Research Journal of Applied Sciences 9 (10): 674-679, 2014
ISSN: 1815-932X

A New-Generation Heat-Insulating Constructional Glass Composite

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Abstract: One of the promising trends now a days is the designing of walling materials which would efficiently fulfill their functions of saving the energy, spent for creating and maintaining the necessary indoor temperature conditions. The increasing demands of the modern society in the sphere of architecture and urban construction impose new higher requirements to building materials many of which haven't been produced in Russia before or have been underproduced. Now a days the designing of high-efficiency building materials is impossible without taking into account the requirements of builders, architects, customers and future dwellers. It requires a new integrated approach to designing general principles of managing the inorganic world objects' development. The study describes the major aspects of producing the highly-efficient walling materials and the processes of pore formation and structure formation of highly-porous heat-insulating materials. By means of electron microscope MIRA SCAN and X-ray phase analysis the microstructure of the obtained glass composite has been researched.

Key words: Foam glass, heat insulation, heat-conductivity coefficient, geonics, porosity, strength, water absorption capacity, effervescence, annealing, heat-insulating material, protective-decorative coating, glass composite

INTRODUCTION

Since, ancient times people have been using natural materials and trying to perceive the technology of obtaining them and to reproduce the geological processes of rocks and minerals formation in order to design the building materials' manufacturing technology (Lesovik, 2012, 2006).

Due to sharp changes of natural climatic conditions, an important aspect of building and reconstruction of objects becomes heat insulation which determines the indoor climate. Among the efficient natural inorganic heat-insulating materials we can single out pumice and tuff.

Pumice is a high-porosity (bubbly, foamed) natural volcanic glass which was formed at the effervescence and hardening of magma, emitted at the volcanic eruptions. It forms as a result of such a rapid hardening of lava that there is no time for minerals to crystallize from the melt.

The average density of pumice is 350-800 kg/m^3; it is chemically inert and fireproof. The softening temperature range is 1300-1400°C. In most cases pumice belongs to acidic rocks by its chemical composition and consists mostly of glass (crystalline minerals content is usually <1%).

The pore size of pumice varies from fractions of millimeter to 3 mm; the shape of pores is round or prolate. The grain porosity measures up to 85%. The ultimate compression strength of pumice is 2.5-40 MPa (Logvinenko, 1984).

Tuff is a natural rock, emitted during volcanic eruption. It often includes impurities of nonvolcanic origin. It has porous structure and is considered an excellent material for ornamental finishing.

This rock material has properties due to which it is widely used in building and architecture. It has a pleasant texture and a wide range of colors is characterized by heat-insulating and sound proof properties, strength and durability. It is used for making handicrafts and household items. The density of tuff is 500-800 kg/m^3, porosity from 21.3-46.6%, ultimate compression strength from 13.3-56.4 MPa, heat conductivity from 0.21-0.33 W/°C (Logvinenko, 1984).

Foam glass is the closest technogenic analogue of pumice and tuff. The term of cellular glass or foam glass

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is used for the glass, having the porous (cellular) structure. Porosity of various types of cellular glass amounts to 80-95%. Such high porosity provides the material with high heat-insulating properties: depending on the volume weight its heat conductivity ranges within 0.058-0.128 W/(m°C).

Cellular glass possesses a number of other properties, essential for building industry relatively high strength, water-resistance, incombustibility, frost-resistance and easy machining; it is easily sawn, cut, drilled; nails can be driven in it and they hold tight.

Due to indispensable and unique properties the foam glass is used for heat-insulation and waterproofing of foundations, cellars, roofing and walls. Application of foam glass and other foam materials in building industry makes it possible to reduce the walling structures' thickness, lower the consumption of basic building materials, lighten the engineering structures, industrialize building expenses and cheapen the construction and maintenance including costs for heating of buildings.

The important advantage of foam glass in comparison with some natural insulating materials is its inorganic composition. Due to this it is resistant to rot, microgerms, influence of high temperatures, acids and alkalis; it is easily disposed (Minko *et al*., 2008). The comparative characteristics of the properties of foam glass and other heat-insulating materials are given in Table 1.

The high environmental and health safety of foam glass has resulted in the fact that this material is unrestrictedly used for heat insulation of cold storage houses and for heat-insulating lining of tanks used in beer, wine and dairy production.

