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Investigation of mechanical properties and coefficients of sound insulation of innovative silicone composite material

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Abstract

A new non-combustible, non-flammable, waterproof, long-lasting, heat-insulating composite material was made of glass foam granules (derived from glass waste) and a hydraulic inorganic binder in the form of a white Portland cement solution (CEM I 52.5 N), zeolite, airborne agent and water. The resulting composite is resistant to climatic temperature fluctuations, characterized by a coefficient of thermal conductivity of λ = 0.047 W/mK and is potentially applicable for the production of sound and heat insulating panels for non-bearing partition walls and external insulation of buildings. The technology for obtaining the product is in line with the current tendencies for the development of ecological productions through the utilization of waste materials and provides the opportunity to produce various standard monolith products suitable for direct use or further processing. Experimental studies of the acoustic and mechanical performance of standard experimental samples made from the developed composite material were carried out. The average sound insulation value is 30 dB. An average tensile strength of 0.036 MPa and an average compressive strength of 0.55 MPa were found.

Keywords: *composites, sound insulation, soundproofing materials, heat insulating materials*

1. Introduction

An important problem with the design, construction and exploitation of buildings is the achievement of necessary energy efficiency and good sound insulation of residential and industrial premises. Increased noise levels in major cities, industrial areas, transport routes, industrial, public and multifamily buildings require the development and application of effective soundproofing materials. By building an appropriate soundproofing system for living buildings, there is a significant reduction in the noise impact of the external environment in the premises used, while at the same time reducing the sound effects from other parts of the building. Various materials are available for effective soundproofing of airborne noise on facade walls of buildings and internal partitions of solid type (masonry, concrete) or drywall construction [1]. For example, membrane type walls (gypsum board or gypsum fiberboard) with appropriate spacing between the membranes and the dampening layer (mineral wool) are likely to significantly reduce the sound field strength and significantly reduce noise or sound insulation from airborne noise [1].

Effective thermal insulation provides a favorable microclimate in living quarters and significantly reduces the energy consumption to maintain the required temperature values during heating in the winter season and summer months. The thermal insulation materials used in modern building construction increase the insulating capability of the individual enclosures (walls, roofs, floors, etc.) [1–3]. One of the main objectives in the field of new construction [2] and the reconstruction of existing building stock (built on different building systems) [3] is to achieve better energy efficiency and to build so-called "energy-saving buildings" characterized by increased thermal insulation capacity of its enclosing structures. A standard option for building an efficient thermal insulation system is the assembly of a suitable insulation material with a special adhesive composition and dowelling to the outer walls, application of a protective polymer-cement coating with reinforcement mesh and laying of a final coating. Other types of insulation are found: sandwich insulation (wall / insulation / wall), combined insulation (inside and outside) and insulation. In today's construction, there are applications with different materials with insulating characteristics: expanded polystyrene (EPS), extruded polystyrene (XPS), mineral wool, aerated concrete, foam concrete, etc.

Expanded polystyrene foam (EPS) is characterized by good sound and thermal insulation properties and adequate vapor permeability, but is unreliable in fire conditions. EPS boards are widely used primarily in the performance of exterior facade thermal insulation and building sound insulation [1−3]. Extruded polystyrene foam (XPS) has a low coefficient of vapor permeability, good mechanical resistance and is mainly used for indoor insulation of buildings [1−3].

Mineral wools (stone, glass, slag) are characterized by a typical fiber structure, A1 combustibility class, vapor permeability, capillary water absorption and good heat and sound insulation performance [1]. Insulation wools produce a variety of products for the sound and thermal insulation of facades, roofs, suspended ceilings, internal walls, pipe insulation systems and aggregates, but because of their increased vapor permeability and capillary water absorption they find limited use.

A heat-insulating construction polystyrene concrete made of polystyrene granules (40−60%), Portland cement, pore-generators and plasticizers is already known [4]. Due to the availability of highly flammable and combustible organic aggregate, this material significantly reduces its design performance in fire conditions. There are other insulation materials: polyurethane (polyurethane foam), wood-fiber insulating sheets, flax, hemp, insulating wallpaper, cork slabs, depron, rubber sheets, foam glass, aerogel, transpiration insulation and others.

The building practice finds the use of thermal insulating concrete and structural thermal insulation concrete suitable for enclosing buildings. Sandless concretes are produced on the basis of a limited amount of binder and large aggregate and they are suitable for building walls, masonry blocks, thermal insulation, drainage, etc. An original physical model of the structure of the pore space in concrete with light fillers was developed [5].

