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Comparative Analysis of the Acoustic Properties of Granular Materials Determined with the Use of Impedance Tube

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Abstract The results of acoustic property tests for six types of granular materials: perlite, vermiculite, active coconut carbon, rubber granulates, pumice and wood chips, which can be used in noise protection structures, are shown in the article. The characteristics of the normal incidence sound absorption coefficient and the normal incidence sound transmission loss for material specimens with seven thicknesses in the range of 10-100 mm were determined based on the results of experimental tests carried out with the use of an impedance tube. The relationships between the first resonant absorption frequencies and the thicknesses of material specimens were determined. Single-number indices for the tested materials, in the form of the weighted sound absorption coefficients, were determined. Subsequently, dependencies of these indices on the surface mass of the tested materials were determined. The research showed that three materials, perlite, vermiculite and active coconut carbon, were distinguished among the examined granules with the best sound-absorbing and sound-insulating properties. Active coconut carbon had the best sound-insulating properties among the granular materials tested.

Keywords: granular materials, sound absorption coefficient, sound transmission loss.

1. Introduction

Both sound-insulating and sound-absorbing materials are used in design solutions for noise protection [1, 2]. Due to the structure and material characteristics, four groups of sound-absorbing materials are distinguished: porous, fibrous, honeycomb and granular [3]. The last group of materials is used in sound-absorbing and insulating baffles, where it is used as the sound-absorbing core of double-walled baffles. Granular materials, which are the subject of the research described in the article, are made of, among others, plastic or natural materials. The results of many years of research on the sound-absorbing properties of such materials have been verified in the construction of noise protection systems for machines and devices, among others, at a workstation for operating a mechanical press [3-5]. These studies have shown that granular materials can be successfully used to reduce the noise level of these sources. Good results have been obtained with the use of granulated materials in the form of lead pellets, plastics, quartz sand or rubber products for the construction of double-walled baffles [3, 4]. The sound-absorbing properties of granular materials have been the subject of theoretical and experimental studies conducted by many researchers [6-11]. The article presents the results of research, which is a continuation of the search for materials in granulated form with good sound-absorbing properties, with the extension of research on the sound-insulating properties of these materials.

The acoustic properties of materials are determined in the conditions of the reverberant sound field with the random incidence of a sound wave on the sample. The sound absorption coefficient α of material sample with an area of not less than $10 \div 12$ m^2 is determined in the reverberation chamber. The airborne sound insulation tests of materials, elements and building partitions, are determined at the laboratory stand of the conjugated reverberation chambers. The characteristic of sound insulation R is then determined. The dimensions of the measurement sample depend on the measurement window of the laboratory. The parameters determining the sound-absorbing and the sound-insulating properties of materials include also the normal incidence sound absorption coefficient and the normal incidence sound transmission loss. These parameters are determined in the impedance tube with conditions of normal incidence of the sound wave on the sample. Usually, such tests, especially the absorption properties, are considered approximate or preliminary, for example, during the initial selection of samples of new materials for target tests, such as tests in reverberation chambers. The article concerns research carried out with the use of an impedance tube, which use samples with small dimensions.

2. Measurement methods and tested materials

The experimental tests were carried out in accordance with the relevant standards: ASTM E2611-19 [12] and ISO 10534-2 [13]. The test stand was a set enabling the measurement of the normal incidence sound absorption coefficient and the normal incidence sound transmission loss [14]. The kit included a Mecanum Inc. impedance tube with a loudspeaker, type 378A14 PCB measuring microphones, a Siemens LMS SCADAS Mobile analyzer, an SMSL SA-36A Pro amplifier, 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 ÷ 2400 Hz and 119 ÷ 5700 Hz, while maintaining the distance between the microphone holders, which was 65 and 29 mm, respectively.

Figure 1 shows an impedance tube prepared for the determination of the normal incidence sound absorption coefficient along with material specimen containers, of 34.9 mm in diameter and 10, 20, 30, 40, 50, 80 and 100 mm thick. The containers with a wall thickness of 0.8 mm were made in 3D printing technology. The PLA filament was used for printing. The edges of the containers were finished on both sides with a textile material. The granulate was placed through the side opening in the container. After filling the container with granules, the opening was secured with paper adhesive tape. The measurements were carried out with the assumption that material specimen containers had an insignificant effect on the test results.