Heat insulation is widely used in construction and many other branches of industry. The structural features of foam glass and other foam materials and the values of their physical, mechanical and chemical properties rank them as the most advanced artificial materials. In spite of all the advantages of foam glass usage, its application is limited. It occurs due to the economic aspects of its manufacturing-relatively high price of a material unit.

The tendency of the recent years is to make the material cheaper by the additional charging of foam-forming mixes with technogenic waste (metallurgical production slags, ashes from heat and power plants, etc.) and local raw materials (diatomites, perlites, zeolites, etc.) (Puchka *et al*., 2013a; Kazmina *et al*., 2012; Ventrella *et al*., 2011).

The comparative characteristics of the most widely used heat-insulating materials confirm that the most promising in a number of properties is the usage of foamglass-based composite heat-insulating materials.

So, the foam glass must be provided with such properties which would characterize it not only as heat-insulating or sound-insulating material which requires depositing protective and decorative coatings on it to use it in building industry but as a glass composite, possessing the high strength and decorative properties of the glazed ware (e.g., ceramic tiles) and not requiring the additional protective coatings to protect it from weather impacts (Puchka *et al*., 2013b).

Table 1: Characteristics of heat-insulating materials

Properties	Foam polystyrene	Preformed mineral wool	Autoclaved gas concrete	------Foam glass (SniP II-3-79)----		
Density (kg/m^3)	40-150	50-350	350-700	200	300	400
Heat-conductivity coefficient (W/m·K)	0.038-0.05	0.036-0.091	0.077-0.175	0.07	0.09	0.11
Vapour permeability, mg/(m·h·Pa)	0.05	0.38-0.60	0.25-0.23	0.03	0.02	0.02
Water absorption capacity	2-15 (%)	Not determined	5-20 (%)	Not above 5 (%)		
The calculated weight moisture content in the material (%)	1-10	2-5	8-14	1-2	1-2	1-2
Air permeability resistance (m^2·h·Pa/kg)	79	2	1960	Air-proof		
Dimensional stability	Shrinks	Satisfactory	Perfect	Perfect		
Compression strength (MPa)	0.8-5.0	2.0	3.6	5.7		
Resistance to the short-term heat exposure (°C)	100	250	450	750		
The upper temperature limit of maintenance (°C)	80	200	400	600		
Durability in service (wearing with the course of time)	After 5-10 years the material embrittles and decays	If dry, the service life is unlimited	Service life is unlimited	Service life is unlimited		
Environmental safety of material	In the course of service emits hazardous dusty and gaseous components	Environmentally safe	Environmentally safe	Environmentally safe		
Application technology	Fastened with nails, requires rigid frame	Fastened with nails, requires rigid frame	Sawed, glued with polymeric and non-organic mastics, stuccoed poorly	Matches with any cement mortars, sawed, glued with polymeric and non-organic mastics, stuccoed well		

THE MAIN PART

For this purpose, there was carried out the analysis of the earlier selected natural materials which has shown the following. Pumice is comprised mostly of amorphous volcanic glass (crystal phase within the range of 1.0-1.5%) and tuff, on the contrary, contains mostly crystal phases and a small amount of amorphous phase. So, adding the finely-dispersed technogenic crystalline raw stuff to foam glass will allow producing a stronger constructional material (due to reinforcing), like tuff and at the same time keeping the high thermal-physical characteristics and low volume weight of pumice.

To obtain glass composite the foamed vitrocrystalline material was used as a base and to deposit the inorganic coatings there were used the specially designed decoration techniques. The foamed vitrocrystalline material was obtained by means of conventional powder technology and as crystallization centers, reinforcing the foam glass frame, there was used the wet magnetic separation waste. The amorphous-crystalline structure determines the high strength properties and thermal-physical characteristics of the material. The model of heat-insulating glass composite structure is presented in Fig. 1. To strengthen the walling material (glass composite) a finely-dispersed reinforcing crystalline component is added to glass matrix and to improve the durability and reduce costs at installation the glass composite will have a plasma-chemical coating on the face surface.

This model is confirmed by the research, carried out by means of scanning electron microscopy. In the micrograph of a heat-insulating constructional glass composite sample shown in Fig. 2, in the interpore partition we can see crystalline inclusions, reinforcing the matrix. The basic aesthetic and consumer properties and technical-performance characteristics of the obtained material are presented in Table 2.

