance and the normal admittance. Based on this method is the impedance tube (Figure 1).

Figure 1. View of the impedance tube

The proposed methodology of measurement includes the use of the impedance tube, two positions of positioning the microphones and the system of numerical frequency analysis for determining the sound absorption coefficient of sound absorbers for normal incidence of sound. It can also be applied for determining acoustic surface impedance or acoustic surface admittance for sound absorbing materials, due to the fact that the impedance ratios of sound absorbing materials are proportional to their physical properties, such as airflow resistance, porosity, elasticity and density.

This test method is similar to the test method specified in ISO 10534-1 [12] in terms of using an impedance tube with a sound source connected to one of its ends and a test specimen mounted into the tube at its other end. However, the actual test method is different. In this test method the plane waves are generated in the tube by the sound source and the decomposition of the interference field is achieved by measuring acoustic pressures in two fixed positions of microphones mounted on the wall of the tube or by a microphone shifted in the tube and the subsequent calculation of the complex acoustic transfer function, by absorption at normal incidence and by impedance ratios of the acoustic material. This test method is designated to provide an alternative method of measurement, in general much faster than that included in ISO 10534-1 [12].

The proposal of methodology for measuring selected acoustic descriptors by using an impedance tube and by applying the method of transfer function is presented in Figure 2.



