ACOUSTIC AND MECHANICAL PROPERTIES OF FOAM GYPSUM DECORATIVE CEILING PANELS

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ABSTRACT

Material structure depends on its production technology and by varying this technology it is possible to obtain similar structures. Physical and mechanical properties depend on the material structure and relating that to the material thickness, it is possible to change the maximal sound absorption coefficient position in the range of frequency. The paper examines the development of foam gypsum sound absorption material production technology, in order to obtain materials with the rules of sound absorption coefficient at the same time fulfilling the strength requirements. The sound absorption coefficient was determined with a ∅40mm impedance tube and in a reverberation chamber according LVS EN ISO 354:2003. Flexural strength for beams was determined in a three-point bending test and for ceiling panels according LVS EN 14246:2006. The study of the results was acquired from a foam gypsum production technology that simultaneously executes the strength requirements and provides a Class B sound absorption material. It has been found that foam gypsum sound absorption material and mineral wool is similar to the behavior of the sound absorption coefficient and the thickness of the product, although these materials are different structures.

Key words: Foam gypsum, acoustic panels, sound absorption, ceiling panels

INTRODUCTION

Material structure depends on its production technology. It is possible to obtain materials of similar structure using different technologies. By varying the structure it can also influence physical and mechanical properties of the material itself. In order to obtain optimal material, it is necessary to know which production technology gives certain material structure with certain properties. By the material's thickness it is possible to adjust the maximal sound absorption coefficient position in a range of frequency. Smith (Шмидт, 1969) in the last century during the '60s determined that the stone cotton sound absorption coefficient maximal value at various frequency ranges are dependent on the material's thickness.

Fine acoustic environments have to be in offices, learning classrooms, stores, and production buildings. Optimal acoustic spaces have to be reached by combining sound absorption and insulation. Latvian Building Norms LBN 016-11 "Building Acoustics" has defined requirements for reverberation time and sound insulation. Absorbents are more necessary for regulating the reverberation time, but insulators – to ensure sound insulation between the premises. Sound insulation is less changeable and the requirements during exploitation do not change so suddenly as in the case of reverberation time. Thus absorption materials have to be available with a broad absorption coefficient range. By executing acoustic indicators, absorbents have to ensure certain sound absorption, and properties of strength may vary for different materials. Certain material structure and thicknesses are needed to ensure strength indicators. By increasing the material's thickness, the absorption coefficient does not increase indefinitely. Such cell concrete absorbents as foam concrete, aerated concrete on a cement basis and aerated concrete on a lime basis reach a maximal sound absorption coefficient already at 35 mm thickness (Laukaitis, et al., 2006). Considering the economy of raw materials, there are no grounds for choosing a thick material that does not ensure a high sound absorption coefficient. Forming composite materials, it is possible to decrease the amount of raw materials, and increase the material strength and sound absorption ability. The flexural strength of foam gypsum acoustic ceiling tiles is determined by LVS EN 14246:2006 requirements. In order to ensure the standard requirements of flexural strength, foam gypsum acoustic tiles' flexural have to be increased by 0.08 MPa. Local pressure during assembling has to be ensured for the acoustic tiles' compressive strength.

The objective of the research is to change foam gypsum sound absorption material production technology to obtain a material with properties which ensure an average weight sound absorption coefficient of $\alpha_w \geq 0.60$ at a frequency range of 250÷4000 Hz, at the same time ensuring strength requirements ($R_{flexural}$> 0.08 MPa, $R_{compressive}$> 0.20 Mpa).

Table 1

Sound-absorbing board materials comparison

Material	Thickness, mm	Sound absorption coefficient α_W	Absorption class according LVS EN ISO 11645
HWL 25AB	25	0.20	E
Fibrolite F 75	75	0.65	C
Fibrolite F 100	100	0.75	C
Isover Focus A	20	-	C
Isover Master A alpha	40	-	A
Armstrong Neeva Board 15	15	1.00	A
Armstrong Perla	17	0.65	C