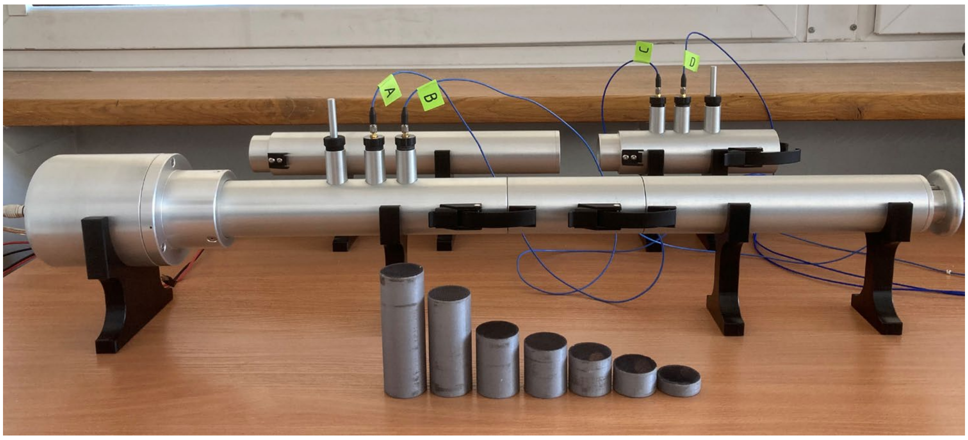

Figure 1. Impedance tube with material specimen containers.

All the tested materials had an irregular grain shape with dimensions ranging from 0.6 to 8 mm. Materials with a porous structure were tested, such as perlite, vermiculite, active coconut carbon, rubber granulates, pumice and wood chips with the composition of 70% alder and 30% beech. Granular materials are shown in Fig. 2. Perlite is produced from rocks of volcanic origin. Vermiculite is a material that is highly resistant to high temperatures and is obtained by airing potassium-magnesium micas. Both materials are used, among others, in construction (perlite concrete, vermiculite boards). Pumice is also used in the construction sector, where it is the basic raw material for the production of lightweight concrete blocks. Granular coconut carbon is produced from coconut shells, and its properties are used, among other things, to purify water or distillates. Rubber granulate is a material obtained by recycling used car tyres. Wood chips are used, among others, in the production of beaverboard, chipboard and cellulose.

Table 1 shows the parameters of granulated materials. The tested materials had different grain sizes ranging from 0.6 to 8 mm and density from 84.6 to 626.2 kg/m^3. The materials with the lowest density were perlite and vermiculite.

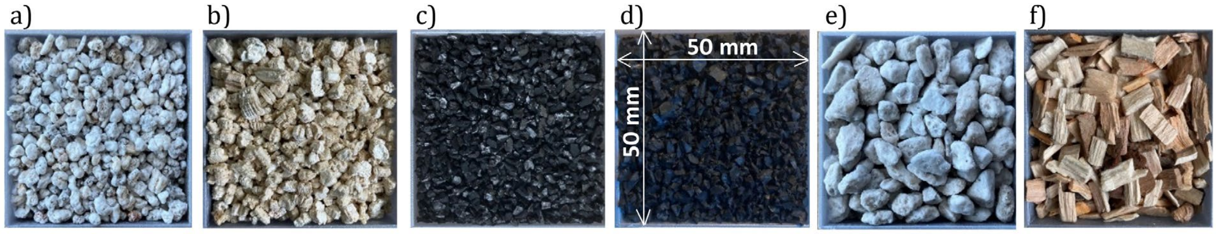

Figure 2. View of the tested materials: a) perlite, b) vermiculite, c) active coconut carbon, d) rubber granulates, e) pumice, and f) wood chips.

Table 1. Material data.

Material	Grain size D [mm]	Density ρ [kg/m^3]
Active coconut carbon	0.6 ÷ 2.4	492.7
Perlite	2 ÷ 5	96.3
Vermiculite	2 ÷ 5	84.6
Rubber granules	2 ÷ 6	477.9
Pumice	4 ÷ 8	626.2
Wood chips	4 ÷ 8	260.2

3. Test results and comparative analysis of acoustic properties

Figures 3-8 show the spectral characteristics of the normal incidence sound absorption coefficient and the normal incidence sound transmission loss for material specimens with thicknesses of 10, 20, 30, 40, 50, 80 and 100 mm.