Methodology for measuring selected acoustic descriptors

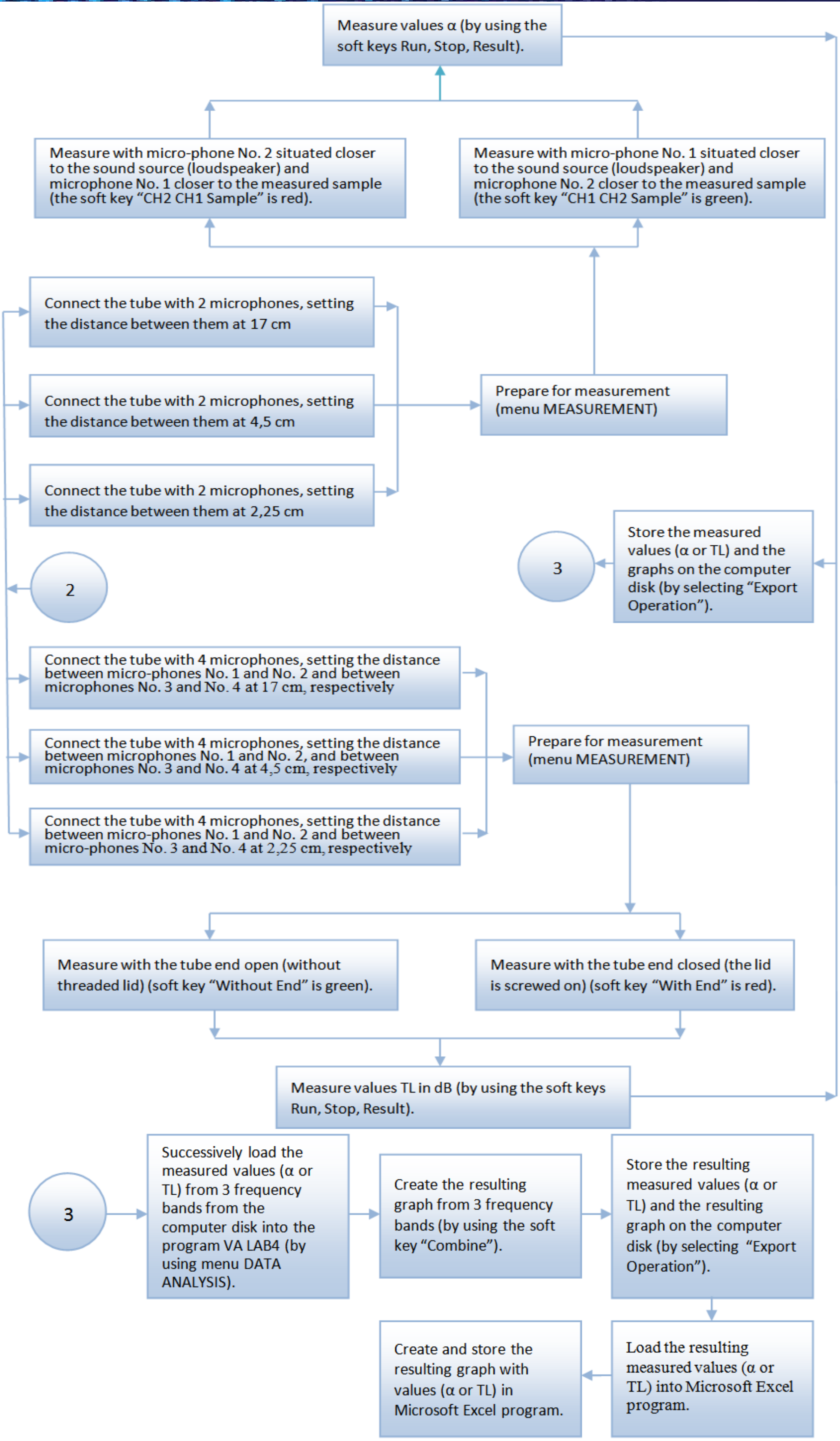


Figure 2. Methodology for measuring selected acoustic descriptors

3. FORMULAS USED FOR MATERIAL SPECIMENS MEASURING IN IMPEDANCE TUBE

— Determination of the sound velocity, wavelength and characteristic impedance

Before starting a measurement, the velocity of sound, c_0, in the tube shall be determined, after which the wavelengths at the frequencies of the measurements shall be calculated.

The velocity of sound can be assessed accurately with knowledge of the tube air temperature from equation (1) [21]:

$$c_0 = 343{,}2\sqrt{T/293} \quad \text{m/s} \tag{1}$$

where: T is temperature, in kelvin.
The wavelength the follows from:

$$\lambda_0 = c_0 / f \tag{2}$$

The density of the air, ρ, can be calculated from:

$$\rho = \rho_0 \frac{p_a T_0}{p_0 T} \tag{3}$$

where: T is the temperature, in kelvin; p_a is the atmospheric pressure, in kilopascals; T_0 = 293 K, p_0 = 101,325 kPa, ρ_0 = 1,186 kg/m^3.
The characteristic impedance of the air is the product ρc_0.

— **Determination of the reflection factor**

$$r = |r|e^{j\phi_r} = r_r + jr_i = \frac{H_{12} - H_I}{H_R - H_{12}} e^{2jk_0 x_1} \tag{4}$$

where: r_r is the real component; r_i - the imaginary component, x_1 - the distance between the sample and the further microphone location, ϕ_r - the phase angle of the normal incidence reflection factor, H_I and H_R are defined in annex D in ISO 10534-2 [21].

— **Determination of the transfer function**

$$H_{12} = \left[\frac{S_{12}}{S_{11}} \cdot \frac{S_{22}}{S_{21}}\right]^{1/2} = H_r + jH_i \tag{5}$$

where: H_r is the real part of H_{12}, H_i - the imaginary part of H_{12}.

— **Determination of the sound absorption coefficient**

$$\alpha = 1 - |r|^2 = 1 - r_r^2 - r_i^2 \tag{6}$$

— **Determination of the specific acoustic impedance ratio**

$$Z/\rho c_0 = R/\rho c_0 + jX/\rho c_0 = (1+r)/(1-r) \tag{7}$$

where: R is the real component, X - the imaginary component, ρc_0 - the characteristic impedance.

— **Determination of the specific acoustic admittance ratio**

$$G\rho c_0 = g\rho c_0 - jb\rho c_0 = \rho c_0 / Z \tag{8}$$

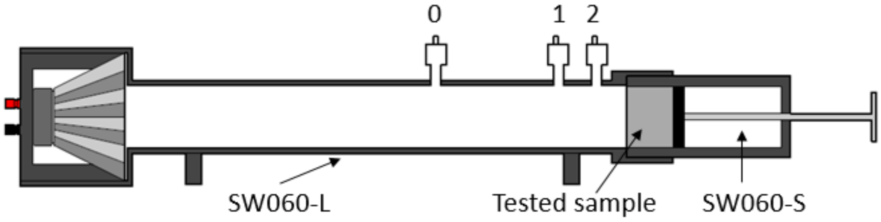
where: g is the real component, b - the imaginary component.

4. VERIFICATION OF THE PROPOSED METHODOLOGY FOR MEASURING ACOUSTIC DESCRIPTORS FOR ACOUSTIC MATERIALS, WHICH ARE CURENTLY IN PROCESS OF DEVELOPMENT

The proposed methodology of measurement was verified by measuring selected acoustic descriptors, namely: the sound absorption coefficient (α) and the transmission loss (TL) for the materials, which are currently in process of development.

