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Experimental Tests of the Acoustic Properties of Sound-Absorbing Linings and Cores of Layered Baffles

Krzysztof KOSAŁA

Corresponding author: Krzysztof KOSAŁA, email: kosala@agh.edu.pl

AGH University of Science and Technology, al. A. Mickiewicza 30, 30-059 Kraków

Abstract The article presents the results of research on the acoustic properties of materials used as sound-absorbing linings and cores in baffles of anti-noise protection. Using an impedance tube the spectral characteristics of the normal incidence sound absorption and sound transmission loss indices of 12 specimens of mineral wool with different density and thickness were determined. From these characteristics, the single-number weighted sound absorption coefficient α_w and the sound reduction index R_w were calculated. To calculate the value of the R_w index on the basis of surface mass of the mineral wool specimen, a new formula was proposed. The insertion loss of an acoustic enclosure with one, two and three-layer walls with dimensions of 0.7×0.7 m, containing mineral wool, was determined. The best efficiency was achieved for the enclosure made of walls of layers: mineral wool, placed on the sound source side, steel plate and aluminium plate.

Keywords: sound transmission loss, sound absorption coefficient, insertion loss, baffles, mineral wool

1. Introduction

Many types of baffles are used in anti-noise protection, among which a group of homogeneous materials can be distinguished, which can be used, for example, in the form of covers or acoustic barriers, and also a group of baffles composed of layers of materials with different acoustic properties [1]. The selection of materials and their parameters is of significant importance, especially in the construction of layered baffles [2,3]. The sound insulation properties of the panels are tested in sound insulation laboratories. These types of materials, with appropriate stiffness, are resistant to the penetration of sound waves and can be used individually [4]. The sound-absorbing material usually has a porous or fibrous structure and constitutes a layer installed in the source-side baffle or may be the sound-absorbing core in a sandwich baffle. The sound-absorbing properties of such soft materials are tested in laboratories in reverberation chambers or in impedance tubes, where preliminary selection of specimens is performed, especially when assessing the properties of new materials [5]. With the use of an impedance tube, it is also possible to determine the sound insulation of such materials in the form of normal incidence transmission loss. Determining the value of normal incidence transmission loss, which is performed relatively less frequently than the normal incidence sound absorption coefficient for these materials, was the main purpose of the research described in this article. In addition to determining the sound insulating properties, the sound absorption properties of materials were also investigated, as well as their effectiveness in application for acoustic enclosures. The test specimens were made of mineral wool of various thicknesses and densities.

2. Materials and measurement methods

The tests of the acoustic properties of mineral wools were carried out in the laboratory of acoustic properties tests of materials and structures, at the Department of Mechanics and Vibroacoustics of AGH. The test stand was a set enabling the measurement of the normal incidence sound transmission loss and the sound absorption coefficient. The kit included a Mecanum Inc. impedance tube with a loudspeaker, an SMSL SA-36A Pro amplifier, type 378A14 PCB measuring microphones, a Siemens LMS SCADAS Mobile analyzer and a computer with Simcenter Testlab software. The internal diameter of the tube was 34.9 mm, which enabled measurements in two frequency ranges: 50 Hz - 2400 Hz and 119 – 5700, Hz while maintaining the distance between the microphone holders, which was 65 and 29 mm, respectively. The tests were carried out in accordance with the relevant standards: ASTM E2611-19 [6] and ISO 10534-2 [7]. Figure 1 shows an impedance tube prepared for the determination of the sound transmission loss along with measurement specimens, such as mineral wool discs 34.9 mm in diameter, 20, 40 and 50 mm thick and densities 25, 70, 110 and 150 kg/m^3.

Fig. 1. Impedance tube with specimens of mineral wool of thickness 20, 40 and 50 mm and density (from the left): 25, 70, 110 and 150 kg/m^3.

Table 1 presents the material data of the specimens and the values of the single-number weighted sound absorption coefficient α_w and the weighted sound reduction index.

Tab. 1. Material data and acoustic parameters of the tested specimens of mineral wool.

