Foamed slag glass – unique insulating material

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ABSTRACT: Technology of synthesis of the thermal insulating environmentally friendly glass material based on thermal power plant's slag waste– foamed slag glass –is developed. Batch compositions and materials synthesis modes using various foaming agents are investigated. Technological and operational properties are defined: a density of not more than 600 kg/m^3; thermal conductivity of not more than 0.08 W/(m·K), unlimited lifetime in the range of -150 ... +550 °C at a cost of 2-3 times lower in comparison with market counterparts.
KEYWORD: slag waste, thermal insulation, foam glass, building materials

1 INTRODUCTION

1.1 *Thermal insulation nowadays*

One of the most important ways to save fuel and energy resources is to minimize heat loss through the building envelope. So it is necessary to use high-quality thermal insulating materials in civil and industrial construction, as well as in heat transportation systems. Lack of effective environmentally friendly thermal insulating materials leads to a large loss of heat energy.

Effectiveness of most materials for thermal insulation decreases rapidly due to the ingress of moisture, condensation, and mechanical or chemical damage to adjacent materials (films, cladding, bedsteads, etc.). Such processes result in increasing maintenance costs, power consumption, equipment damaging, structures destroying, etc.

1.2 *Foam glass – unique material*

Foam glass - cellular glass with foam structure – is especially allocated among the thermal insulating materials. The basis for its production is glass and various inorganic and organic materials used as foaming agents. Exclusive properties of foam glass allow its use in cases where any other heat insulating material is ineffective or does not correspond to the requirements of safety and technical conditions. It can be rightfully said that it is a versatile material. Its lifetime is practically unlimited, and the physical properties do not change over time.

Due to its structure and chemical composition foam glass has low thermal conductivity, compressive high strength and low density. It is moisture- and vapor-impermeable, enclosed glass cells (bubbles) do not absorb water. Foam glass is non-toxic and completely fireproof, it does not change size under the influence of high temperatures. Foam glass is not conducive to corrosion of metal structures, to which is mounted. It is resistant to pests and rodents. Foam glass has a minimum processing during installation works.

Thermal insulation is not the only purpose of the foam glass, it is used for protection against noise, as a filler in three-dimensional details and even as decorative material. And finally, it is also important that foam glass an environmentally friendly product (Ponsot & Bernardo, 2013). The main drawback of foam glass is in its high price compared with the market counterparts. In this regard there has been investigated the possibility of development of thermal-insulating material - low-density foamed slag glass (FSG) - with partial replacement of glass cullet on the thermal power plants slag waste which is similar to it in chemical composition and significantly reducing cost of the final material.

2 LABORATORY SAMPLES

2.1 *Preparing the samples*

Foamed slag glass is based on two main raw materials: cullet and TPP slag waste, chemical composition of which is given in Table 1. Besides, it is possible to introduce boron-containing compounds to reduce foaming temperature.

Table 1. Chemical composition of raw materials.

Material	Chemical composition*, wt. %						
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O
Slag waste	57.5	23.0	10.8	1.9	1.2	3.6	0.9
Glass cullet	71.2	2.70	0.8	3.4	7.6	0.8	13.2

* Oxides content of which in the material is less than 0.2% are not shown.

Foaming agents used in this research are inorganic carbon (Yatsenko et al. 2013), carbonate (Liao & Huang 2012), and organic materials.

On the basis of the above materials there was developed a number of compositions, which differs in types of foaming agents and main materials proportions. Then samples of developed compositions were heat-treated according to Figure 1.

Figure 1. Figure of FSG laboratory samples synthesis.

2.2 *Structure and properties*

Basic physical and mechanical properties of the samples were determined due to standard methods. According to the results of determination there were selected five optimum compositions which properties shown in Table 2. Photographs of the samples are shown in Figure 2. It should be noted that depending on the type of foaming agent materials obtained may have different properties. So, for example, Figure 2c shows that the carbonate foaming agent forms a channel-like pores which provides improved sound insulation properties, thus extending the range of materials application.

Table 2 - Main properties of FSG

№	Foaming agent	Slag quantity, wt. %	Density, kg/m^3	Compressive strength, MPa	Thermal conductivity, W/(m·K)
1	organic	20	160	1.5	0.061
2	organic	30	240	2.6	0.071
3	carbonate	30	250	3.1	0.072
4	carbon	30	330	4.1	0.074
5	organic	50	500	7.2	0.080