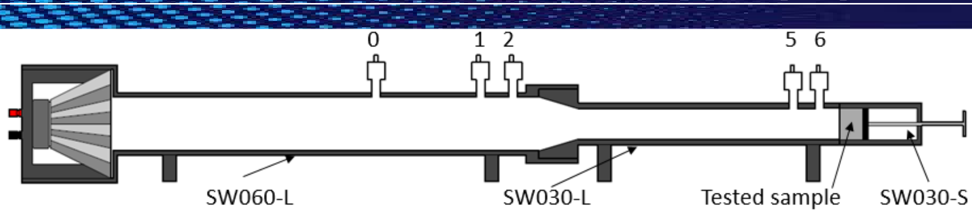
— **Instruments, software and other equipment**

The system for measuring sound absorption coefficient (α) (for the frequency bands of 100 Hz to 800 Hz and 400 Hz to 2500 Hz, respectively) is shown in Figure 3. It is comprised of a tube with inner diameter of 60 mm – SW060-L and of a holder of the tested sample with inner diameter of 60 mm – SW060-S.



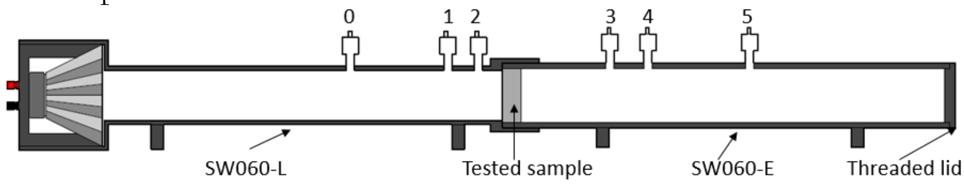
Legend: 0, 1, 2 – mounting sockets for microphones
Figure 3. The system for measuring sound absorption coefficient (100 Hz to 800 Hz and 400 Hz to 2500 Hz, respectively)

The system for measuring sound absorption coefficient (α) (for the frequency bands of 800 Hz to 6300 Hz) is shown in Figure 4. It is comprised of a tube with inner diameter of 60 mm – SW060-L, of a tube with inner diameter of 30 mm – SW030-L and of a holder of the tested sample with inner diameter of 30 mm – SW030-S.



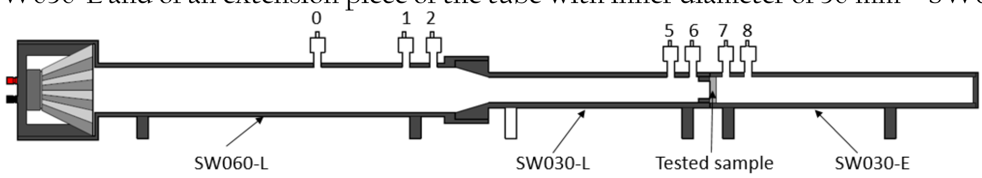
Legend: 0, 1, 2, 5, 6 – mounting sockets for microphones
Figure 4. The system for measuring sound absorption coefficient (800 Hz to 6300 Hz)

The system for measuring transmission loss (TL) (for the frequency bands of 100 Hz to 800 Hz and 400 Hz to 2500 Hz, respectively) is shown in Figure 5. It is comprised of a tube with inner diameter of 60 mm – SW060-L and of an extension piece of the tube with inner diameter of 60 mm – SW060-E.



Legend: 0, 1, 2, 3, 4, 5 – mounting sockets for microphones
Figure 5. The system for measuring transmission loss TL (100 Hz to 800 Hz and 400 Hz to 2500 Hz, respectively)

The system for measuring transmission loss (TL) (for the frequency bands of 1600 Hz to 6300 Hz) is shown in Figure 6. It is comprised of a tube with inner diameter of 60 mm – SW060-L, of a tube with inner diameter of 30 mm – SW030-L and of an extension piece of the tube with inner diameter of 30 mm – SW030-E.