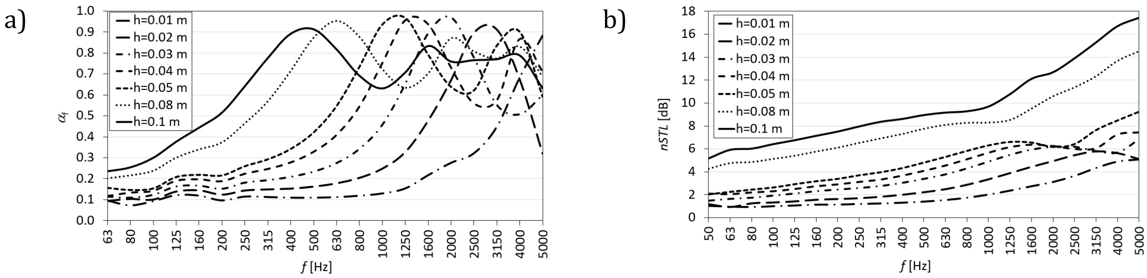

Figure 3. Spectral characteristics for active coconut carbon with a sample thickness of 10 ÷ 100 mm: a) the normal incidence sound absorption coefficient, b) the normal incidence sound transmission loss.

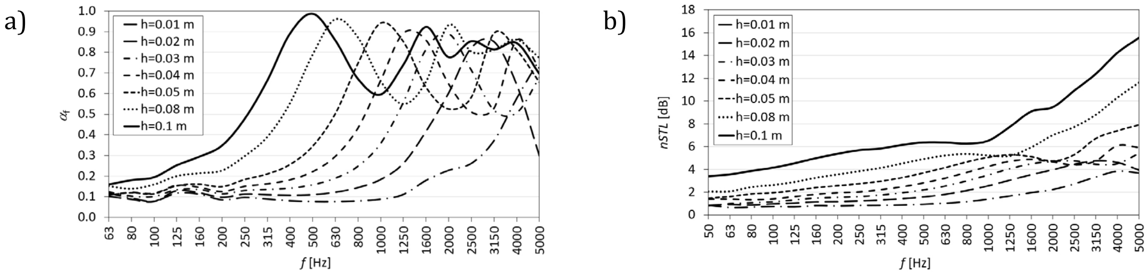

Figure 4. Spectral characteristics for perlite with a sample thickness of 10 ÷ 100 mm: a) the normal incidence sound absorption coefficient, b) the normal incidence sound transmission loss.

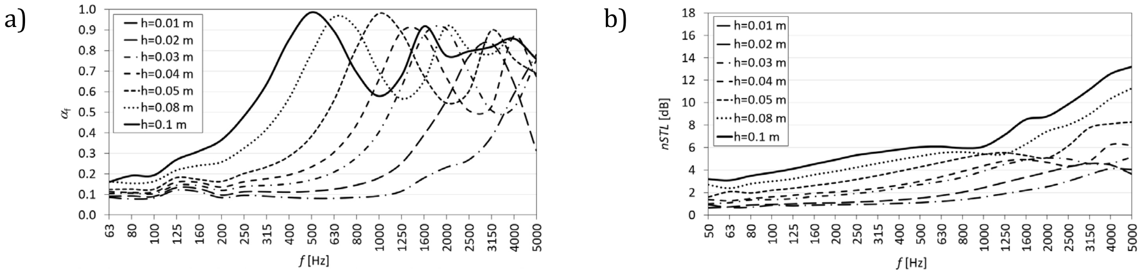

Figure 5. Spectral characteristics for vermiculite with a sample thickness of 10 ÷ 100 mm: a) the normal incidence sound absorption coefficient, b) the normal incidence sound transmission loss.

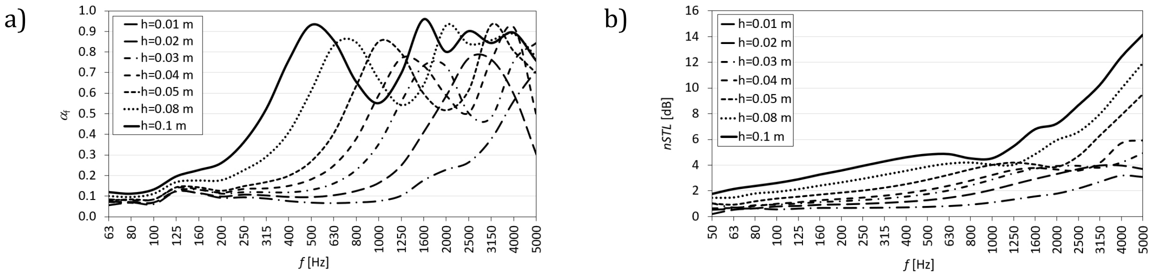

Figure 6. Spectral characteristics for wood chips with a sample thickness of 10 ÷ 100 mm: a) the normal incidence sound absorption coefficient, b) the normal incidence sound transmission loss.