MATERIALS AND METHODS

Sound absorption

In order to determine the absorption coefficient in a reverberation chamber, foam gypsum panels of 300×300×40 mm were produced using the method of dry mineralization (Горлов et al., 1984; Скуянс et al., 1985; Skujans et al., 2007; Iljins et al., 2009; Skujans et al., 2010). According to Standard LVS EN ISO 354:203 the minimal absorbent area of a reverberation chamber, Fig. 1., is 6.0 m². In order to ensure the necessary requirements, 68 samples with a 0.09m² area each and with a total square of 6.12m² were produced. Material size was chosen in order to produce as many samples as possible to avoid mistakes. Reverberation time measurements and absorption coefficient calculations were determined after the Standard LVS EN ISO 354:2003 "Acoustics Sound Absorption Measurements in Reverberation Chamber." The sound absorption coefficient average weight value was determined after the Standard LVS EN ISO 11654:2000 "Acoustics-Sound Absorbents in Buildings-Sound Absorption Parameters."

A sound source with a 12-side (dodecahedron) all directional loudspeaker which produces a regular sound field in the chamber was placed in the reverberation chamber. A microphone was placed in 5 places by turn (Fig.1.) in an empty chamber and in a chamber with foam gypsum samples. At the beginning, the reverberation time and sound pressure level of empty and full chambers were measured. After that the average values of five microphones' measurements were determined.

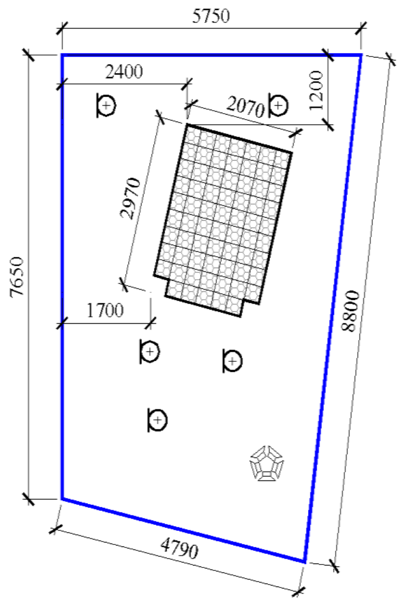


Figure 1. Foam gypsum acoustic ceiling tiles measuring scheme in reverberation chamber

After the Standard LVS EN ISO 254:2003 requirements, the sound pressure level comparison among values of side 1/3 octave band was made. If these values do not differ more than 6 dB, the sound field can be considered as diffusive. The value of sound absorption coefficient at 1/3 octave band has been determined using equation 1:

$$a_S = \frac{A_2 - A_1}{S_p} = \frac{A_T}{S_p}, \qquad (1)$$

where:

A_1 - equivalent absorbent area of an empty reverberation chamber (equation 2), m^2;

A_2 - equivalent absorbent area with a sample (equation 3), m^2;

A_T - equivalent absorbent area for a sample, m^2;

S_p - actual geometrical area (Fig.1.) of a sample, m^2;

$$A_1 = V\left(\frac{55.3}{c_1 T_1} - \frac{4\alpha_1}{10\lg(e)}\right), \quad (2)$$

$$A_2 = V\left(\frac{55.3}{c_2 T_2} - \frac{4\alpha_2}{10\lg(e)}\right), \quad (3)$$

where:
V - free volume of reverberation chamber (203), m³;
$c_1;c_2$ - sound velocity (LVS ISO 354:2003 6. equation), m s^{-1};
$T_1;T_2$ - reverberation time in 1/3 octave bands, s;
α_1; α_2 - attenuation coefficient of sound in atmosphere (ISO 9613-1).