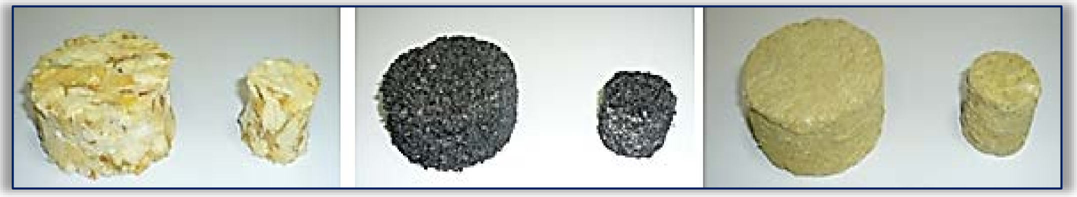
Legend: 0, 1, 2, 5, 6, 7, 8 – mounting sockets for microphones
Figure 6. The system for measuring transmission loss TL (1600 Hz to 6300 Hz)

— **Selection of materials for the experimental part**

The selected acoustic descriptors (the sound absorption coefficient α, the transmission loss TL) were measured for the following acoustic materials, which are currently in process of development:

- Ekomolitan (Figure 7 a),
- Recycled rubber (Figure 7 b).

Measurement were also carried out, for comparison, for the material Nobasil (Figure 7 c), which is a component part of various sandwich structures of noise walls (barriers).



a) Ekomolitan b) Recycled rubber c) Nobasil
Figure 7. Test samples

— **Preparation of test samples**

The test samples of the two-layer sandwich absorbers were prepared in various combinations of materials, such as Ekomolitan, Nobasil and recycled rubber (Figure 8 and Figure 9).

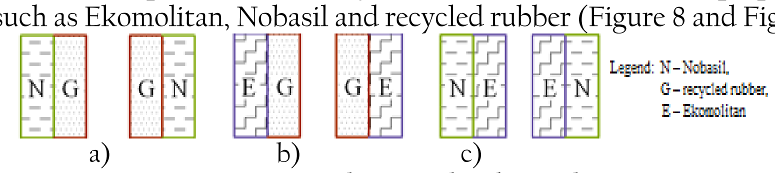


Figure 8. Two-layer sandwich samples

Dimensions of the test sample in figure 9 are presented.

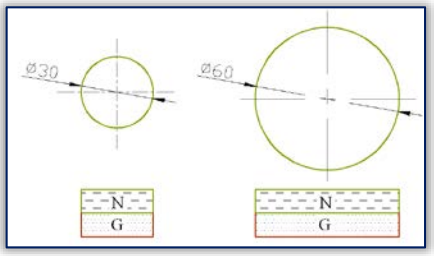


Figure 9. Dimensions of the two-layer test sample

— **The measured values of the sound absorption coefficient and of the transmission loss**

This part of the paper presents outputs from the measurement of the sound absorption coefficient carried out for a two-layer sandwich test sample composed of 2 cm thick recycled rubber positioned closer to the sound source and of 2 cm thick Ekomolitan positioned at the end (Figure 10 - Figure 13), as well as outputs from the measurement of transmission loss for a two-layer sandwich having the same material composition (Figure 14 - Figure 17) [1].

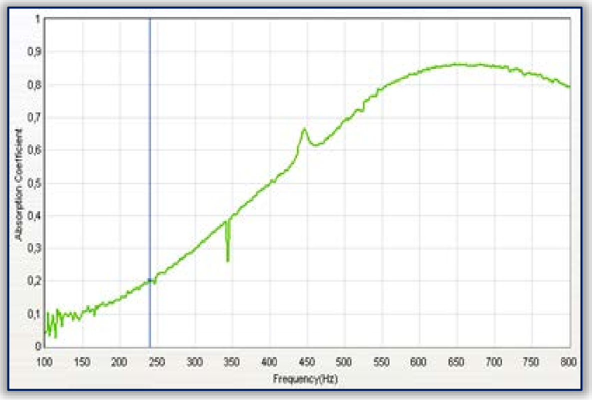


Figure 10. Display of the sound absorption coefficient for a two-layer material, composed of 2 cm thick recycled rubber positioned closer to the sound source and of 2 cm thick Ekomolitan positioned at the end in the frequency range of 100 to 800 Hz

Figure 11. Display of the sound absorption coefficient for a two-layer material, composed of 2 cm thick recycled rubber positioned closer to the sound source and of 2 cm thick Ekomolitan positioned at the end in the frequency range of 400 to 2500 Hz

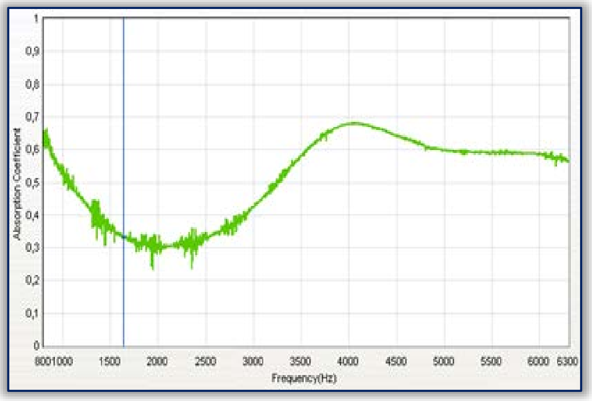


Figure 12. Display of the sound absorption coefficient for a two-layer material, composed of 2 cm thick recycled rubber positioned closer to the sound source and of 2 cm thick Ekomolitan positioned at the end in the frequency range of 800 to 6300 Hz