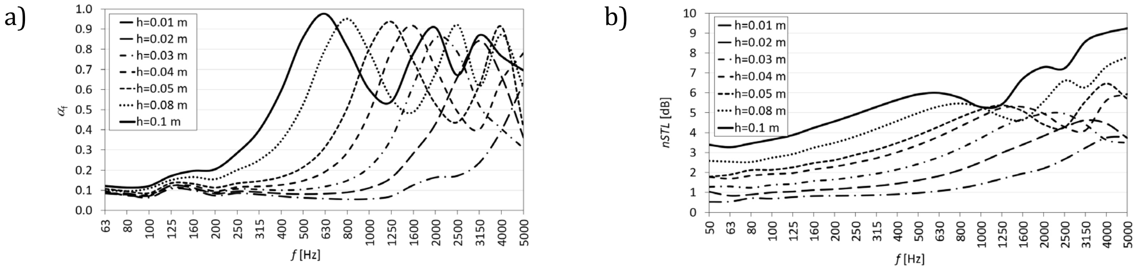

Figure 7. Spectral characteristics for rubber granulates with a sample thickness of 10 ÷ 100 mm: a) the normal incidence sound absorption coefficient, b) the normal incidence sound transmission loss.

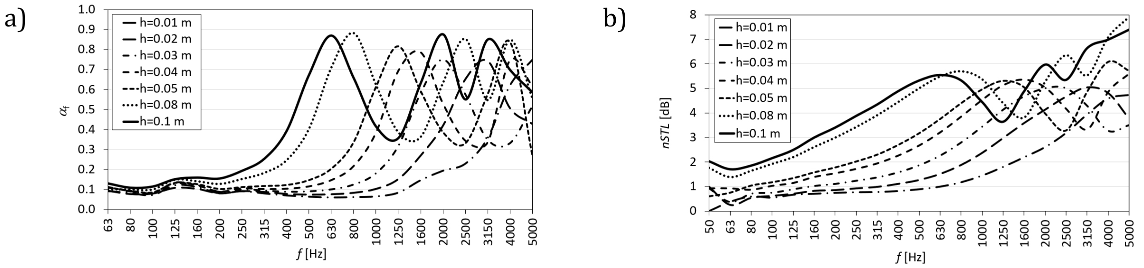

Figure 8. Spectral characteristics for pumice with a sample thickness of 10 ÷ 100 mm: a) the normal incidence sound absorption coefficient, b) the normal incidence sound transmission loss.

Comparing the graphs of sound absorption by the tested granular materials, a similar course of the α_f curves with characteristic resonance frequencies can be noticed. For the samples with the greatest thickness (h = 0.1 m), there are three resonance frequencies for which the coefficient α_f has reached its maximum values. For samples with the smallest thickness (h = 0.01 m), the first resonance frequencies are not visible in the graphs (Figs. 3a-8a), as they fall outside the considered frequency range. The best sound absorption at low frequencies is shown by active coconut carbon (sample thickness h = 0.1 m), which is the material with the smallest fraction (Fig. 3a). For samples made of active coconut carbon, the coefficients α_f for the first resonant frequencies increase from 0.9 to 0.98 for h = 0.1 m and h = 0.04 m, respectively. In the case of perlite and vermiculite, i.e. the materials with the smallest of the tested densities, α_f values for the first resonance frequencies are close to 1 (Fig. 4a and 5a), and they decrease with the reduction of the sample thickness h, down to approx. 0.85 for h = 0.02 m. A similar relationship can be observed in Fig. 7a for the rubber granulate. This material, like the pumice shown in Fig. 8a, differs from other materials in that it has a higher first resonance frequency ($f_{r1} \cong 630$ Hz).