The application of foamglass-based heat-insulating composite with protective-decorative coating on the face surface in the building industry will allow erecting the more lightweight energy-saving constructions and thus developing areas on loose and boggy grounds in hot and cold climate areas, reconstructing the existing buildings. At this all the buildings, constructions or structures, built with the use of heat-insulating glass composite will provide the considerable mitigation of the damage at the adverse technogenic and environmental effects. The glass composite keeps all the basic unique properties of foam glass. In comparison with conventional heat-insulating building materials the glass composite is characterized by low heat conductivity, high strength and processing ease as well as by ease of installation, environmental safety and longevity. Such a complex of properties is not possessed by any other known heat-insulating or constructional material (Puchka *et al.*, 2013c).

Table 2: Performance characteristics of the designed material

Properties	Values
Acid resistance	AA class
Water resistance of the coating	III hydrolytic class
Compression strength (MPa)	6.03-6.5
Bending strength (MPa)	2.16-2.24
Freeze-thaw durability (cycles)	>50
Heat conductivity (W/m·K)	0.07-0.09
Density (kg/m^3)	240-260
Water absorption capacity (%)	<8

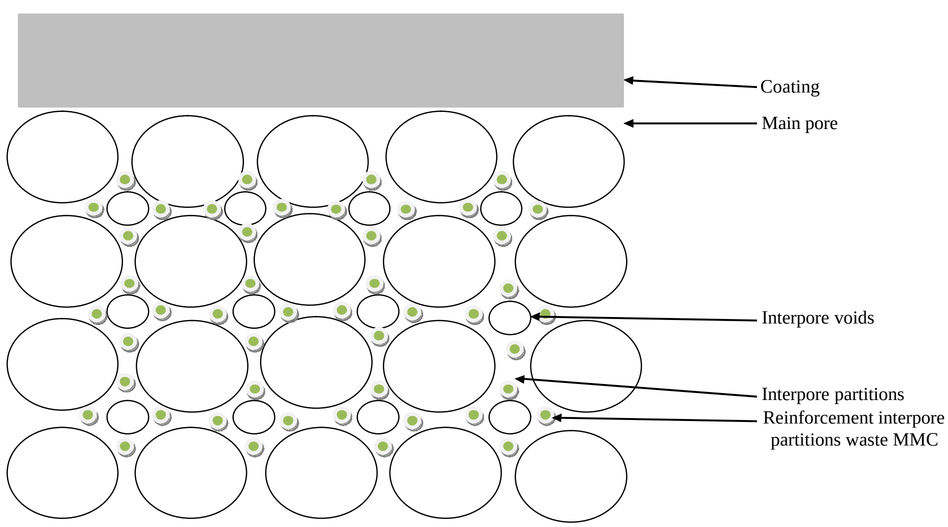

Fig. 1: The structure of heat-insulating constructional glass composite

Table 3: Comparative characteristics of glass composite and gas-concrete blocks

Materials	Geometrical parameters (mm)	Average density (kg/cm^3)	Sample weight (kg)	Mass performance standard (kg) (SNiP 23-02-2003)
AEROBEL gas-concrete blocks	600×400×200	500	25	Not above 32
Heat-insulating constructional glass composite	800×500×200	300	24	