Cellular kinds of concrete (e.g., aerated concrete and foam concrete) have evenly distributed porosity in volume and are made on the basis of a binder, water, a suitable pore-forming agent (blowing and foaming additives), etc. The material is fire-resistant, non-combustible (class A1), ecological, durable, resistant to weathering, has low density, good vapor permeability, sound and thermal insulation properties. The low weight, easy workable, versatile and compound dimensions make it easy to use. Cellular concrete products are used for wall-building applications, indoor thermal and acoustic insulation of buildings, etc.

The main types of sound and heat insulating materials are available and provided by different manufacturers in the form of a variety of products that occupy specific niche markets. At the same time, there is a tendency to develop alternative insulation materials potentially applicable in construction [6−12]. A team of IMSET-BAS improved the technology for the production of foam glass [12,13] and developed a horizontal model for the production of composite thermal insulation materials on a glass-based foam [14]. The necessary facilities for production of granulated granules with energy efficient technology [15] have been designed and a pilot production line is being developed in industrial conditions (INHOM Ltd., Beloslav, Bulgaria). Experimental batches of sintered granules have been produced on the innovative technology developed and, after analysis of the semi-industrial research data; the technology has been improved and claimed through a patent [16]. On the basis of granulated granules and binder as an aqueous dispersion colloid system including Portland cement and zeolite, an innovative non-combustible, non-flammable, long-lasting, ecological, waterproof composite material is developed [10,11]. The material is resistant to climatic fluctuations and is characterized by a coefficient of thermal conductivity λ = 0.050−0.055 W/mK, noise absorption 30−40 dB, density 210−280 kg/m^3 and compressive strength 4−5 MPa. The developed technology for obtaining the product is in line with the current trends for the use of waste-water ecological productions and the development of technologies for efficient utilization of waste products (glass waste from households and biogas), which at present are not recycled on a large scale in Bulgaria. The applied technological scheme allows the production of monolithic composite blocks, from which it is possible to produce different sized cut-out samples. The composite insulating material is presented in a patent application [10] and the innovation of the product is confirmed by novelty research. The material complies with the existing fire safety requirements addressed in the Fire Safety Regulation [15] and all amendments made and consistent with European requirements [16].

For the optimal application of the developed composite, a sandwich panel (putty / composite / putty) [12] is constructed, consisting of an inner layer formed by the composite material [10,11] and a front and a tiled outer surface with a waterproofing putty. Applying appropriate coatings with features that are tailored to the particular application of the panels allows the performance of the product to be enhanced. Preliminary acoustic tests were performed in laboratory conditions and the dependence of sound insulation coefficients in the frequency range from 65 Hz to 8000 Hz was obtained for both types of composite samples (KM1 and KM2) [12]. The results show average sound insulation over the entire frequency range R = 36 dB and R = 34 dB both types of materials that are better than the results obtained for ytong [12]. After the study of the existing standard and new alternative sound and thermal insulation materials, a new composite material based on silicate was developed in the contemporary construction and comparison of their exploitation characteristics and application conditions. The purpose of the present work is to examine in the laboratory the mechanical properties and the coefficients of sound insulation of experimental model samples, prepared by the developed innovative material. The resulting experimental results are considered as the basis for determining the directions for further optimization of the technical performance of the product.

2. Experimental procedure

Appropriate formwork matrices are required and designed to form experimental laboratory specimens (cubes, prisms, panels) provided for the present study. The experimental specimens were made on the basis of 5 to 20 mm glass-granulated granules (obtained from household glass waste) and a hydraulic inorganic binder – white Portland cement CEM I 52.5 N (manufacturer Devnya Cement, Bulgaria). 4% (zeolite) clinoptilolite subjected to thermal treatment at 500°C was introduced into the formulation system. The presence of a modifying additive (zeolite) in the composition of the binder system shortens the time to collect the required strength of the experimental specimens. A Vimachem-Foam Concrete Injection Admixture (made in Vimatec – Greece) was introduced to prepare the cement solution. To the homogenized cement solution, with continuous stirring, the foamed granules are added until a full surface coating is achieved. The resulting mixture is applied to the perforated bottom formwork forms which allow (by vibration) to remove the excess liquid phase of the aqueous dispersion colloidal system. Depending on the applied vibration time and granularity, the bulk density of the product varies before drying and bonding the residual portion of the aqueous dispersion colloid system. The bulk density of the composite product in the raw and dry state grew by increasing the amount of smaller sintered glass granules in the feed mixture. Forms are free formwork after 72 hours and spent 10 days at 15°C to 28°C to achieve the required strength. The material allows a variety of mechanical processing by cutting without requiring significant qualification and specific equipment, and because of its low weight it is easy to transport. Laboratory tests have produced the necessary experimental details: a cube size 10 × 10 × 10 cm, prism size 4 × 4 × 16 cm, composite panel size 36 × 27 × 8.4 cm. For a comparison, a test sample (panel) was prepared without the presence of foam granules but with an identical ratio of the other components.

