Jan SIKORA*, Jadwiga TURKIEWICZ*

SOUND ABSORPTION COEFFICIENTS OF GRANULAR MATERIALS

SUMMARY

This paper presents the results of the expanded research program on sound absorbing properties of granular materials (granular polypropylene, foamed polystyrene, gravelite, rubber, mineral wool, and high-silica sand) being often applied as sound absorbing cores in double-wall partitions of constructions limiting noises of machines and devices.

***Keywords**: sound absorption coefficient, sound absorbing materials, noise control*

WSPÓŁCZYNNIKI POCHŁANIANIA DŹWIĘKU MATERIAŁÓW ZIARNISTYCH

W artykule przedstawiono wyniki rozszerzonego programu badań właściwości dźwiękochłonnych materiałów ziarnistych (granulaty z polipropylenu, styropianu, keramzytu, gumy, wełny mineralnej, piasek kwarcowy) mających zastosowanie jako rdzenie dźwiękochłonne w przegrodach dwuściennych rozwiązań konstrukcyjnych ograniczających hałas maszyn i urządzeń.

***Słowa kluczowe**: współczynnik pochłaniania dźwięku, materiały dźwiękochłonne, zwalczanie hałasu*

1. INTRODUCTION

The authors have worked for several years on granular materials in their natural form and on granulated products formed from processed solids, expecting that it would be possible to use them as the sound absorbing core in protection walls that limit the excessive acoustic activity of internal and external noise sources. The papers published in 2007 (Sikora 2007, Sikora and Turkiewicz 2007), presenting the findings of preliminary research on acoustic properties of the selected granular materials, aroused interest among the manufacturers of noise control, including acoustic screens. New acoustic panels have been created, with layers of various granular materials, featuring very good acoustic insulation.

Vibroacoustics uses the term "baffle" that is characterised by sound-insulating or sound-absorbing and insulating properties, utilized in constructions of noise control. The designed baffles include laminated baffles, both single and composite, especially dual ones (two-sided). In both types of baffles layers of sound-absorbing materials are applied, which function as the external sound-absorbing liner or sound-absorbing core. The function of the sound-absorbing core can be successfully fulfilled by granular material layers (granular products) of natural and artificial origin. Figures 1 and 2 show the classification of baffles and sound-absorbing materials applied in noise control.

2. EXPERIMENTAL TESTS

Research program on sound-absorbing properties (physical sound absorption coefficient a_f) assumed executing tests on 10 granular materials (granular products) with various bulk densities, fractions and grain shapes, and made of various materials. Experimental tests were conducted on samples of granulated products in five versions of layer thickness (10, 20, 30, 40 and 50 mm). Thus it was possible to determine the influence of layer thickness on sound absorption characteristics. The adopted layer thickness range resulted from the practical application of sound-absorbing cores and external sound-absorbing layers made of granular materials, both in acoustic screen panels, and in wall solutions of the integrated sound-absorbing and insulating enclosure elements, as well as in the body of machines with the enhanced acoustic insulation. The tests included granulates of plastics (5 types of polypropylene, foamed polystyrene), LECA – light expanded clay aggregate (gravelite), natural material (high-silica sand), rubber and mineral wool produced as fibre clusters (called "granulate" by the manufacturer). This untypical "granulate" was selected for the tests for two reasons: The first is application – similarly as granular materials, "granulate" made of mineral wool is used in baffle spaces and chambers, where sound-absorbing materials in a form of plates or mats cannot be used ("granulate" made of mineral wool is used as the sound-absorbing core in channel floor slabs). The second is comparison of sound absorption characteristics with test results for real granulates (granular materials). Table 1 contains the list of 6 materials used in the tests.

Detailed analysis of experimental test results for a general quantity of 50 samples of granular materials (ten types of material for five thickness layers) was carried out based on the following assessment criteria:

- material layer thickness,
- material type (plastic, natural material, building material),
- material structure (grain size and shape),
- bulk density (apparent).