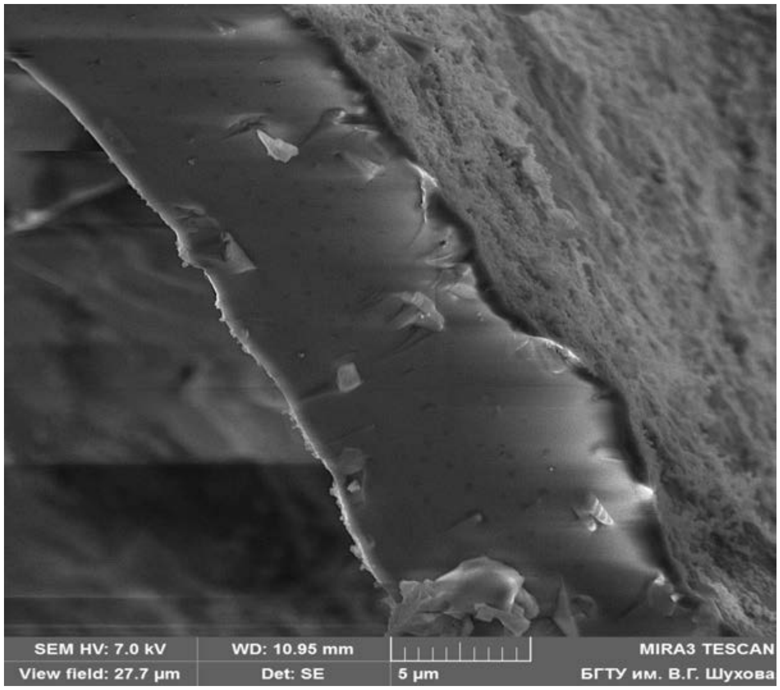

Fig. 2: Micrograph of heat-insulating constructional glass composite sample (interpore partition, reinforced with WMS waste)

The complex of glass composite properties low heat conductivity, high strength, stability and technological effectiveness makes this heat-insulating material virtually irreplaceable both in building industry and in many other spheres.

Due to its cellular structure and vitreous properties, the heat-insulating glass composite is a sufficiently rigid and resilient material. Its ultimate compression strength is within the range from 2-6 MPa. At the same time this material lends itself favorably to machining which allows producing items of any shape.

The blocks of heat-insulating constructional glass composite have the advantage of gas-concrete blocks and meet the requirements to heat-insulating properties of SNiP 23-02-2003 «BUILDINGS HEAT INSULATION». With account of performance standards requirements we have determined the admissible outline dimensions of glass composite blocks and carried out the comparative analysis with gas-concrete blocks (Fig. 3). Table 3 gives the comparative characteristics of the blocks.

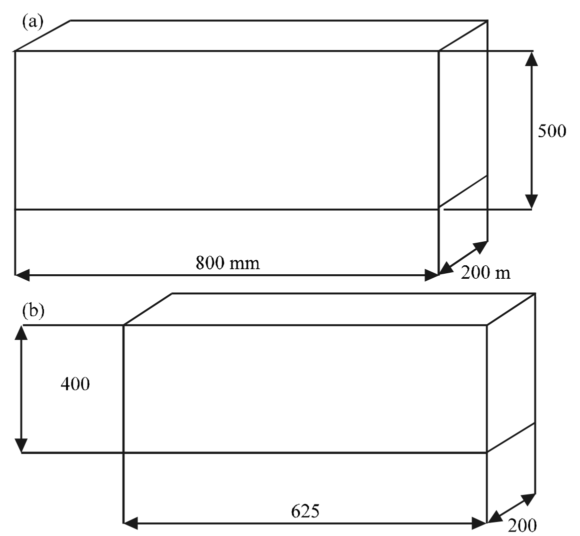

Fig. 3: Outline dimensions: a) heat-insulating constructional glass composite and b) gas-concrete blocks

The comparative analysis of a glass composite block and a gas-concrete block (Fig. 3 and Table 3) has demonstrated that a glass composite block weighs 24 kg, more or less similarly to a gas-concrete block

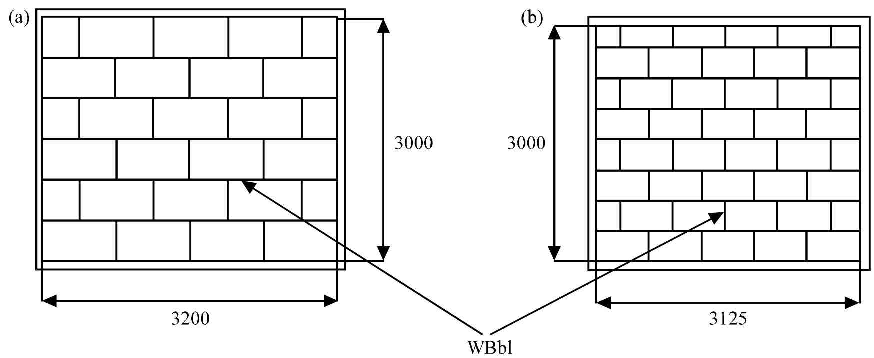

Fig. 4: Comparative assessment of walling fragments: a) fragment of heat-insulating constructional glass-composite blocks wall and b) fragment of gas-concrete blocks wall