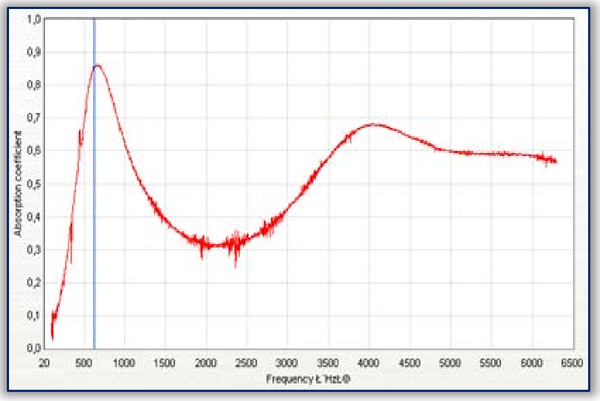


Figure 13. Display of the sound absorption coefficient for a two-layer material, composed of 2 cm thick recycled rubber positioned closer to the sound source and of 2 cm thick Ekomolitan positioned at the end in the resultant frequency range of 100 to 6300 Hz

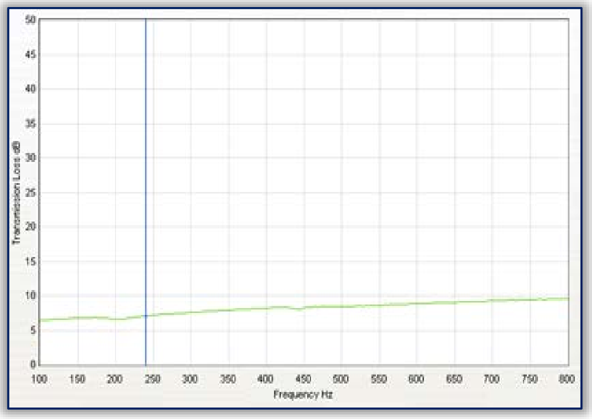


Figure 14. Display of the transmission loss for a two-layer material, composed of 2 cm thick recycled rubber positioned closer to the sound source and of 2 cm thick Ekomolitan positioned at the end in the frequency range of 100 to 800 Hz

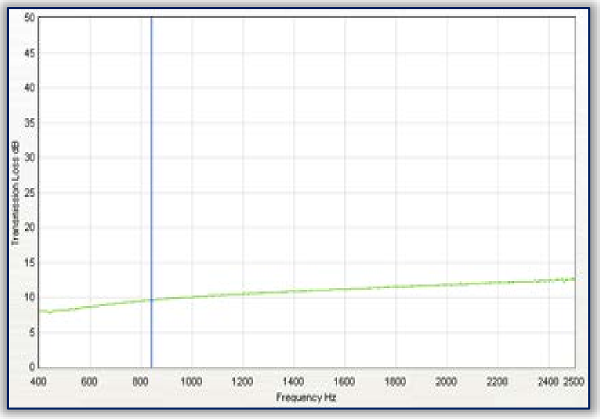


Figure 15. Display of the transmission loss for a two-layer material, composed of 2 cm thick recycled rubber positioned closer to the sound source and of 2 cm thick Ekomolitan positioned at the end in the frequency range of 400 to 2500 Hz

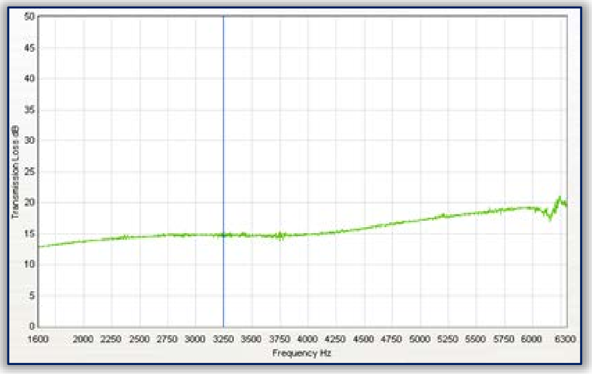


Figure 16. Display of the transmission loss for a two-layer material, composed of 2 cm thick recycled rubber positioned closer to the sound source and of 2 cm thick Ekomolitan positioned at the end in the frequency range of 1600 to 6300 Hz