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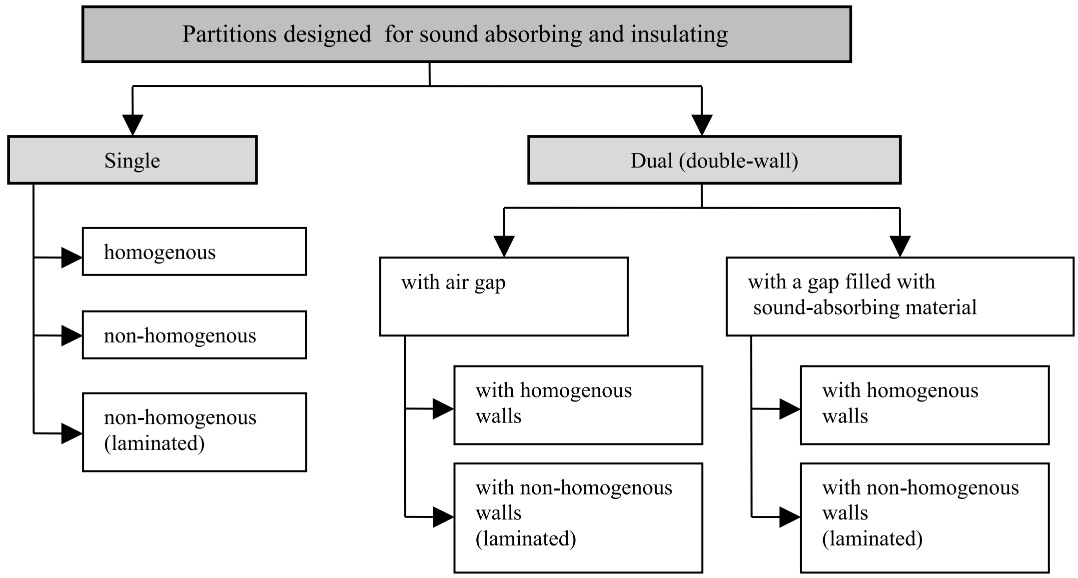


Fig. 1. Classification of sound insulating and sound-absorbing insulating partitions designed in solutions of classical and integrated enclosures

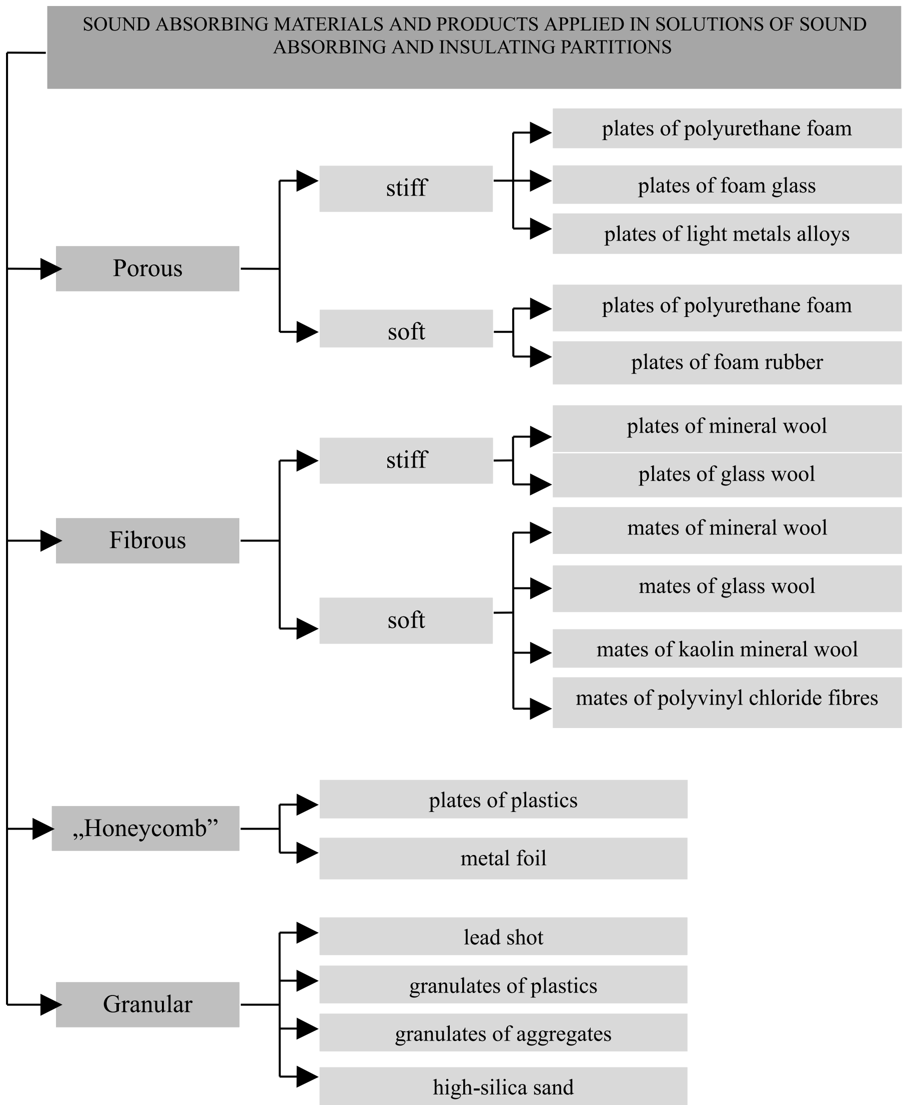
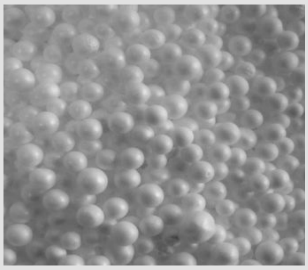
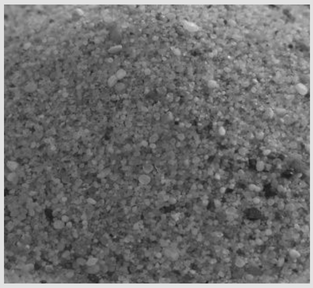