In the mechanical tests, a standard machine (press) was used for combined examination and pressure stressing ZD 10/90. The experimental specimens were tested using a mercury porosimeter.

The acoustic tests were conducted in two chambers, between which the test pieces were placed. The volume of the cameras is 0.125 m^3. Cameras have thick walls and are lined with sound-absorbing materials. In order to determine the insulating power of composite materials, the sound insulation coefficient R is used, which is the sound pressure ratio $P1$ of the falling sound wave to the sound pressure $P2$ of the wave passing through the barrier [12]. The sound field created is homogeneous and isotropic and the transmission of sound outside the panel is minimized. The mode of operation is stationary. The sound pressure $L1$ of the falling sound wave is measured with a microphone. A second microphone measures the $L2$ pressure of the wave passing through the sample in the second chamber.

The sound pressure measurements L (dB) in the two chambers are carried out in two ways:

1. Using a sinusoidal signal supplied to the single frequency speakers in octave bands 63, 125, 250, 500, 1000, 2000, 4000, 8000 Hz and sound pressure measurements L (dB) with microphones in both chambers at each detected frequency. The recording of the sound level in the cameras is done with the RFT 00024 sounder.

2. By using a broadband signal generated by a sweep generator in the 65 to 10 000 Hz frequency band that is transmitted to the loudspeaker, and the sound pressure measurements L (dB) of the sounding waveform passing through the sample with microphones, subsequent recordings and signal treatment (spectral analysis).

The coefficient of sound insulation is determined by the dependence [12]:

$$R = L1 - L2, \text{ dB} \quad (1)$$

where:

$L1$ and $L2$ are the measured sound pressure levels, respectively, in the chamber with the sound source and the receiving chamber.

3. Results and discussion

Figures 1–4 show photographs of the composite panel. Figures 5–7 show photographs of standard experimental specimens (obtained from the developed composite material) subjected to mechanical tests (Table 1 and Table 2).