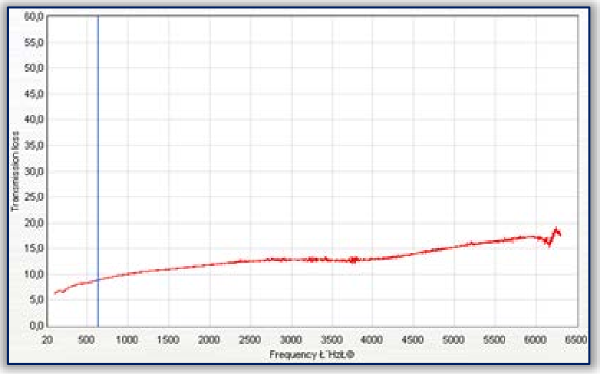


Figure 17. Display of the transmission loss for a two-layer material, composed of 2 cm thick recycled rubber positioned closer to the sound source and of 2 cm thick Ekomolitan positioned at the end in the resultant frequency range of 100 to 6300 Hz

5. CONCLUSION – EVALUTION OF MEASURED VALUES

The sound absorption coefficient (α) is a dimensionless number varying from 0 to 1. The closer is the measured value to 1 or is equal to 1, the sample of the measured absorber, and thus the absorber itself, will have a better (higher) sound absorption.

We have also measured the transmission loss (TL). It is a value in dB, based on the ratio of the sound wave incident at the front side of the acoustically absorbing material to the sound waves transmitted from the rear side. TL represents the sound damping properties of the material, i.e. the higher that value is, the more efficient is the damping of the sound.

The authors have measured the coefficient of sound absorption (α) and the transmission loss (TL) for various combinations of two-layer sandwich absorbers composed of materials such as Ekomolitan, recycled rubber and Nobasil. Table 1 includes the measured values of descriptors.

The frequency spectrum of noise caused by transportation reaches its maximum in the frequency range of 500 Hz to 1500 Hz, and the most intensive noise is caused at the frequency of 1000 Hz.

Noise walls (barriers) are often constructed as noise panels with a supporting frame using sandwich absorbers. For the purpose of the thesis, samples representing a sandwich composed of materials such as recycled rubber, Nobasil and Ekomolitan were made. The arrangement of individual layers of the sandwich was different. Measurements have been carried out for two-layer sandwiches. (Figure 18 and Figure 19).

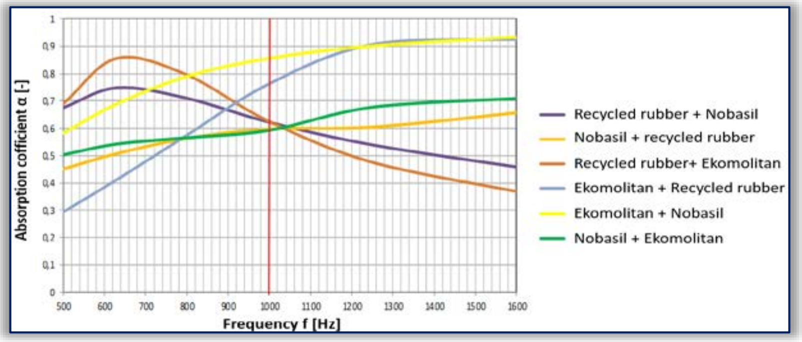


Figure 18. Sound absorption coefficient of two-layer sandwiches (total thickness of the sandwiches: 4 cm

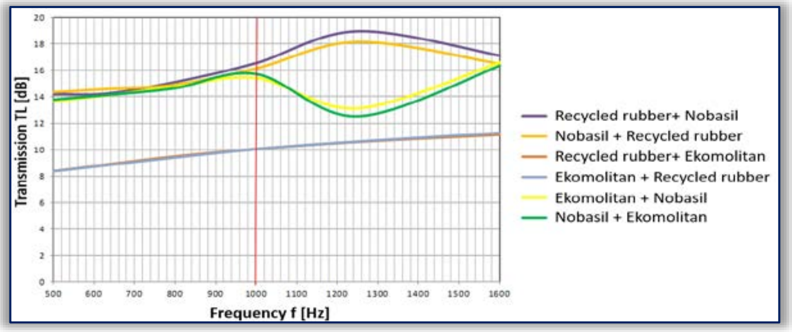


Figure 19. Transmission loss of two-layer sandwich absorbers (total thickness of the sandwiches: 4 cm)