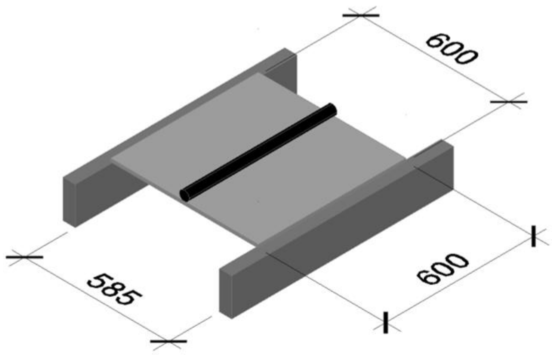
Flexural and compressive strength

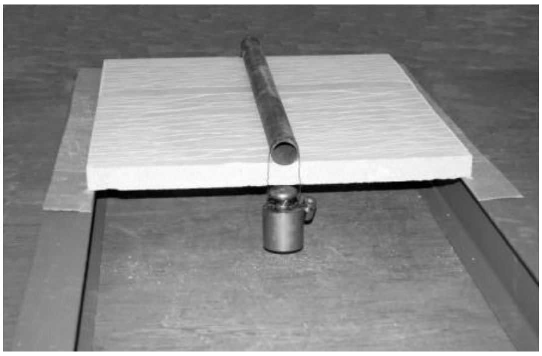
Samples of 40×40×160 mm were made to determine material flexural and compressive strength. Samples were tested in a three-point bending test with a 100 mm distance between supports. The flexural strength indicator was calculated using equation 4:

$$f = \frac{3FL}{2bh^2}, \quad (4)$$

where:
F - maximal load, N;
L - span between supports, mm;
b - sample width, mm;
h - sample height, mm.

Requirements of flexural and compressive strength according to LVS EN 14246:2006 "Foam Gypsum Elements of a Suspended Ceiling. Definitions, Requirements, Testing Methods" ask for 600×600 mm tiles. The tiles are produced using the same technology and thickness (40 mm) as they were tested at the reverberation chamber. Foam gypsum was dried and tested at 23±2°C and humidity 50±5 %.Testing was made for 600×600mm samples placed on supports with span 585 mm. The sample placed on supports was loaded with 6000±100 g a round loading beam on all sample length parallel to supports. Test was done for 30 min and damages (cracks) were estimated afterwards. Sample shouldn't crash and cracks are not allowed after the testing. The testing scheme is shown at Fig.2a and the test at Fig. 2b.





a b

Figure 2. Foam gypsum acoustic ceiling tiles a - loading scheme; b-foam gypsum acoustic ceiling tiles loading

RESULTS AND DISCUSSION

Gypsum ceiling elements with the Standard LVS EN 14246:2006 for 600x600 tile with a length of 585 mm have to withstand a pressure of 6 kg. Knowing the pressure and possible thinner foam gypsum tile thickness (35 mm (Laukaitis et al., 2006)) by the equation (4.) the minimal allowed flexural strength was determined according to the standard – 0.08 MPa. Parameters of flexural and compressive strength are shown in Fig. 3. Foam gypsum with a production technology using 4 ml surface active stuff (SAS) corresponds to the parameter >0.08 MPa.
From these technologies foam gypsum with a production technology w/g 0.9 SAS 4 ml and w/g 0.8 SAS 4 ml can't be used, because of the average weight sound absorption coefficient at 100 mm, the thickness is under 0.5. Useable technologies are w/g 0.6 SAS 4 ml and w/g 0.7 SAS 4 ml, which average a weight sound absorption coefficient at 100 mm thickness is 0.61 and 0.52 which corresponds with C class (0.61) and D class (0.52) after the Standard LVS EN ISO 11654:2000. Volume mass of foam gypsum w/g 0.6 SAS 4 ml is close to 400 kg m^{-3}, which is the highest limit allowed, making the weight <15 kg m^{-2}. The weight of fibrolite acoustic tiles is 11.5 kg m^{-2} (HWL 25… 2012).
Analyzing the data of indicators in compressive strength Fig.4. the highest indicators are for the foam gypsum with a production technology w/g 0.6 SAS 4 ml, but w/g 0.7 SAS 4 ml has been changed

by foam gypsum with a production technology w/g 0.8 SAS 4 ml, with the medium sound absorption coefficient at 100 mm 0.43 (D class).