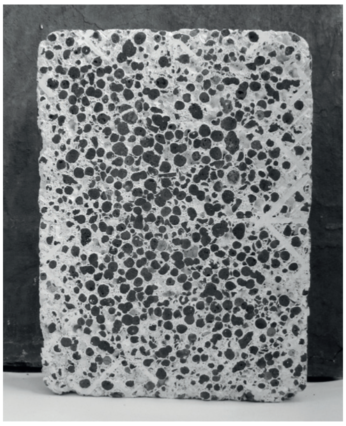

Fig. 1. Experimental specimen – composite panel with dimensions 36 × 27 × 8.4 cm

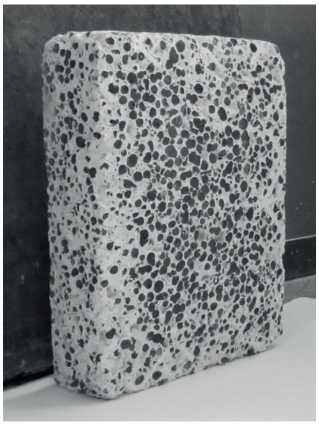

Fig. 2. Experimental specimen – composite panel with dimensions 36 × 27 × 8.4 cm

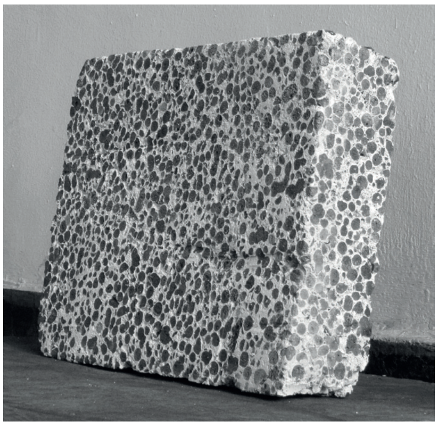

Fig. 3. Experimental specimen – composite panel with size 36 × 27 × 8.4 cm

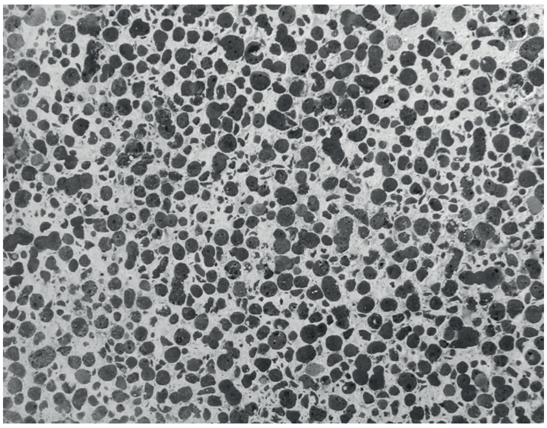

Fig. 4. Front surface of a composite panel

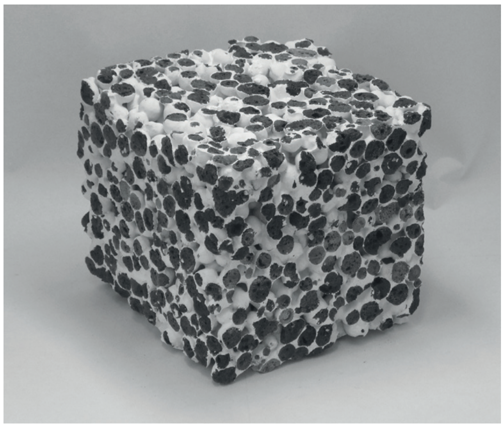

Fig. 5. Experimental composite specimen – a cube size 10 × 10 × 10 cm

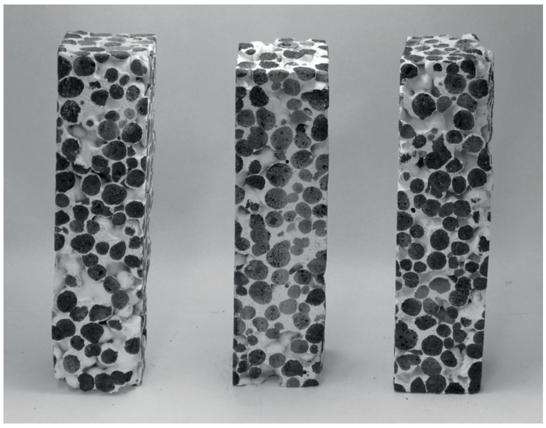

Fig. 6. Experimental composite specimens – prisms with size 4 × 4 × 16 cm

Table 1. Test results of experimental specimens – cubes sizes 10 × 10 × 10 cm

Sample No.	Mass, g	Density, kg/dm³	Force of pressure F_c, kgf	Toughness of pressure R_c, MPa
1	330	0.330	2.50	0.250
2	500	0.500	5.76	0.576

Table 2. Test results of experimental specimens – prisms sizes 4 × 4 × 16 cm

Sample No.	Volume, cm³	Mass, g	Density, kg/dm³	Destroying load of sagging, kgf	Flexural tensile strength R_b, MPa
1	256	125	0.488	12.0	0.030
2	256	130	0.508	16.0	0.040
3	256	115	0.445	13.0	0.035
4	256	115	0.445	16.0	0.040

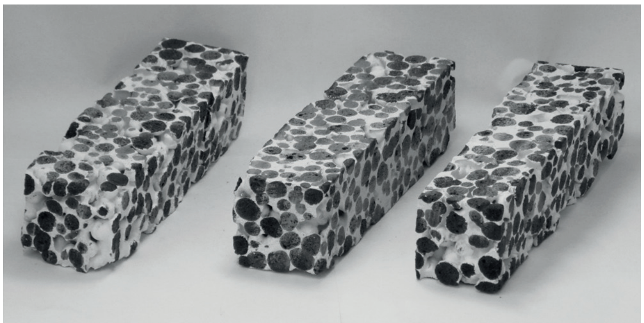

Fig. 7. Experimental composite specimens – prisms with dimensions 4 × 4 × 16 cm

On the basis of the results, an average tensile strength of Rb = 0.036 MPa was found.

Experimental specimens have been found to have a compressive strength of half a prism with a pressure area of 16 cm².