Quantity	Density	Thickness	Surface density	Weighted sound absorption coefficient	Weighted sound reduction index	Weighted sound reduction index (from the formula (1))
Symbol	ρ	h	m	α_w	R_w	R_w'
Unit	kg/m^3	m	kg/m^2	-	dB	dB
Id						
d25 h20	25	0.020	0.5	0.2	2	2
d25 h40	25	0.040	1	0.4	4	4
d25 h50	25	0.050	1.25	0.5	5	5
d70 h20	70	0.020	1.4	0.2	4	5
d70 h40	70	0.040	2.8	0.5	7	9
d70 h50	70	0.050	3.5	0.6	10	11
d110 h20	110	0.020	2.2	0.3	9	7
d110 h40	110	0.040	4.4	0.5	13	13
d110 h50	110	0.050	5.5	0.7	16	17
d150 h20	150	0.020	3	0.3	11	10
d150 h40	150	0.040	6	0.6	19	19
d150 h50	150	0.050	7.5	0.6	25	26

3. Results of experimental tests

Figure 2 shows the spectral characteristics of the normal incidence sound absorption coefficient in the 1/3 octave frequency bands, obtained from the measurements for 12 specimens. It can be seen from the graphs that, as the thickness of the specimens increases, the sound absorption curves shift towards lower frequencies. The maximum values of the sound absorption coefficient close to 1 occur for the higher centre frequencies of the 1/3 octave bands, above 1.25 kHz. Mineral wools with the highest density (ρ = 150 kg/m^3) have a maximum sound absorption coefficient of 0.83, while they absorb lower frequencies better than other wools, which is especially visible for the sample d150 h50 (Fig. 2).

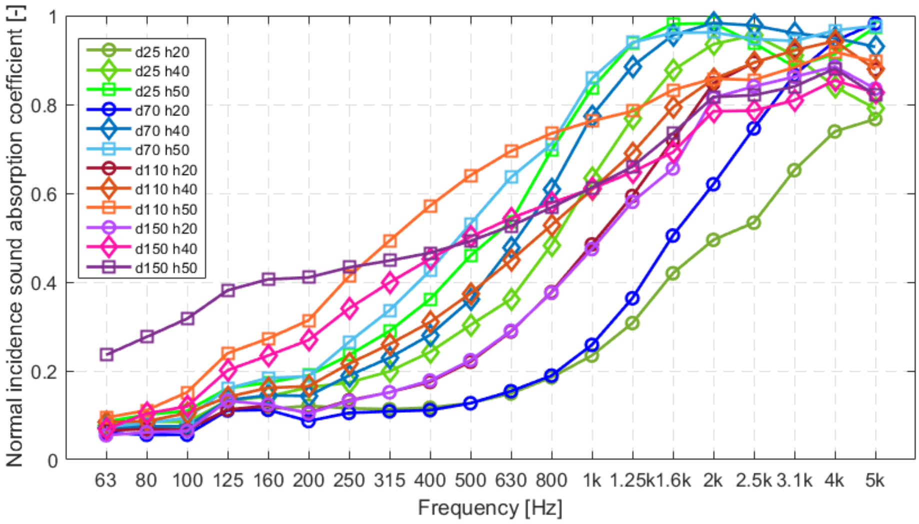

Fig. 2. The spectral characteristics of normal incidence sound absorption coefficient of the 12 mineral wool materials of density 25, 70, 110 and 150 kg/m^3 and thickness 20, 40 and 50 mm.

Figure 3 presents a comparison of the spectral characteristics of normal incidence transmission loss for 12 tested mineral wool specimens in the 1/3 octave frequency bands. It can be seen from Fig. 3 that the sound insulation of mineral wools determined with the use of normal incidence transmission loss increases with the surface mass of the sample *m*, which is the result of multiplying the density ρ and thickness *h* of the specimen.

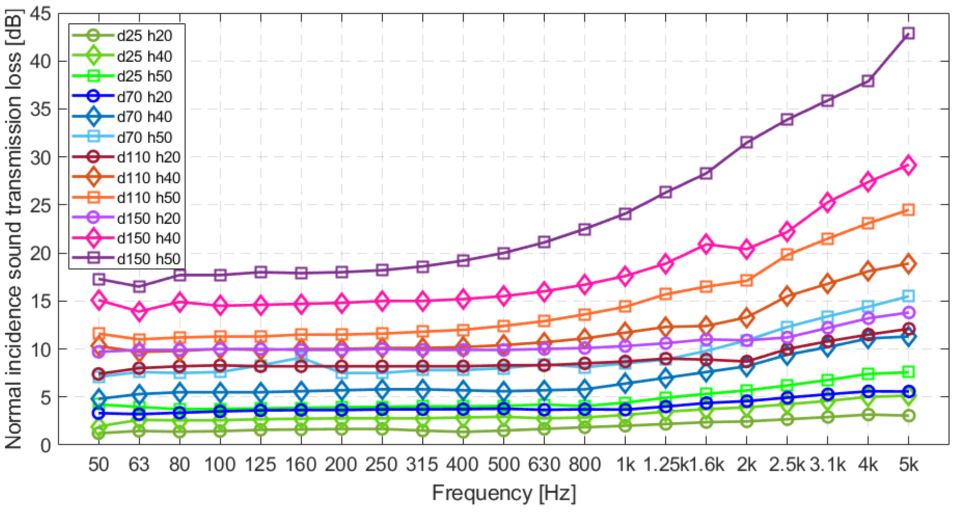

Fig. 3. The spectral characteristics of normal incidence sound transmission loss of mineral wool of density 25, 70, 110 and 150 kg/m^3 and thickness 20, 40 and 50 mm.