The tests of granulated materials have shown that, in addition to sound-absorbing properties, these materials also have sound-insulating properties, as shown in the graphs (Figs. 3b-8b). The values of the normal incidence sound transmission loss coefficients of the tested granular materials increase with frequency, and at certain cut-off frequencies (f_g), depending on the thickness of the sample, the increase is more rapid. This applies to active coconut carbon, perlite, vermiculite and wood chips (Fig 3b-6b). The frequency f_g for these materials corresponds to the frequency of the first local minimum α_f above the value of f_{r1}. The different nature of the normal incidence sound transmission loss curves, in relation to the rest of the studied materials, can be observed in Figs. 7b and 8b, concerning pumice and rubber granules. Pumice was characterised by the highest density among the examined materials, but also by large grains (4 ÷ 8 mm) with the most irregular shapes (Fig. 2e). The highest resistance to sound penetration was demonstrated by granulated materials with the largest sample thickness (h = 0.1 m) and the smallest fraction (active coconut carbon, Fig. 3b). Among the tested materials, pumice had the lowest *nSTL* values (Fig. 8b).

Figure 9 shows the developed approximation curves of the first resonance frequencies for the tested granular materials with thicknesses h = 0.02, 0.03, 0.04, 0.05, 0.08 and 0.1 m.

On the basis of these curves, the first resonance frequencies f_{r1} of the tested materials, for the thickness of specimens that were not tested, such as h = 0.06, 0.07, 0.09 and 0.15 m, or exceeded the upper range of the considered frequencies, amounting to 5 kHz (h = 0.01 m), were calculated (Table 2). As the specimen thickness increases, the values of f_{r1} move towards lower frequencies. As shown in Table 2, for the highest specimen thickness (h = 0.15 m), the lowest resonance frequencies were for active coconut carbon (f_{r1} = 311 Hz), perlite (f_{r1} = 323 Hz) and vermiculite (f_{r1} = 337 Hz).

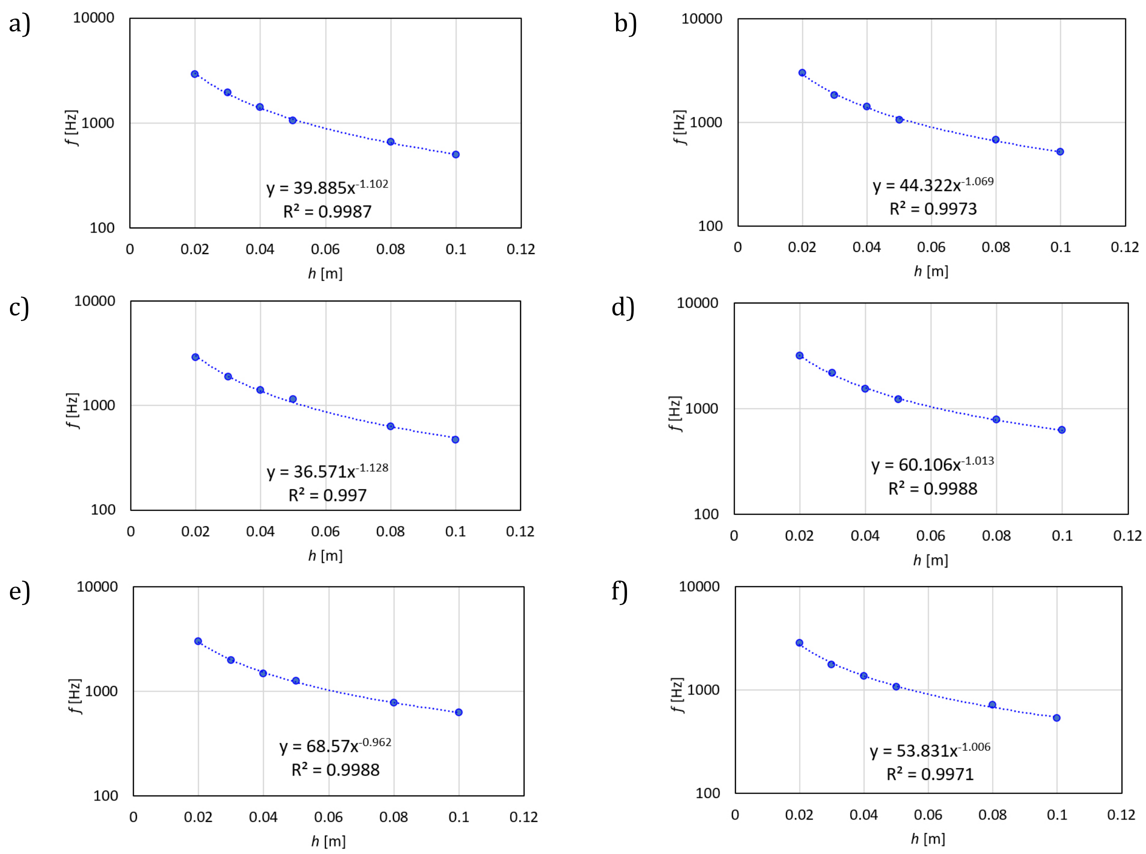

Figure 9. The first resonance frequencies as a function of the thickness of granulated materials: a) perlite, b) vermiculite, c) active coconut carbon, d) rubber, e) pumice, and f) wood chips.