Table 4: Basic figures of the wall

Materials	Load on foundation (kg)	Overall joints length (m)	Heat conductivity of a block (W/m°C)
AEROBEL gas-concrete blocks	937.5	34	0.14
Heat-insulating constructional glass composite	720.0	25	0.08

Table 5: Properties of perlite and vermiculite compositions

			Ultimate strength (MPa)	
Materials	Average density (kg/m^3)	Heat conductivity (W/m°C)	Compressive	Bending
Perlite cement	250-350	0.07-0.0810	-	0.22-0.26
Heat-insulating glass perlite	180-300	0.064-0.093	0.3-1.2	0.2-0.7
Cement vermiculite	400-500	0.08-0.1000	0.5-1.0	-
Vermiculite based on soluble glass	250-300	0.07-0.0900	0.4-0.6	0.2

Table 6: The results of adhesion shear test in 24 h after placing mortar

Bases	Tearing force (F, kg)	Weight of the placed mortar (M, kg)	Area of the placed mortar (cm)	Actual value of adhesion (F/M)	Specified value of adhesion (F/M)
Lime bricks	17.8	0.590	30×30	23.6	20
Ceramic bricks	13.7	0.580	30×30	30.1	20
Foam concrete	13.3	0.570	30×30	23.3	20
Heat-insulating constructional glass composite	13.6	0.570	30×30	23.5	20

(performance standard not above 32 kg) but due to lesser density the geometrical parameters at the same thickness are larger. This will allow decreasing the number of expansion masonry joints and reducing the load on foundation.

We have carried out the assessment of walling fragments made of gas-concrete blocks and of heat-insulating constructional glass composite blocks of the relatively same dimensions (3200/3125 mm long, 3000/3000 mm high, 200/200 mm thick).

In Fig. 4 and Table 4, we can see that for the considered walling fragment the smaller number of glass-composite blocks is used. This allows decreasing the mortar consumption by 29%, the overall length of joints (cold bridges) by 26%, the load on foundation by 23% and the projected reduction of heat losses amounts to 18-20%.

Taking into account that thermal and physical characteristics of heat-insulating constructional glass composite are higher, than those of a gas-concrete block by 42% (heat conductivity is 0.08/0.14), the thickness of 200 mm is enough to provide the necessary heat transmission resistance.

To reduce heat losses through the masonry joints one can use perlite and vermiculite sands which are close in their heat-conductivity properties to the heat-insulating constructional glass composite (Table 5). We have carried out the adhesion tests for walling materials. As we can see from Table 6 at the shear test after placing mortar the actual value of adhesion for heat-insulating constructional glass composite was 23.5.

To simulate the operating conditions there was conducted the contact area freezing-and-thawing test of the glass composite. As we can see from the results, by tearing force value the heat-insulating constructional glass composite is close to foam concrete and ceramic bricks. The freezing-and-thawing test (25 freeze-thaw cycles) has shown that the decrease of adhesion bond strength for heat-insulating constructional glass

Table 7: Results of contact area freezing-and-thawing test

Base	Average adhesion bond (MPa) strength of test samples	Average adhesion bond strength of test samples (Mpa)	Decrease of adhesion bond strength (MPa %)	Performance standard of the adhesion bond strength decrease according to GOST 31356-2007 (%)
Lime bricks	0.65	0.24	14.3	Not above 20
Ceramic bricks	0.60	0.22	15.4	Not above 20
Foam concrete	0.50	0.21	16.0	Not above 20
Heat-insulating constructional glass composite	0.52	0.22	15.5	Not above 20

composite amounted to 10.6% which doesn't exceed the performance standard (not above 20%) according to GOST 31356-2007 (Table 7).

RESULTS

So, there has been designed a new high-efficient inorganic heat-insulating constructional material for insulating buildings' and constructions' walling structures which can be competitive at the building materials market due to its high structural and heat-insulating performance.

CONCLUSION

The production of foamglass-based heat-insulating composite with protective-decorative coating on the face surface is environmentally oriented, as it allows using any scrap glass and glass manufacturing waste and application of foam glass will make it possible to obsolete the environmentally hazardous heat-insulating materials for example, the environment-damaging and fire-prone foam plastic, etc.

The proposed material can be effectually used for private housing construction according to programs of «Improving the living standards of Belgorod region population» and «Development of individual housing construction».

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