Fig. 2. Classification of sound absorbing materials and products utilized in partitions (walls) of noise protecting devices

Table 1

The list of granular materials used for the test

Properties of granular material	View of structure Name of material	Properties of granular material	View of structure Name of material
Bulk volume: 500 kg/m^3 Grain fraction: 4–6 mm Grain shape: oval, regular	 Polipropylene	Bulk volume: 1 kg/m^3 Grain fraction: 1–5 mm Grain shape: spherical, regular	 Foamed polystyrene
Bulk volume: 450 kg/m^3 Grain fraction: 3–15 mm Grain shape: oval, irregular	 Gravelite	Bulk volume: 460 kg/m^3 Grain fraction: 1×2–4 mm Grain shape: shavings, irregular	 Rubber
Bulk volume: 40 kg/m^3 Grain fraction: 10×20–40 mm Grain shape: clusters, irregular	 Mineral wool	Bulk volume: 1440 kg/m^3 Grain fraction: to 1–2 mm Grain shape: oval, irregular	 High-silica sand

The above mentioned criteria served as a base to compile comparative summaries of the obtained sound absorption characteristics in 1/3 octave frequency bands, which allow to answer the following questions:

- what is the influence of granular material layer thickness on sound absorption characteristics?
- is there a relation between the type or origin (natural or artificial) of material from which a granulate was made and sound absorbing properties?
- does the structure (grain size and shape, permeability or fibrousnesses of a granulate) of granular material affect sound absorption characteristics?
- what is the influence of bulk volume on sound absorbing properties of granular materials?

The impedance tube (Kundt's tube) was applied in tests since it allows to determine the physical sound absorption coefficient a_f by means of the method utilizing the coefficient of stationary wave. This method is useful for a conceptual approach as well as for preliminary tests enabling assessing the suitability of news materials with a view to their sound absorbing properties. Small samples of material, disc of a diameter 30 and 100 mm are sufficient for performing tests. Individual materials were placed in specially developed plastic sleeves closed on one side by solid walls and the other side (the one from the side of the wave incidence) by elastic, thin unwoven fabrics of small meshes (Sikora and Turkiewicz 2009). Sleeves made in five versions of thickness and two versions of diameters.

Below there are test results in a form of charts (Fig. 3–8) and tables (Tab. 2–7), with the comparison of sound-absorbing properties for 6 tested materials, for five layer thicknesses.