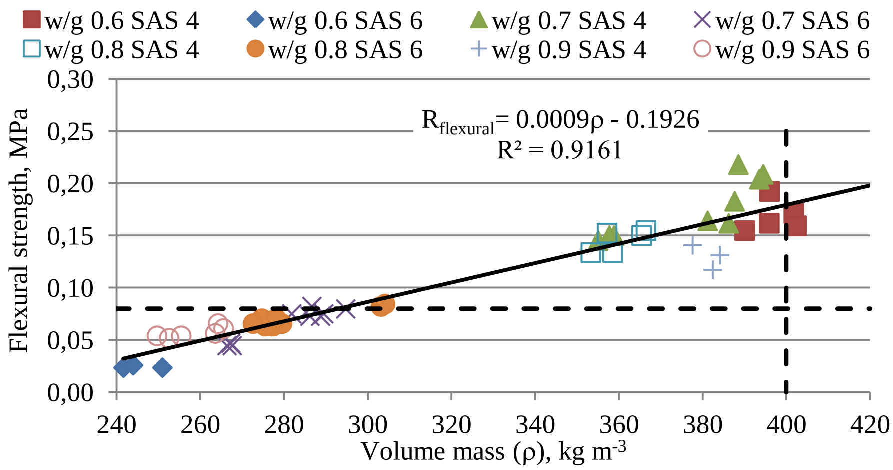


Figure 3. Foam gypsum flexural strength depending on the volume mass at different production technologies

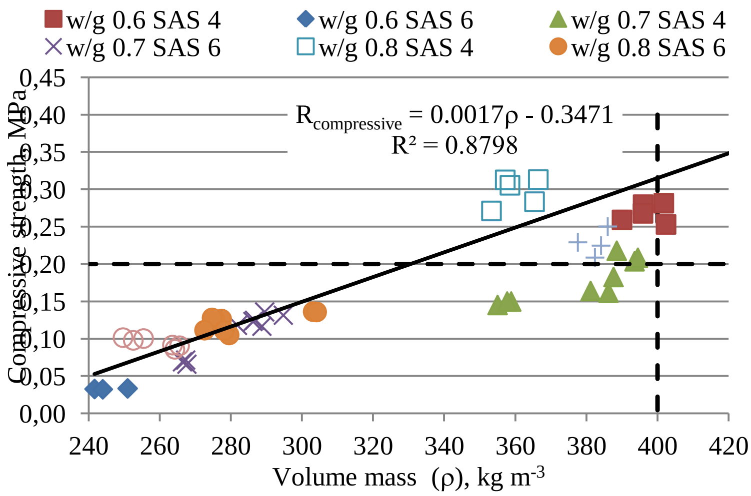


Figure 4. Foam gypsum compressive strength depending on the volume mass at different production technologies

Sound absorption tiles can be with various thicknesses depending on their usage and necessity to absorb sound. Figures 5 a,b,c,d show medium sound absorption values at different thicknesses depending on the production technology. Based on strength indicators, foam gypsum which can be used for production of sound absorption tiles, is with a production technology w/g 0.6 SAS 4ml and w/g 0.7 SAS 4 ml. From these production technologies the best sound absorption properties are w/g 0.6 SAS 4 ml at a material thickness of 30 mm; 40 mm and 50 mm, and its properties are the same as for the production technologies with 6 ml SAS, which provide better sound absorption properties. With the material thickness of 100 mm of this production technology has lower indicators than 0.11, and this sound absorption tile isn't of practical usage.

Considering the average weight values of the sound absorption coefficients at different technologies Fig.5 a,b,c,d, as well as indicators of flexural and compressive strength, the foam gypsum with technology w/g 0.6 un SAS 4 ml was chosen for continuous material testing.