Table 1. The values of the absorption coefficient and transmission loss for materials with thickness of 4 cm

	Absorption coefficient α [-]						Transmission loss TL [dB]					
Frequency f [Hz]	Recycled rubber + Nobasil	Nobasil + Recycled rubber	Recycl. rubber + Ekomolitan	Ekomolitan + Recycl. rubber	Ekomolitan + Nobasil	Nobasil + Ekomolitan	Recycled rubber + Nobasil	Nobasil + Recycl. rubber	Recycl. rubber + Ekomolitan	Ekomolitan + Recycl. rubber	Ekomolitan + Nobasil	Nobasil + Ekomolitan
100	0,022	0,100	0,042	0,060	0,044	0,121	13,822	13,911	6,391	6,442	13,144	13,170
125	0,095	0,109	0,096	0,065	0,109	0,153	13,685	13,902	6,588	6,586	13,137	13,277
160	0,135	0,136	0,107	0,078	0,130	0,232	13,703	13,881	6,806	6,806	13,200	13,289
200	0,206	0,193	0,144	0,097	0,180	0,290	13,733	13,922	6,604	7,091	13,259	13,371
250	0,295	0,246	0,221	0,120	0,247	0,345	13,782	14,000	7,170	7,384	13,402	13,171
315	0,425	0,311	0,330	0,159	0,318	0,404	13,858	14,106	7,680	7,264	13,143	13,300
400	0,571	0,382	0,497	0,216	0,457	0,461	14,035	14,261	8,184	8,057	13,413	13,600
500	0,675	0,451	0,689	0,294	0,582	0,503	14,202	14,323	8,375	8,387	13,660	13,789
630	0,747	0,507	0,855	0,412	0,689	0,542	14,239	14,559	8,869	8,831	14,095	14,137
800	0,709	0,562	0,794	0,574	0,789	0,565	15,101	14,882	9,497	9,412	14,751	14,659
1000	0,622	0,596	0,623	0,762	0,855	0,592	16,537	16,126	10,057	10,044	15,410	15,726
1250	0,540	0,603	0,474	0,905	0,900	0,677	18,928	18,146	10,599	10,616	13,146	12,540
1600	0,460	0,655	0,367	0,924	0,932	0,709	17,095	16,483	11,146	11,260	16,576	16,346
2000	0,406	0,718	0,314	0,870	0,944	0,685	20,952	20,038	11,840	11,957	18,131	17,675
2500	0,381	0,722	0,327	0,933	0,969	0,709	27,005	23,036	12,547	12,838	20,360	20,291
3150	0,456	0,747	0,465	0,999	0,958	0,779	19,843	23,555	12,794	12,676	23,451	23,243
4000	0,598	0,792	0,679	0,949	0,935	0,810	23,324	26,717	12,936	13,143	26,127	26,120
5000	0,650	0,827	0,599	0,906	0,929	0,838	28,611	29,171	15,241	15,374	28,525	28,062
6300	0,632	0,858	0,564	0,940	0,955	0,862	28,947	30,473	17,970	17,585	30,782	32,385

It follows from the measured values of the sound absorption coefficient of the sandwich absorbers that the sequence of individual layers (of utilized materials) is of crucial importance. The sequence of the sandwich layers of the measured materials, starting from the noise source (for the frequency of 1000 Hz), is recommended as follows:

- ≡ Ekomolitan + Nobasil,
- ≡ Ekomolitan + recycled rubber,
- ≡ Recycled rubber + Nobasil.

It can be stated on the basis of the measured values of transmission loss of the sandwich absorbers (Figure 13), that the sequence of individual layers of materials utilized in the sandwich is also of crucial importance. The sequence of the sandwich layers of the measured materials utilized for two-layer sandwiches, starting from the noise source, is recommended as follows:

- ≡ Recycled rubber + Nobasil,
- ≡ Recycled rubber + Ekomolitan,
- ≡ Nobasil + Ekomolitan.

Acknowledgement
This paper has been prepared on the basis of the research project KEGA 045TUKE-4/2018.