Table 2. The values of the first resonance frequencies f_{r1} of the normal incidence sound absorption coefficient of materials.

	f_{r1} [Hz]				
Sample thickness, h [m]	0.01	0.06	0.07	0.09	0.15
Pumice	5756	1027	885	695	425
Perlite	6380	886	747	567	323
Active coconut carbon	6594	874	734	553	311
Vermiculite	6090	897	761	581	337
Rubber	6381	1039	889	689	411
Wood chips	5534	912	781	607	363

Based on the graphs shown in Figs. 3a-8a, the values of the single-number weighted sound absorption coefficient α_w of the tested materials were determined. This index is determined, in accordance with the standard requirements [15], on the basis of the sound-absorbing characteristics of the reverberant field. The sound absorption coefficients α of tested materials were calculated on the basis of the normal incidence sound absorption coefficient (Figs. 3a-8a), using the nomogram given in [16]. This approach made it possible to compare the sound-absorbing properties of the tested granulated materials using single-number indices. The summary of the calculated values of the α_w indices for the tested materials with a sample thickness from 0.02 to 0.1 m is shown in Fig. 10.

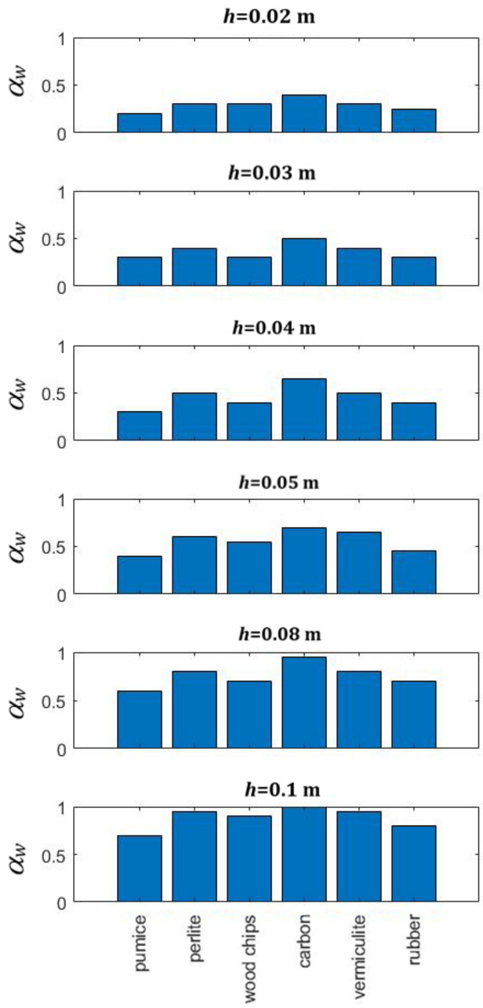

Figure 10. Single-number indices α_w for tested materials with a specimen thickness ranging from 0.02 to 0.1 m.

Figure 10 shows that, in principle, for each sample thickness, the material with the smallest fraction, i.e. active coconut carbon, has the best sound-absorbing and sound-insulating properties. Similar sound-absorbing properties are shown by perlite and vermiculite for the sample thickness h = 0.1 m. Pumice has the lowest values of α_w among the tested granulated materials.

Figure 11 shows the dependence of the weighted sound absorption coefficient α_w on the surface mass m of the tested granulated materials together with the equations of the approximation curves. The highest correlation (R^2 = 0.9987) between α_w and m was obtained for the material in the form of perlite (Fig. 11b).

