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FOAMED GLASS BASED ON SLAG WASTES

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Abstract

Technology of synthesis of environmental-friendly thermal insulating glass material based on thermal power plant's slag wastes –foamed slag glass was developed. Studies identified the optimal charge's compositions and modes of synthesis, defined technological and operational properties: flammability , high resistance to water, acids, resistance to insects and rodents, low density and water absorption; thermal conductivity of not more than 0.08 W/(m · K) compressive strength of not less than 2.5 MPa; unlimited lifetime in the range of -150 ... +550 °C at a cost of 3-5 times lower in comparison with market counterparts.

Key words: *Slag wastes, building materials, thermal insulation, foam glass.*

1. INTRODUCTION

Modern humanity has reached a high level of development and is capable of receiving a wide variety of materials in large quantities. However, this level is still not sufficient for the appearance of completely wasteless technologies. In this regard, our planet is polluted with plenty of wastes of different industries, largest of which are slag waste. Slag dumps employing thousands of hectares of land, which are not only became useless in agriculture, but also pollute by compounds, which release from slag with time.

Range of slag waste is extremely wide, so in this paper we consider one of the most large-type slag wastes: slag waste from coal combustion in thermal power plants (TPP). Volume of existing dumps of fuel and energy sector slag, according to various sources, ranging from 500 to 1200 million tons Total dumps employ more than 1 million hectares.

Slag dumps have huge negative impact on the environment - groundwater and surface water, soil, etc. Contaminants are deposited into surface water reservoirs with surface runoff, changing their chemical composition. Precipitation infiltrate through the body of the dump, saturate with water-soluble components and pollute the soil.

Thus very relevant topic is recycling of slag waste into different types of products. However, before using any material its composition, properties and ways of application should be determined. The chemical composition of slag depends on the composition of the solid mineral fuels, so it vary within wide limits. Contents of major oxides in slags of different solid fuels are typically in the following ranges: SiO_2 - 35-65%, Al_2O_3 - 10-25%. Besides the slag contains a large amount (20% or greater) of iron oxides, mainly represented in the ferrous form.

The slag founds the main application in the construction industry. There are three main areas of their use:

- Manufacture of binders;

- Production of fillers;

- Manufacture of piece products.

Mainly the slag is used as filler in the road construction and in concrete of various densities. Production of piece products based on slag waste is the most underdeveloped area of recycling, despite the wide range of materials which can be obtained on its basis.

Among this diversity we choose such material to develop as a thermal insulating glass material - foam glass - cellular glass with structure of foam. This choice was not accidental: the issue of energy efficiency of buildings in Russia is very poignant. Heat loss through the building envelope is 2-4 times higher than in European countries. As for insulating materials used in domestic practice, basically it is a variety of organic insulation, extremely flammable and short-lived. At the same time, the foam glass has all the advantages of glass materials - is not flammable, is impassable for rodents, resistant to moisture and vapor, has stable geometric shapes, etc.

(Table 1). Its main drawback is high (compared to other insulation materials) price. From this, it becomes very urgent to develop a new economical insulation material based on foam glass technology - foamed slag glass.

Table 1– Properties and applications of foam glass

Property	Application
Low thermal conductivity	- insulation in industrial (including, and in harsh environments), civil and individual building; - usage for thermal insulation of pipelines and gas pipelines
Low density with maintaining high strength	- construction on soft soils; - addition of the upper floors of buildings; - insulation of roofs and floors; - filler for lightweight concrete; - filler for thermal insulation plaster and dry construction mixtures; - manufacturing pontoon and other floating structures.
Low vapor-permeability	- vapor- and waterproofing in industrial and civil constructions.
Flame retardant, non-flammability	- insulation in construction of tall buildings; - creation of the flame-obstructing constructions; - insulation of pipelines and other equipment operating at temperatures up to 500 °C.
Environmental safety	- construction of reservoirs and production lines in the food and pharmaceutical industries.
High frost resistance	- thermal insulation of the roadway.
Chemical inertness, high corrosion stability	- production of reusable insulation; - construction of reservoirs and pipelines for oil and acids; - protection of granaries, economic and residential premises.

2. MATERIALS AND METHODS

Foamed slag glass is foam glass, where part of cullet, which is the main raw material component is replaced with slag waste. The possibility of such replacement explained by the proximity of the chemical composition of cullet and slag waste, and therefore similar properties. Similarity properties also confirmed by X-ray analysis (Figure 1), indicating that the structure of slag is glassy.

Chemical composition of raw materials used in this study is listed in Table 2. Calculation of a number of formulations, which include slag waste, glass, various kinds of foaming agents: carbonate (chalk), carbon (anthracite) and organic (glycerol), and in some cases the borax, is shown in the Table 3.