From the spectral characteristics (Figs. 2 and 3) single-number values of the α_w and R_w indices were calculated, respectively, as shown in Table 1. The analysis of the results of the weighted sound reduction index R_w calculated for mineral wools of various thickness and density showed that there is a relationship between this index and the surface mass (Fig. 4).

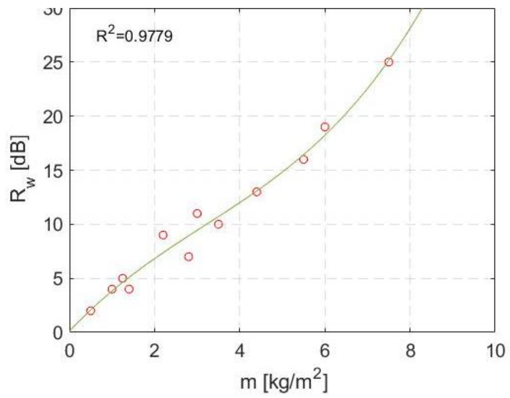

Fig. 4. Weighted sound reduction index R_w vs. the surface mass m for 12 specimens of mineral wool.

The weighted sound reduction index R_w' can be calculated using approximation by a third degree polynomial from the proposed formula:

$$R_w' = 0.054m^3 - 0.51m^2 + 4.2m + 0.12,\ \text{dB} \tag{1}$$

where m is the surface mass of mineral wool, [kg/m^2].

Figure 5 shows the histogram specifying the frequency (in %) of prediction error, i.e. the difference between the weighted sound reduction index measured (calculated from measurements) and predicted (calculated from formula (1)) for 12 specimens of mineral wool.

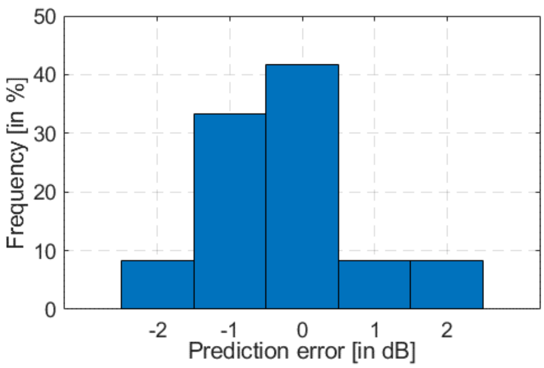

Fig. 5. Histogram of the frequency (in %) of prediction error, i.e. difference between the measured and predicted weighted sound reduction index for 12 specimens of mineral wool.

It can be seen that the use of the proposed formula showed small discrepancies of ±1 dB, for 83% of observations. 42% of observations show no error between the predicted and measured values.

4. Possibility of applying the tested materials to acoustic enclosures

The next stage of testing the acoustic properties of mineral wools was the verification of the insertion loss of an enclosure consisting of five identical walls with dimensions of 0.7 × 0.7 m, the layers of which contained one of the tested mineral wools, i.e., with a thickness of 50 mm and density of 110 kg/m^3 (d110 h50). The tests were carried out in a room with a capacity of 79 m^3 using the survey method to determine the sound power level of a sound source without and with an enclosure, in accordance with PN-EN ISO

3746:2011 [8]. Measurements were carried out for 4 variants of walls with the following layer arrangement: a) mineral wool, b) mineral wool and steel plate (*h*=1 mm), c) steel plate (*h*=1 mm), mineral wool and aluminium plate (*h*=2 mm), and d) mineral wool, steel plate (*h*=1 mm) and aluminum plate (*h*=2 mm). Figure 6 shows an enclosure constructed with the use of a prototype stand for determining the acoustic properties of materials and enclosures [9, 10], for one of the analysed variants - panels of mineral wool (d110 h50).