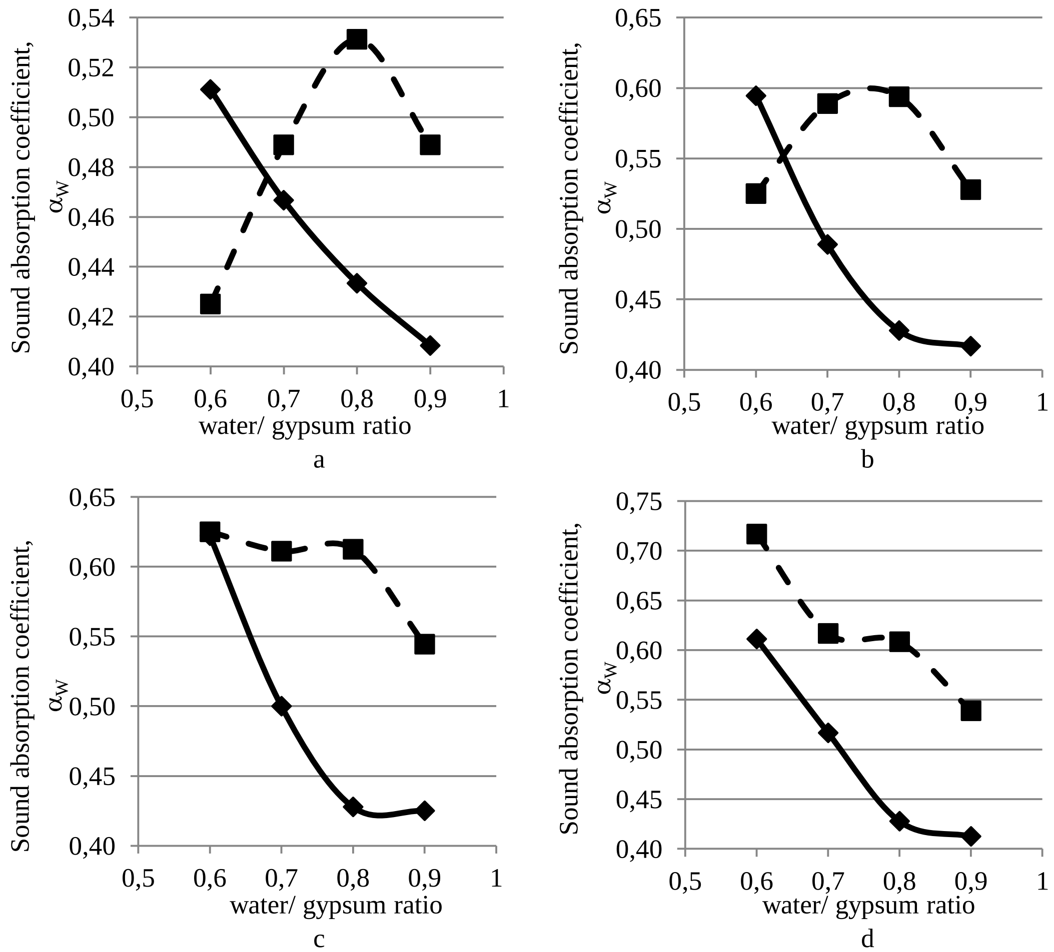


Figure 5. Foam gypsum weighed average sound absorption coefficient at different production technology. ▬ SAS 4 ml; ▬ ▬ SAS 6 ml, a-30 mm thick sample; b-40 mm thick sample; c-50 mm thick sample; d-100 mm thick sample

Material thickness and frequency connection of sound absorption tiles of mineral wool basis has been researched already in the '60s of the last century. Smith (Шмидт, 1969) has determined the sound absorption coefficient for acoustic tiles and has concluded that by decreasing material thickness the maximal value of sound absorption coefficient moves to a higher frequency range. In research with foam gypsum the same concurrence has been observed as in research with mineral wool Table 2 which is a fibrous material. We foresee that this concurrence is of a general character, and we will try to confirm it with further investigations.

Table 2

Foam gypsum of production technology w/g 0.6 SAS 4 ml average volume mass 377 kg m^{-3}, sound absorption coefficient, depending on the thickness of material

Thickness, mm	The sound absorption coefficient of the average octave bands, α					
	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	Average
10	0.08	0.12	0.27	0.72	**0.85**	0.22
20	0.14	0.33	0.61	**0.73**	0.69	0.37
30	0.24	0.51	**0.64**	0.70	0.76	0.51
40	0.35	**0.58**	0.62	0.71	0.76	0.59
50	0.43	0.57	0.61	0.71	0.75	**0.62**
100	**0.48**	0.53	0.61	0.71	0.75	0.61

The results of the sound absorption coefficient of foam gypsum tested at the reverberation chamber are shown in Fig. 6. The figure shows values of the sound absorption coefficient at 1/3 octave bands and at average octave bands. The maximal value of the sound absorption coefficient is at 1 kHz (0.91) and siding 1/3 octave band frequency response is very close to 500 Hz (0.860 and 2 kHz (0.89). Decrease of absorption coefficient value of the material was observed at lower frequencies. This can be prevented by installing a material into the suspended ceiling system or placing rockwool behind the material. The sound absorption coefficient according to the Standard LVS EN ISO 11654:2000 is 0.8 that corresponds to the B class absorbent.