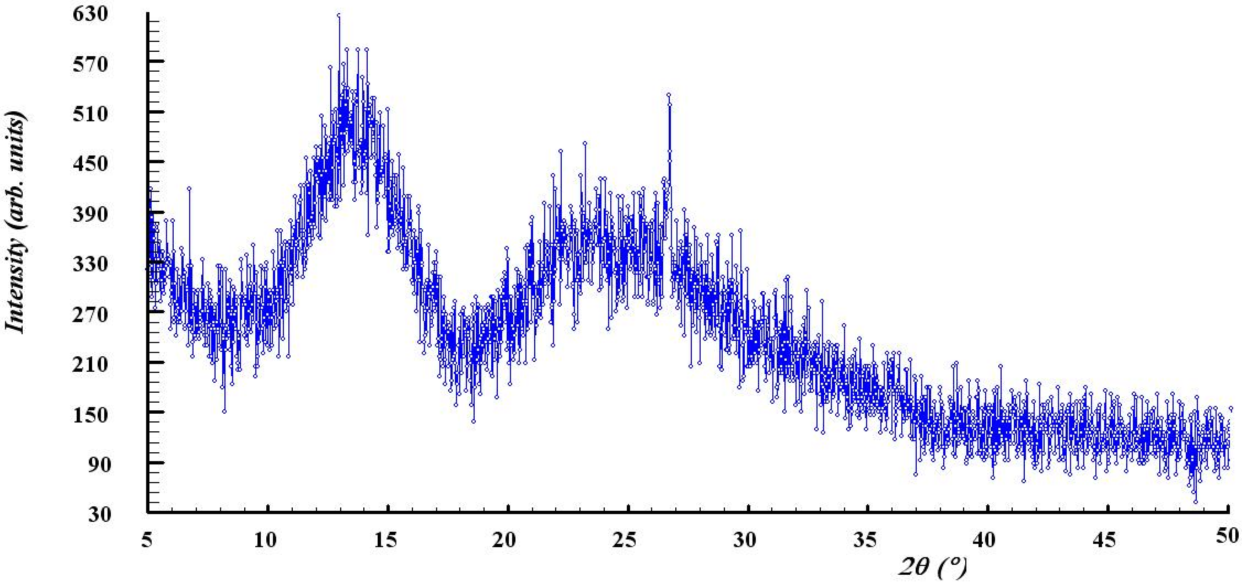


Figure 1 – X-ray analysis of slag.

Table 2 - Chemical composition of raw materials.

Raw material	Chemical composition, wt. %														
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	TiO_2	K_2O	Na_2O	P_2O_5	MnO	B_2O_3	C	Loss upon calcination	Σ
Slag waste	57,50	22,97	10,84	1,88	1,16	0,03	0,84	3,59	0,90	0,15	0,12	-	-	-	100,00
Cullet	71,20	2,70	0,80	3,40	7,60	0,30	-	0,80	13,20	-	-	-	-	-	100,00
Borax	-	-	-	-	-	-	-	-	16,26	-	-	36,52	-	47,22	100,00
Chalk	-	-	-	56,02	-	-	-	-	-	-	-	-	-	43,98	100,00
Anthracite	-	-	-	-	-	-	-	-	-	-	-	-	97,00	3,00	100,00

Table 3 - Chemical composition of developed materials.

№	Foaming agent	Chemical composition, wt. %												
		SiO_2	Al_2O_3	B_2O_3	MgO	Na_2O	Fe_2O_3	CaO	K_2O	TiO_2	SO_3	P_2O_5	Loss upon calcination	Σ
1	chalk	50,57	9,86	8,06	1,05	5,54	5,76	7,60	1,06	0,47	0,03	0,05	9,95	100,00
2	anthracite	50,59	9,88	8,06	1,05	5,54	5,76	4,90	1,06	0,47	0,03	0,05	12,61	100,00
3	glycerol	56,47	11,26	8,95	1,17	6,15	6,40	8,44	1,18	0,52	0,03	0,06	-	100,62

The Archimedes method was employed to measure the specific gravity and water adsorption after the foams had been placed in boiling water for 24 h. The density and water adsorption were calculated as follows:

Density = $\frac{W_D}{W_S - W_I}$

Water adsorption (%) = $100 \cdot (\frac{W_S - W_D}{W_D})$

where W_D is the dry weight of the sintered foams, W_S is the 24-h saturated surface-dry weight, and W_I is the immersed weight in water. The compressive strength of the sintered foam was calculated as follows:

Compressive strength = P / S

where P is the fracture load and S is the area of the sample. Each recorded testing value was the mean of the results from five samples. Finally, powders of the sediment and of the sintered foams were prepared and passed through a No. 100 mesh. The mineral phases were measured using X-ray diffraction (XRD) (Fernandes 2009).

3. RESULTS AND DISCUSSION

Samples of developed compositions were subjected to thermal treatment according to Figure 2. It consists of 4 main areas: calefaction (1), foaming (2), rapid cooling with stabilization of porous structure (3), gradual cooling – annealing (4) (Yatsenko 2013). Photos of the synthesized samples are shown in Figures 3-5.