(a) (b)

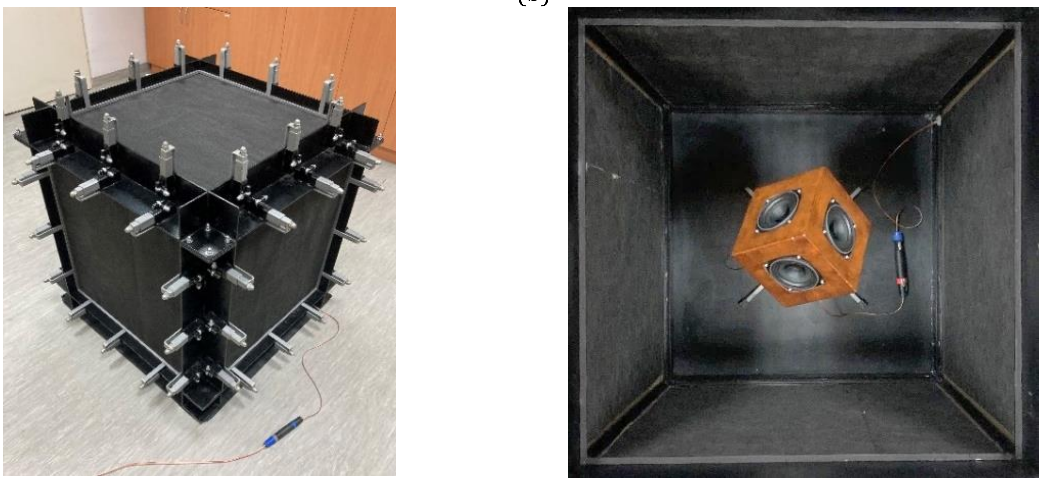

Fig. 6. Enclosure with walls of mineral wool (d110 h50): a) external view, b) inside.

The spectral characteristics of insertion loss in 1/3 octave frequency bands obtained from the tests are shown in Fig. 7.

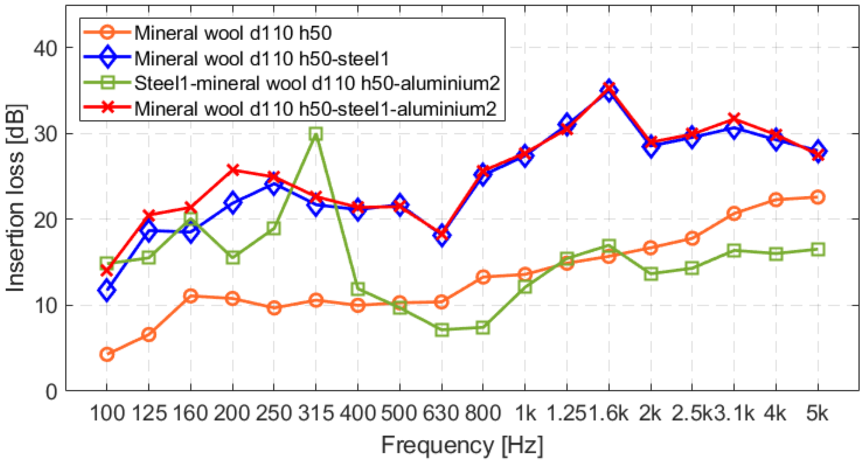

Fig. 7. The spectral characteristics of insertion loss of enclosures with walls of layers: mineral wool 50 mm (density 110 kg/m^3); mineral wool 50 mm and steel plate 1 mm; steel plate 1 mm, mineral wool 50 mm and aluminium plate 2 mm; mineral wool 50 mm, steel 1mm and aluminium 2 mm.

Comparing the spectral characteristics, it can be concluded that the best acoustic properties are found in the enclosure with 3-layer walls (mineral wool, steel plate and aluminium plate), in which the mineral wool was placed from the side of the sound source. Very similar properties were shown by a two-layer baffle (mineral wool with steel plate), as well as with mineral wool from the sound source side, but they are slightly weaker in the region of lower frequencies (<400 Hz). For the enclosure with walls for which mineral wool was used as a sound-absorbing core, the acoustic efficiency determined by the insertion loss is much weaker compared to other tested layered-wall variants, especially in the region of 500 Hz and higher frequencies, for which the properties of the enclosure with walls made of only mineral wool are even slightly better.

5. Conclusions

Experimental tests carried out on mineral wools, used as sound-absorbing linings and cores in layered baffles, showed that these materials also have sound-insulating properties, which was confirmed by normal incidence transmission loss tests carried out with the use of an impedance tube, as well as insertion loss tests of the enclosure with walls containing mineral wool. The most effective way is to place the layer of mineral wool from the side of the sound source, which is commonly used. The use of mineral wool as a sound-absorbing core may give worse results compared to two-layer wall solutions with mineral wool from the sound source side, in the form of lower efficiency in reducing the noise level, especially in the medium and high frequency range. For the purpose of an approximate comparison of the insulating properties of materials, the single-number indice R_w can be used, which in the case of mineral wools and normal incidence of a sound wave on a specimen can be determined on the basis of the surface mass of the specimen. The analysed acoustic properties of the sound-absorbing linings and cores of layered baffles will be further used for modelling the effectiveness of anti-noise solutions.

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