References

[1] Badida, M. – Lumnitzer, E. – Bartko, L. (2011) Posibilities of traffic noise decreasing. Košice: Elfa, 303 p.
[2] Badida, M. – Králiková, R. – Lumnitzer, E. (2011) Modeling and the Use of simulation methods for the design of lighting systems. Acta Polytechnica Hungarica. Volume 8 (2), pp. 91-102.
[3] Lumnitzer, E. – Badida, M. – Biľová, M. (2011) Porous sound absorbers and determination of their acoustical properties, Acta Mechanica Slovaca, Volume 15 (2), pp. 28-33.
[4] Badida, M. – Králiková, R. – Kevická, K. (2012) Theoretical basis and application possibility of radiosity methods for lighting researches. Acta Mechanica Slovaca, Volume 16 (1), pp. 6-17.
[5] Moravec, M. – Badida, M. – Lukáčová, K. (2012) Vibrations assessment in the car interior. In.: Proceedings of SGEM, Albena, Bulgaria, pp. 1047-1051.
[6] Badida, M. – Bartko, L. – Džoganová, Z. – Králiková, R. – Hricová, B. (2012) Sandwich absorbers and their acoustic properties. In: Proceedings of DAAM Symposium, Zadar, Croatia, pp. 0811-0814.
[7] Badida, M. – Lumnitzer, E. – Lukáčová, K. – Szabó, R. (2010) Solid aerosols, Elfa s.r.o., Košice, 94 p.
[8] Kralikova, R. – Wessely, E. (2007) Evalution of thermo humidity microclimate in hot working environment. In: Proceedings of DAAM Symposium, Vienna, Austria, 2 p.

[9] Andrejiová, M. – Králiková, R. – Wessely, E. – Sokolová, H. (2012) Assesment of the microclimate in the work environment. In: Proceedings of DAAM International Book. Vol. 11 (2), pp. 509-516.

[10] Kačírová, E. – Anna, V. – Frimer, R. (2007) Measurement of local non-ionizing sources in working environment. In: Bezpečnosť - Kvalita - Spoľahlivosť. – Košice, TU, pp. 13-17.

[11] Neubergová, K. (2005) Ecological aspects of traffic. Praha: ČVUT, 163 p.

[12] ISO 10534-1: (1996), Acoustics. Determination of sound absorption coefficient and impedance in impedance tubes. Part 1: Method using standing wave ratio.

[13] EU council directive of 6 February (1970) on the approximation of member states enactments about allowable noise level and about motor vehicles exhaust tracts.

[14] Bartko, L. (2011) Selected acoustic properties analysis of developed materials suitable forantinoise walls construction (dissertation thesis), Košice, 252 p.

[15] Badida, M. – Lumnitzer, E. - Fiľo, M. - Biľová, M. (2008) Determination of the uncertainties of noise measurements. In: Annals of the Oradea University: Faculty of management and technological engineering. Vol. 7, pp. 64-72.

[16] Badida, M. – Lumnitzer, E. – Romanová, M. (2006) The application of recycled materials for products that provide noise reduction in living and working environment. In: Acta Acoustica United with Acoustic. Vol. 92. Stuttgart: Hirzel Verlag, p. 108.

[17] Matel, F. – Ochocová, R. – Badida, M. – Lumnitzer, E. (2003) Compact elements made of rubber-making recycled material made by microwave heating technology. Industrial property office of the Slovac Republic, Banská Bystrica, 2003.

[18] Anna, V. – Kačírová, E. – Stavnikovičová, D. (2007) Measurement of local non-ionizing sources in working environment. In: MteM, Cluj-Napoca: MTeM, pp. 31-34.

[19] Lukáčová, K. – Badida, M. – Moravec, M. (2011) Guidance for the assessment of exposure by inhalation to solid aerosols for comparison with limit values. In: Annals of Faculty of Engineering Hunedoara.Vol. 9, pp. 141-144.

[20] Lukáčová, K. – Moravec, M. – Piňosová, M. (2011) Methodology for calculating measured value in the process of objectification employees` exposure to solid aerosols. In: The 2nd International Conference for Development of Environmental Engineering Education - Conference Proceedings: November 9-11, 2011, Herľany, Slovakia. - Košice: elfa, 2011, pp. 101-102.

[21] ISO 10534-2: (1998), Acoustics. Determination of sound absorption coefficient and impedance in impedance tubes. Part 2: Transfer function method.

[22] EN 1793-1: (1997), Road traffic noise reducing devices - Test method for determining the acoustic performance. Part 1: Intrinsic characteristics of sound absorption.

[23] EN 1793-2: (1997), Road traffic noise reducing devices. Test method for determining the acoustic performance. Part 2: Intrinsic characteristics of airborne sound insulation.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665