The obtained result is for 0.2 higher than the sound absorption coefficient obtained in the absorption tube. That is because in the acoustic tube, sound falls on the measurement sample perpendicular to the sample surface, but in a reverberation chamber a diffused sound field has been formed, and the sound falls at various angles in such a way improving the absorption capacity.

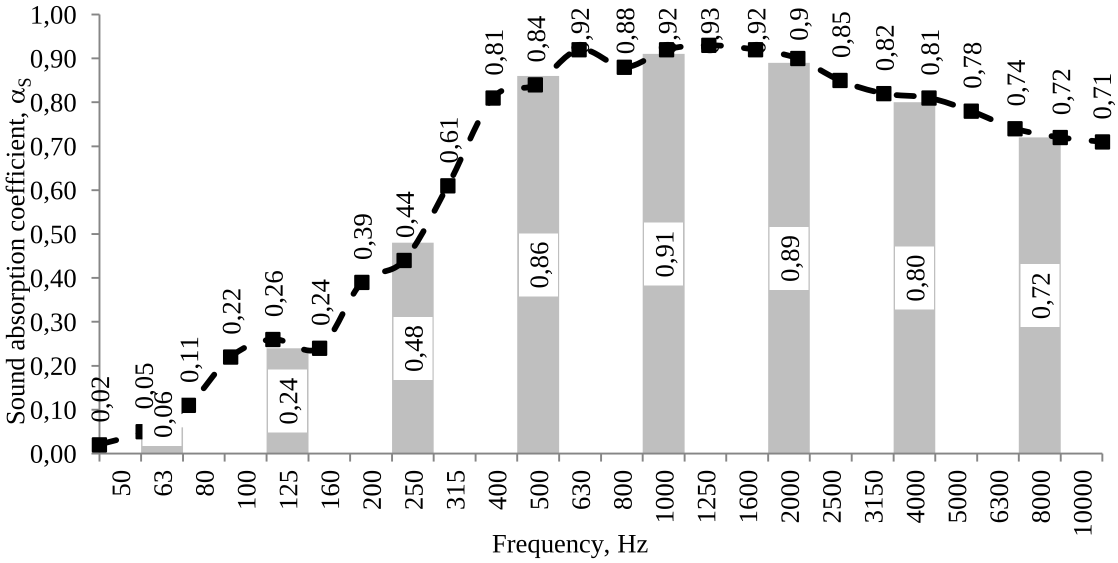


Figure 6. Measurement of sound absorption coefficient in a reverberation chamber. Frequency response curve of 1/3 octave bands foam gypsum with production technology w/g ratio 0.6, SAS 4 ml. — — - α value measured frequency response (1/3 octave band); ■ - Absorption coefficient, α, average octave bands

For foam gypsum tiles tested for flexural strength in the reverberation chamber, all samples underwent a pressure test of 6 kg. The visual test didn't show any cracks, and samples were tested by Fig. 2. scheme till sample crushing, gradually increasing the pressure by 400 g till the samples were crushed. By equation 4 the determined standard material flexural strength is 0.055 MPa, but after strength tests with balks (40×40×160mm) the three-point bending test with production technology foam gypsum strength in flexural is 0.13 MPa, which is two times bigger than standard requires. For foam gypsum ceiling tiles crushing was necessary at an average weight of 15 kg, which by equation 4 in flexural strength is 0.137 MPa and 2.5 times greater flexural strength as determined by the Standard LVS EN 14246:2006 and 5% greater than the strength after material testing with balks on a three-point bending test.

CONCLUSIONS

By using production technology with composition w/g 0.6 and SAS 4 ml, the foam gypsum of volume/ mass till 400 kg m^{-3} was obtained. Flexural strength 0.13 MPa, 40 mm thick tiles foam gypsum absorption increases the Standard LVS EN 14246:2003 requirements 2.5 times, reaching 0.137 MPa and compressive strength >0.20 MPa. sound absorption coefficient, measured at an impedance tube 0.62 (50 mm) C class material and reverberation chamber 0.80 (40mm) B class material.

It has been determined that foam gypsum sound absorption material and mineral wool has analogical behavior between sound absorption coefficient and the material thickness, although these materials have different structures. The sound absorption coefficient at 250 Hz is better for materials having a 100 mm thickness. By increasing the sound frequency a maximal sound absorption coefficient has been reached for samples with less thickness.

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