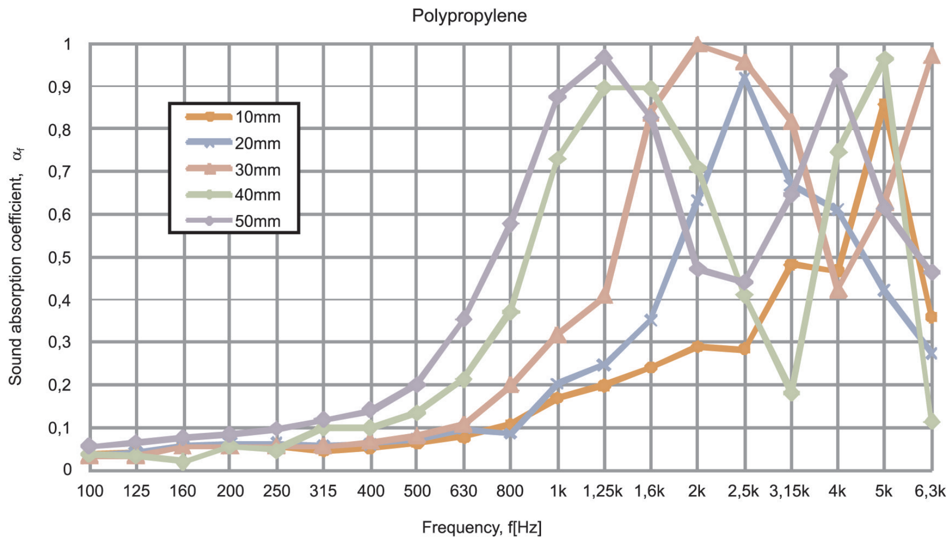


Fig. 3. Comparison of sound absorption characteristics of granular polypropylene for various layer thicknesses

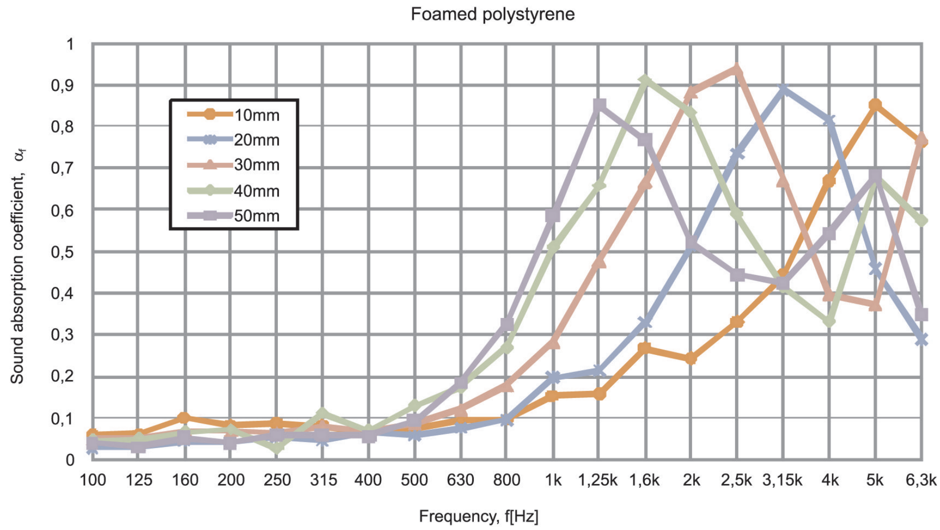


Fig. 4. Comparison of sound absorption characteristics of granular foamed polystyrene for various layer thicknesses

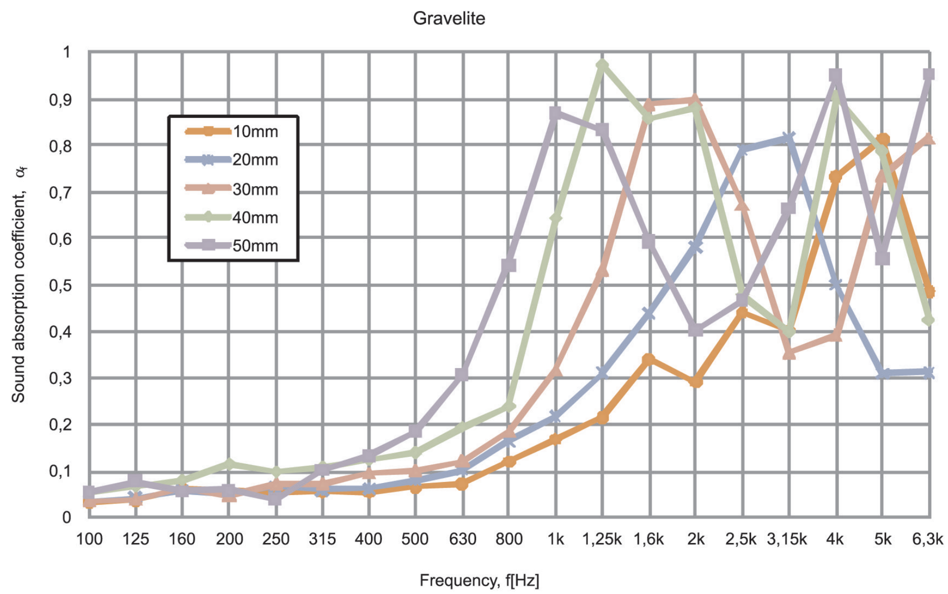


Fig. 5. Comparison of sound absorption characteristics of granular gravelite for various layer thicknesses