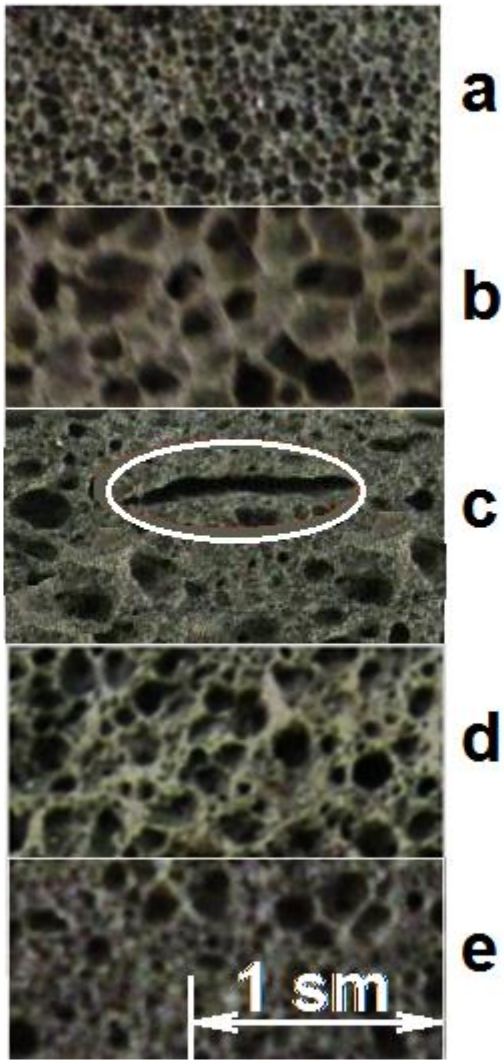

Figure 2. Photographs of the FSG laboratory samples.

3 FSG-BASED PRODUCTS

3.1 *Synthesis and appearance*

Technologies of various kinds of products based on foamed slag glass, namely, technology of granulated and block FSG were developed on the basis of the optimum compositions. Its modes of synthesis are given in Figure 3.

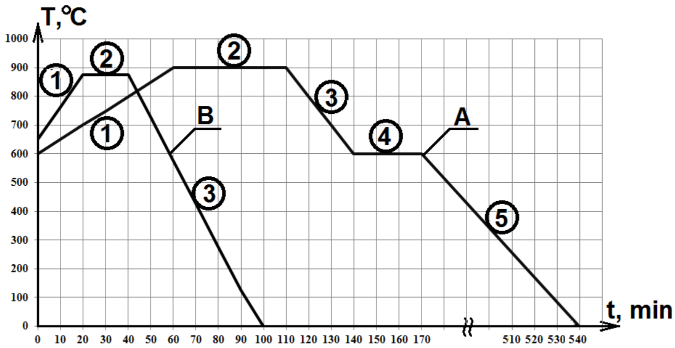

Figure 3. The optimum temperature-time modes of block (A) and granulated (B) FSG synthesis:
1 - calefaction, 2 - foaming, 3 - rapid cooling with porous structure stabilization, 4 additional stabilization, 5 - gradual cooling – annealing

Differences in modes of synthesis caused by the size of samples: additional stabilization stage 4 (Figure 3A) as well as extended foaming 2 and annealing 5 steps is due to the large thickness of the material, and therefore, the time needed for uniform cooling. Otherwise, temperature gradients lead to reduced mechanical strength of the material until its destruction. Ability to be destructed by thermal difference provides another type of FSG-based products – breakstone – which can be obtained according to Figure 3B with replacement of granules by blocks

3.2 *Comparison with counterparts*

Comparative analysis of the properties, structure and market prices of FSG and its counterparts was carried out, results of which are shown in Table 3 and Figure 4. As counterparts there were taken foam glass blocks produced by "Gomelglass" (Gomel, Belarus) and foam glass breakstone by "ICM Glass Kaluga" (Kaluga, Russia).

Table 3 - Comparative characteristics of FSG

Material	Density, kg/m^3	Compressive strength, MPa	Thermal conductivity, W/(m·K)	Price, \$/m^3
Blocks				
Foam glass «Gomelglass»	160	0,5	0,062	350
FSG Composition 1	160	1,5	0,061	150
Breakstone				
Foam glass «ICM Glass Kaluga»	220	0,5	0,070	150
FSG Composition 2	240	2,9	0,072	70

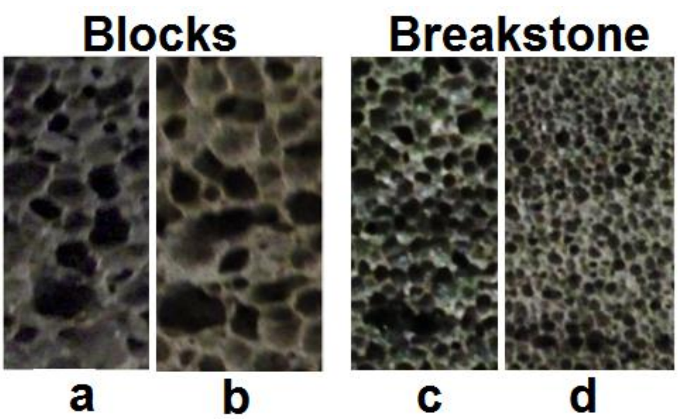

Figure 4. Photographs of macrostructure of materials obtained in comparison with market counterparts:
a - «Gomelglass» foam glass block;
b – FSG Composition 1 block;
c – «ICM Glass Kaluga» foam glass breakstone;
d - FSG Composition 2 breakstone.

Figure 4 shows that the structure of the developed materials is virtually identical to counterparts, and the properties (Table 3) even slightly surpass them. At the same time through the use of slag waste selling price of developed material is 2-3 times lower than that of the foam glass, which is currently on the building materials market.

4 CONCLUSION

Thermal power plants slag wastes can be recycled into foam glass by partial replacing of cullet. It is possible to get a wide range of products based on the developed material –foamed slag glass - with both insulation and construction-insulation properties by varying the ratio of the components and the type of foaming agent. At the same time synthesized material in its characteristics and structure will not yield to market counterparts at a lower cost due to the partial replacement of raw materials on the waste .

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