Sample No. 1 – 0.60 MPa, No. 1a – 0.47 MPa,
Sample No. 2 – 0.52 MPa, No. 2a – 0.61 MPa,
Sample No. 3 – 0.53 MPa, No. 3a – 0.43 MPa,
Sample No. 4 – 0.70 MPa, No. 4a – 0.56 MPa,
Average compressive strength – 0.55 MPa.

Figures 8 and 9 show the results of the acoustic measurements for the developed composite panel with sintered glass granules and the non-granular composite material realized in the two ways described above: measured at individual frequencies and across the frequency range.

Figure 10 compares the results for the composite panel with sintered glass granules and the reference panel without granules obtained from measurements at separate frequencies 63, 125, 250, 500, 1000, 2000, 4000, 8000 Hz. The average value of the sound insulation over the entire frequency range is R = 30 dB for the innovative composite material and R = 28 dB for the non-granular material.

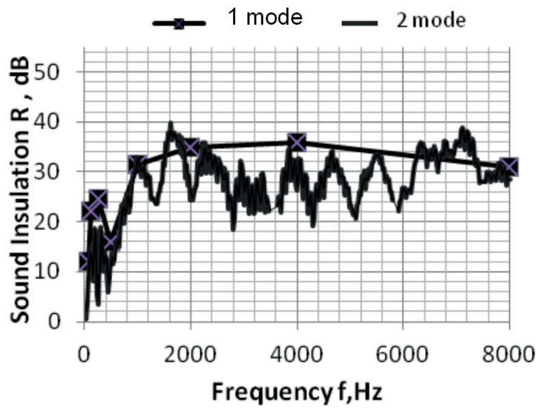

Fig. 8. Coefficient of sound insulation of the composite panel with sintered glass granules

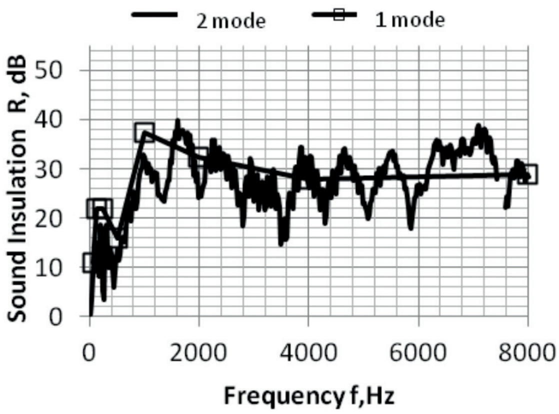

Fig. 9. Coefficient of sound insulation of composite panel frequency without sintered glass granules

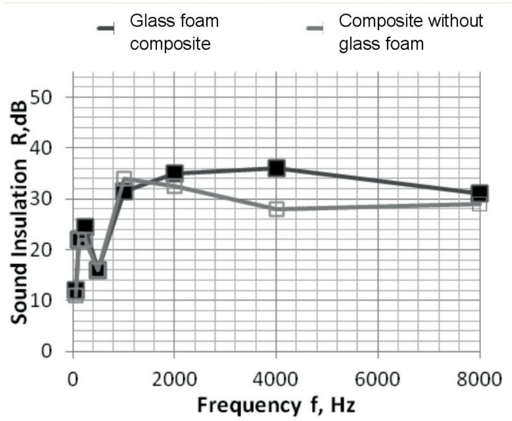

Fig. 10. Sound insulation of composite panel with foam granules and composite panel without sintered glass granules

4. Conclusions

After the study and analysis of the technological, operational and market characteristics of the existing sound and heat insulating materials, an innovative, non-flammable, non-combustible, heat-insulating (heat conduction λ = 0.047 W/mK), durable, waterproof and weather-resistant composite material based on silicate was produced. The product is made of granules made of glass (derived from glass waste), a hydraulic inorganic binder (glaze white Portland cement CEM I 52.5 N), zeolite (clinoptilolite), air-entraining additive and water. Ecological technology for the production of articles using recyclable raw materials is presented which allows the production of monolithic products for direct application or additional technological processing (cutting, reinforcement, deposition of single-layer and multi-layer coatings and screed, etc.).

Laboratory tests of the acoustic and mechanical characteristics of experimental samples obtained from the developed innovative material were performed. The average sound insulation value is 30 dB. An average tensile strength of 0.036 MPa and an average compressive strength of 0.55 MPa were recorded in the tests performed. The resulting experimental data sets out the main directions for impending optimization of material performance that is considered to be potentially applicable in the design of sound and heat insulating panels for non-load-bearing partition walls and external insulation of buildings and would extend the product scope to the market for building materials.

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