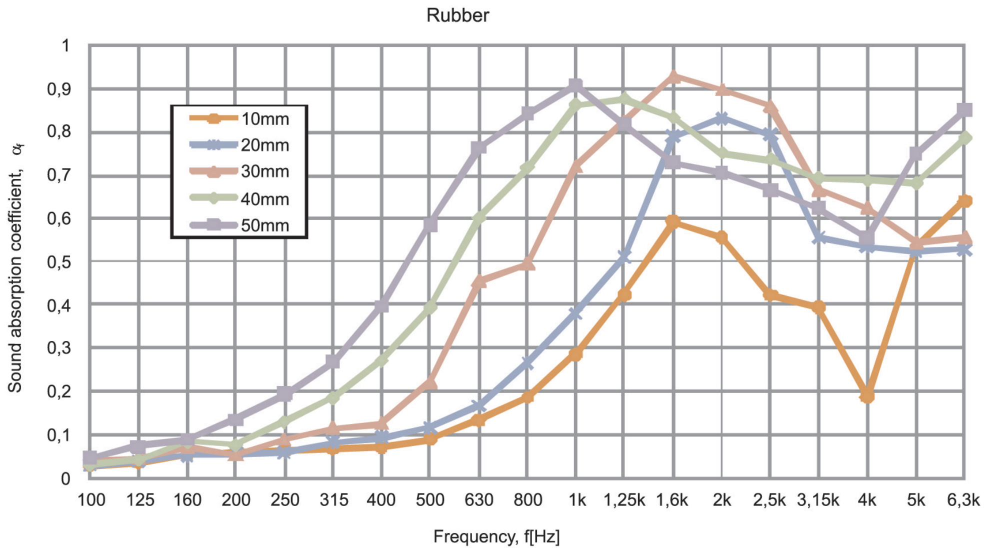


Fig. 6. comparison of sound absorption characteristics of rubber granulate for various layer thicknesses

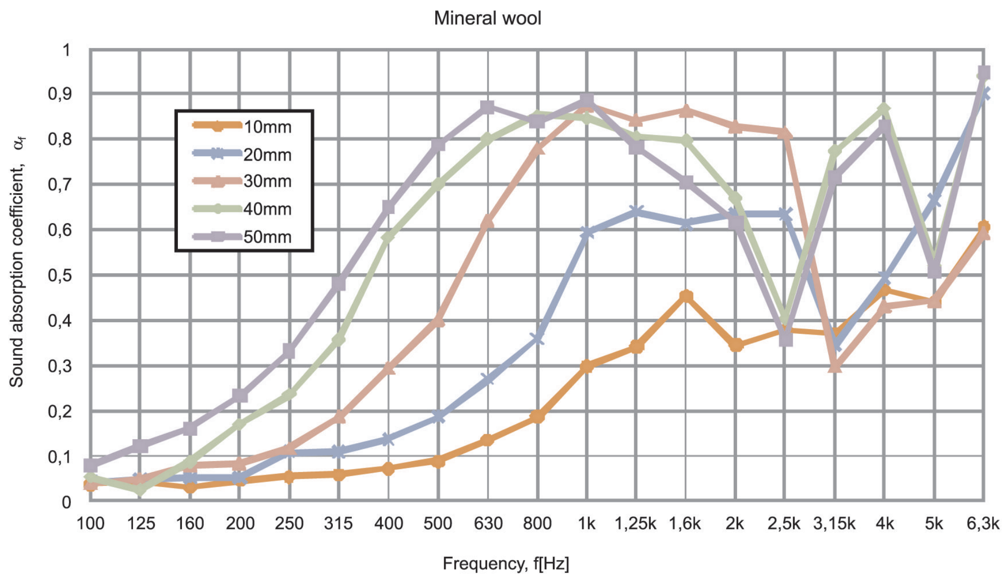


Fig. 7. Comparison of sound absorption characteristics of mineral wool granulate for various layer thicknesses