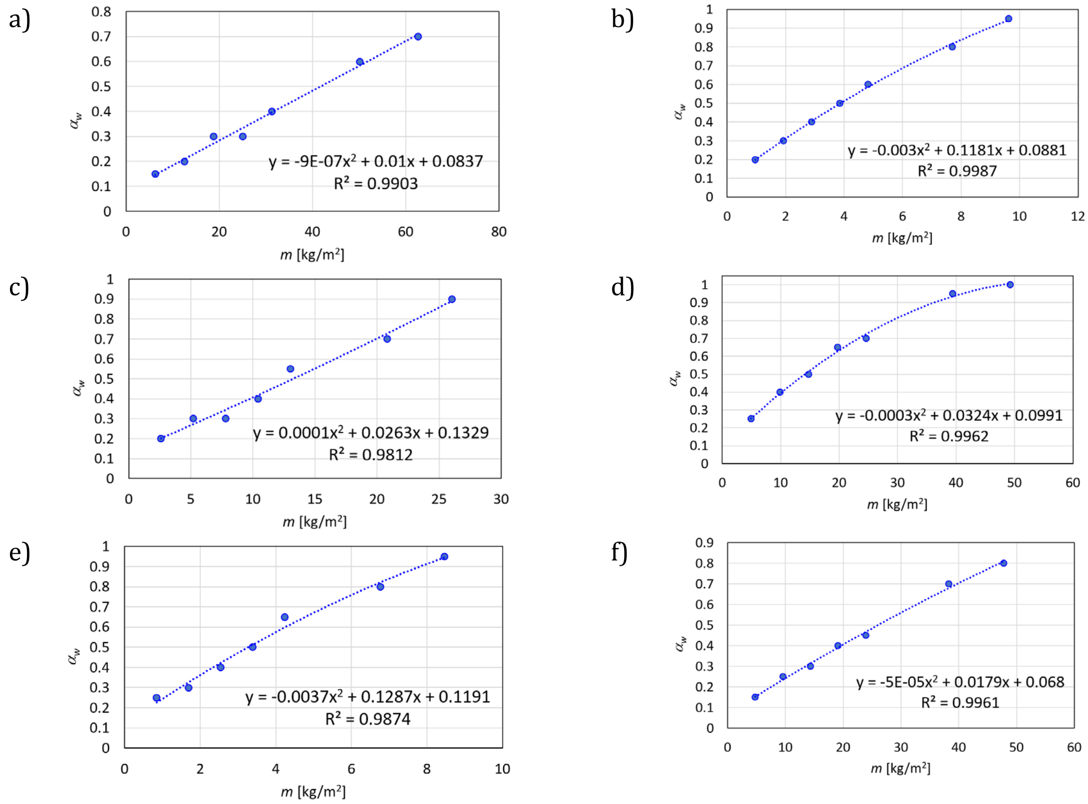

Figure 11. The weighted sound absorption coefficient α_w vs. the surface mass m of the granular material: a) pumice, b) perlite, c) wood chips, d) active coconut carbon, e) vermiculite, and f) rubber.

4. Conclusions

The tests of the acoustic properties of materials with the use of an impedance tube, i.e. for the conditions of normal incidence of the sound wave on the specimen, are usually performed as preliminary tests, before more detailed tests of this type are performed on a larger amount of the tested material in reverberant field conditions. The conducted research has shown that:

- the tested materials, mainly due to the specific porous structure, have sound-absorbing properties, and while maintaining an appropriate sample thickness (over 50 mm), they can compete with other materials used in noise protection, e.g. mineral wool, especially as a sound-absorbing core of an irregularly-shaped double-walled partition.
- the best sound-absorbing properties were demonstrated by perlite, vermiculite and active coconut carbon, while the sound-insulating properties were shown by the material with a porous structure, the smallest fraction and relatively high density, which was active coconut carbon. Based on the calculations with the use of the developed model, the first resonance frequency for this material with a thickness of 150 mm was 311 Hz.
- for the four tested granular materials of perlite, vermiculite, active coconut carbon and wood chips, a dependence of the increase in sound insulation, defined by the normal incidence sound transmission loss, was observed with the frequency up to a certain cut-off frequency, above which the increase in insulation is more rapid. The value of this cut-off frequency corresponds to the frequency of the first local minimum of α_f, which is twice the value of the first resonant frequency f_{r1}.

- the weighted sound absorption coefficient α_w can be estimated from the proposed dependencies, taking into account the surface mass of the granulated material.

The obtained results of tests of sound-absorbing and sound-insulating properties of granular materials, concerning small samples, resulting from the measurement conditions of the impedance tube, may differ for the results for samples with large dimensions tested in reverberation chambers.

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Additional information

The author declares: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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