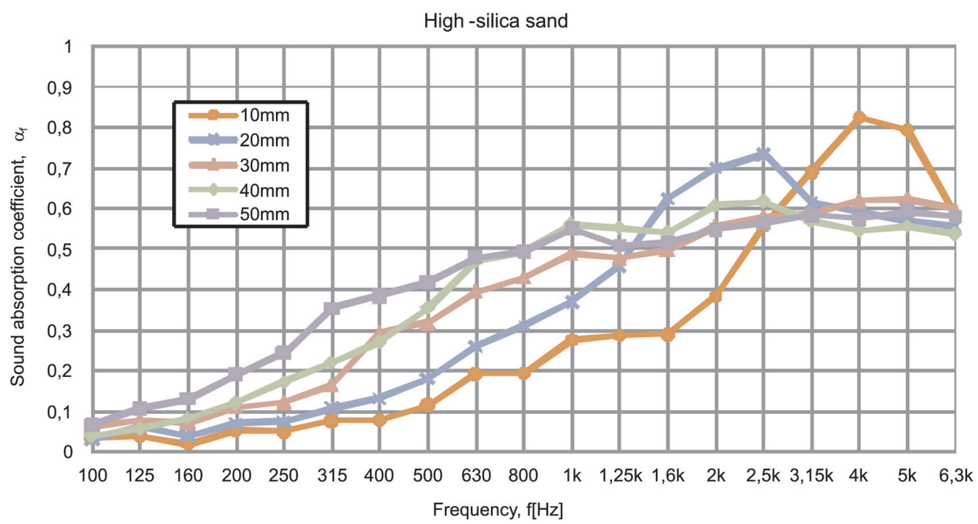


Fig. 8. Comparison of sound absorption characteristics of high-silica sand for various layer thicknesses

Table 2

Sound-absorbing properties of granular polypropylene

Polypropylene			Thickness of layer [mm]				
			10	20	30	40	50
Sound absorption coefficient α_f	Frequency f [Hz]	100	0.036	0.035	0.031	0.038	0.055
		125	0.042	0.039	0.033	0.035	0.064
		160	0.056	0.057	0.054	0.020	0.075
		200	0.053	0.062	0.054	0.056	0.081
		250	0.055	0.062	0.056	0.046	0.095
		315	0.045	0.057	0.055	0.099	0.116
		400	0.052	0.060	0.065	0.101	0.139
		500	0.061	0.072	0.080	0.135	0.199
		630	0.077	0.097	0.106	0.214	0.353
		800	0.105	0.085	0.200	0.372	0.578
		1000	0.168	0.203	0.317	0.731	0.878
		1250	0.198	0.247	0.408	0.898	0.969
		1600	0.241	0.350	0.838	0.897	0.828
		2000	0.289	0.633	0.999	0.710	0.471
		2500	0.284	0.921	0.959	0.412	0.441
		3150	0.483	0.669	0.819	0.181	0.647
		4000	0.467	0.612	0.422	0.747	0.927
		5000	0.860	0.422	0.627	0.965	0.614
		6300	0.360	0.274	0.972	0.114	0.463
$\alpha_{śr}$			**0.207**	**0.261**	**0.373**	**0.356**	**0.421**

Table 3

Sound-absorbing properties of granular foamed polystyrene

Foamed polystyrene			Thickness of layer [mm]				
			10	20	30	40	50
Sound absorption coefficient α_f	Frequency f [Hz]	100	0.059	0.029	0.050	0.045	0.039
		125	0.060	0.031	0.050	0.049	0.030
		160	0.100	0.044	0.068	0.067	0.052
		200	0.083	0.041	0.070	0.071	0.039
		250	0.088	0.053	0.066	0.026	0.059
		315	0.081	0.046	0.081	0.111	0.059
		400	0.066	0.065	0.069	0.069	0.057
		500	0.075	0.058	0.086	0.129	0.095
		630	0.093	0.076	0.120	0.173	0.185
		800	0.097	0.096	0.177	0.268	0.325
		1000	0.153	0.197	0.282	0.509	0.586
		1250	0.158	0.215	0.476	0.657	0.852
		1600	0.267	0.330	0.666	0.912	0.768
		2000	0.243	0.514	0.882	0.833	0.521
		2500	0.331	0.735	0.938	0.588	0.445
		3150	0.444	0.889	0.671	0.415	0.424
		4000	0.670	0.816	0.397	0.331	0.543
		5000	0.852	0.458	0.372	0.679	0.681
		6300	0.763	0.290	0.774	0.573	0.348
$\alpha_{śr}$			**0.246**	**0.262**	**0.331**	**0.342**	**0.321**

Table 4

Sound-absorbing properties of granular gravelite

Gravelite			Thickness of layer [mm]				
			10	20	30	40	50
Sound absorption coefficient α_f	Frequency f [Hz]	100	0.033	0.036	0.036	0.054	0.054
		125	0.037	0.043	0.039	0.067	0.077
		160	0.062	0.058	0.064	0.080	0.057
		200	0.056	0.050	0.047	0.113	0.059
		250	0.054	0.066	0.072	0.097	0.039
		315	0.056	0.059	0.073	0.108	0.102
		400	0.054	0.063	0.095	0.125	0.132
		500	0.066	0.079	0.101	0.138	0.185
		630	0.072	0.102	0.122	0.184	0.306
		800	0.121	0.164	0.185	0.238	0.543
		1000	0.168	0.217	0.316	0.643	0.869
		1250	0.214	0.311	0.532	0.973	0.834
		1600	0.341	0.439	0.889	0.857	0.593
		2000	0.291	0.581	0.899	0.879	0.403
		2500	0.440	0.790	0.673	0.479	0.467
		3150	0.402	0.816	0.354	0.398	0.665
		4000	0.732	0.500	0.392	0.905	0.951
		5000	0.814	0.310	0.735	0.786	0.556
		6300	0.485	0.313	0.816	0.423	0.953
$\alpha_{śr}$			**0.237**	**0.263**	**0.339**	**0.398**	**0.413**

Table 5

Sound-absorbing properties of rubber granulate

Rubber			Thickness of layer [mm]				
			10	20	30	40	50
Sound absorption coefficient α_f	Frequency f [Hz]	100	0.028	0.028	0.038	0.030	0.046
		125	0.034	0.039	0.046	0.043	0.073
		160	0.054	0.051	0.069	0.083	0.088
		200	0.060	0.057	0.052	0.077	0.135
		250	0.063	0.058	0.088	0.130	0.194
		315	0.067	0.082	0.115	0.184	0.269
		400	0.070	0.093	0.125	0.271	0.397
		500	0.089	0.116	0.220	0.395	0.586
		630	0.134	0.167	0.454	0.600	0.763
		800	0.185	0.267	0.495	0.717	0.840
		1000	0.284	0.379	0.719	0.861	0.907
		1250	0.425	0.509	0.824	0.875	0.818
		1600	0.592	0.789	0.927	0.831	0.728
		2000	0.556	0.830	0.897	0.750	0.704
		2500	0.422	0.793	0.859	0.735	0.665
		3150	0.395	0.556	0.665	0.691	0.624
		4000	0.187	0.533	0.624	0.686	0.556
		5000	0.533	0.524	0.543	0.680	0.750
		6300	0.640	0.528	0.556	0.785	0.850
$\alpha_{śr}$			**0.254**	**0.337**	**0.438**	**0.496**	**0.526**

Table 6

Sound-absorbing properties of mineral wool granulate

Mineral wool			Thickness of layer [mm]				
			10	20	30	40	50
Sound absorption coefficient α_f	Frequency f [Hz]	100	0.038	0.043	0.039	0.054	0.079
		125	0.042	0.049	0.049	0.025	0.122
		160	0.032	0.052	0.080	0.087	0.161
		200	0.047	0.052	0.083	0.169	0.232
		250	0.055	0.108	0.116	0.236	0.331
		315	0.059	0.110	0.186	0.358	0.480
		400	0.072	0.137	0.294	0.583	0.651
		500	0.089	0.187	0.401	0.702	0.786
		630	0.135	0.270	0.620	0.801	0.871
		800	0.187	0.360	0.780	0.854	0.839
		1000	0.298	0.595	0.875	0.847	0.886
		1250	0.342	0.640	0.843	0.808	0.782
		1600	0.454	0.614	0.864	0.798	0.706
		2000	0.345	0.635	0.829	0.670	0.617
		2500	0.378	0.634	0.816	0.404	0.357
		3150	0.372	0.345	0.297	0.774	0.717
		4000	0.468	0.493	0.431	0.869	0.830
		5000	0.440	0.665	0.443	0.521	0.505
		6300	0.606	0.902	0.592	0.941	0.947
$\alpha_{śr}$			**0.235**	**0.363**	**0.455**	**0.553**	**0.574**

Table 7

Sound-absorbing properties of high-silica sand

High-silica sand			Thickness of layer [mm]				
			10	20	30	40	50
Sound absorption coefficient α_f	Frequency f [Hz]	100	0.037	0.032	0.061	0.041	0.067
		125	0.041	0.063	0.079	0.057	0.108
		160	0.021	0.040	0.072	0.084	0.130
		200	0.054	0.071	0.111	0.122	0.190
		250	0.050	0.075	0.122	0.172	0.245
		315	0.077	0.107	0.165	0.220	0.355
		400	0.079	0.133	0.294	0.272	0.385
		500	0.115	0.181	0.319	0.356	0.418
		630	0.192	0.260	0.396	0.471	0.479
		800	0.193	0.312	0.431	0.493	0.495
		1000	0.276	0.369	0.488	0.562	0.550
		1250	0.288	0.460	0.479	0.552	0.509
		1600	0.291	0.623	0.498	0.542	0.515
		2000	0.383	0.699	0.556	0.606	0.547
		2500	0.556	0.732	0.581	0.617	0.564
		3150	0.689	0.614	0.588	0.567	0.583
		4000	0.825	0.590	0.619	0.546	0.575
		5000	0.793	0.570	0.624	0.556	0.593
		6300	0.584	0.556	0.600	0.538	0.580
$\alpha_{śr}$			**0.292**	**0.341**	**0.373**	**0.388**	**0.415**

The analysis of experimental test results provides the following essential conclusions that are useful for designers of noise control:

1. In all of the tested samples of granular materials there is a clear influence of layer thickness on the increase of sound absorption. Irrespective of the structure and bulk volume, the increase in layer thickness results in the increased average sound absorption coefficient.
2. The shape of sound absorption characteristics depends on the structure of granular material, irrespective of its type. Granular polypropylene, gravelite and foamed polystyrene may be regarded as narrow-band sound-absorbing materials, due to their frequency band (below one octave), in which the greatest sound absorption is observed. With the increased layer thickness resonance frequency, for which the greatest sound absorption is observed, is shifted towards middle frequencies (1000 Hz–1600 Hz).
3. The shape of sound absorption characteristics of rubber granulate and high-silica sand is similar to the characteristics of mineral wool "granulate". These granular materials can be regarded as wide-band sound-absorbing materials (more than four octave width), but sound absorbing properties of rubber granulate are almost identical as those of mineral wool "granulate". High-silica sand is characterised by much lower absorption than rubber granulate in the frequency range of 500 Hz–2500 Hz. On the other hand, within the range of low frequencies, below 315 Hz, sand absorption is better than this of rubber granulate.
4. Bulk volume of the tested granular materials has the least influence on sound absorption characteristics. No significant differences were observed, even in the case when granular foamed polystyrene (1 kg/m^3) and polypropylene (630 kg/m^3) were compared.

3. CONCLUSIONS

In the extended experimental tests sound-absorbing properties of the selected group of materials (indicated after initial exploratory tests in 2007 (Sikora 2007)), and consequently the utility there of in new solutions of wall noise control elements were proven. The executed tests suggest that considering the frequency band, in which the greatest sound absorption occurs, granular materials may be divided into narrow- and wide-band ones. The first group includes granular polypropylene, gravelite and foamed polystyrene. The second includes rubber granulate and quartz sand, similarly as for mineral wool „granulate". Both groups of granular materials may be applied in practice. Granulates with narrow-band absorption within the frequency range of 500 Hz to 2000 Hz may be very useful as extra sound-absorbing layers in panels – elements of wall acoustic screens, resulting in the increase in single-number quantities R_w [dB] (single-number quantity for airborne sound insulation of building elements according to PN-EN ISO 717-1:1999) and DL_R [dB] (single-number quantity of evaluation for airborne sound insulation according to PN-EN 1793-2:2001). The first innovative solutions of acoustic screen panels with gravelite layers and granular plastics obtained by recycling are characterised by very good acoustic parameters, which guarantee competitiveness as compared with acoustic panels with classic sound-absorbing layers. Quartz sand is especially used as a sound-absorbing core in sound-insulating baffles in protections_limiting noise sources with very high acoustic activity. The author rests great hopes with rubber granulates, especially that they are obtained from production waste and used rubber products. They may be found in a form of granulates, but also as plates from laminated rubber granulate. This type of rubber layers may be applied in elements of wall noise protections, resulting in the increased of acoustic insulation.

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