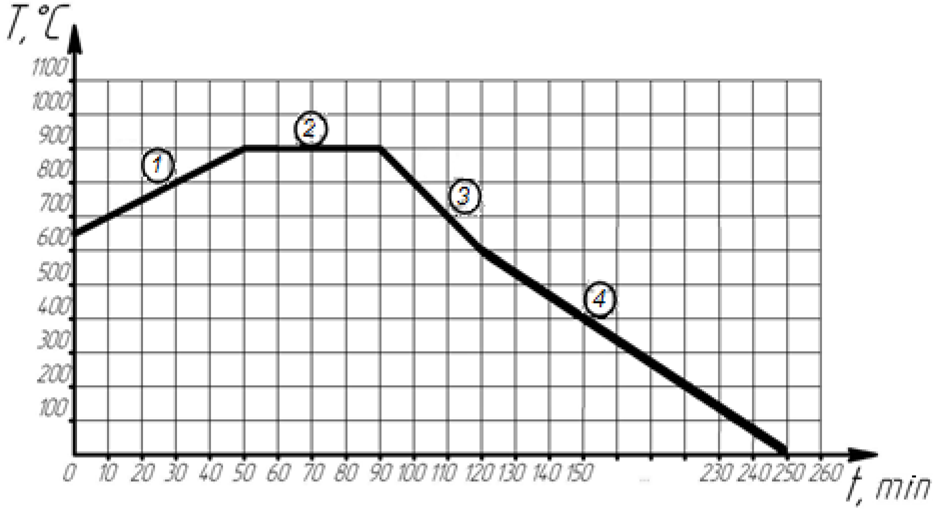


Figure 2 – Graph of foamed slag glass laboratory samples synthesis.

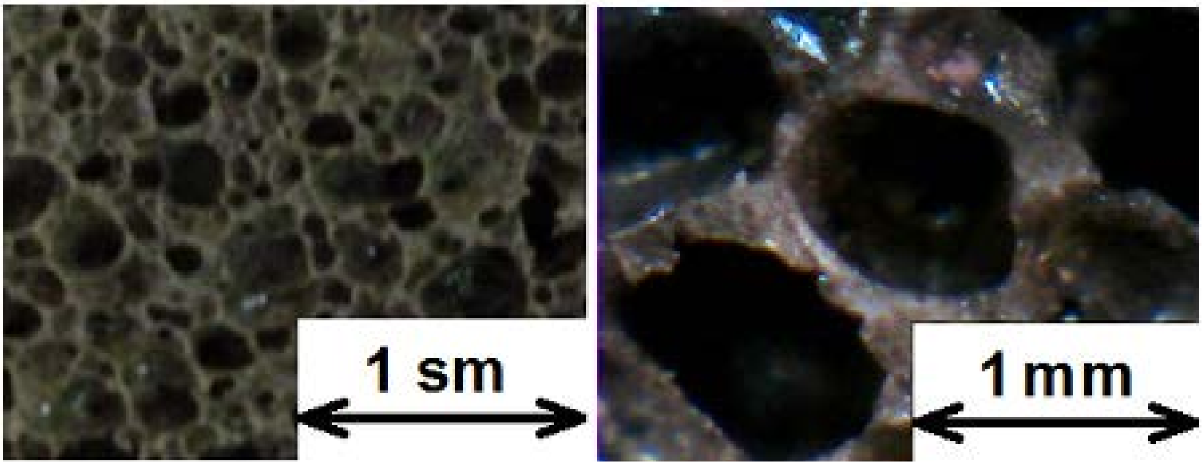


Figure 3 – Photo of foamed slag glass sample (foaming agent – chalk)

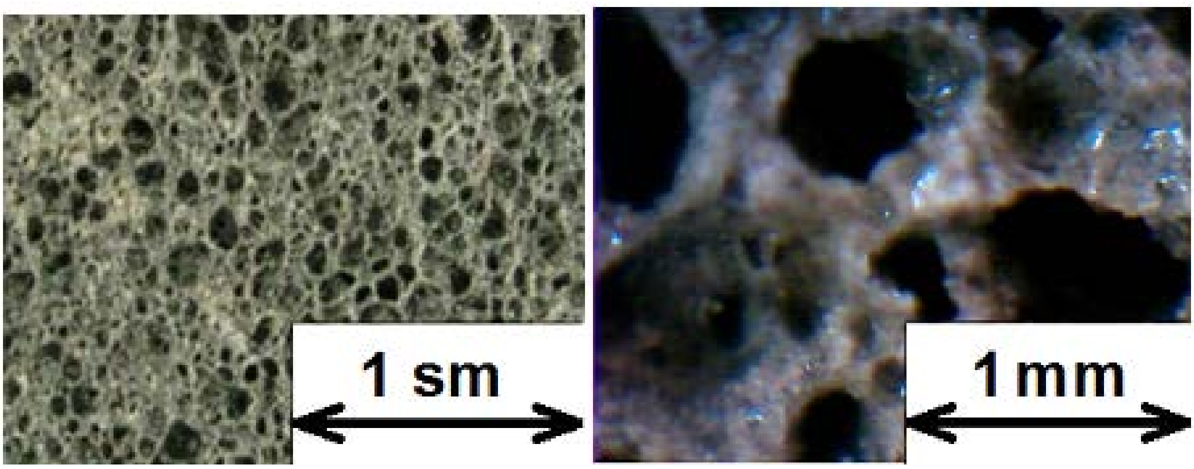


Figure 4 – Photo of foamed slag glass sample (foaming agent – antracite)

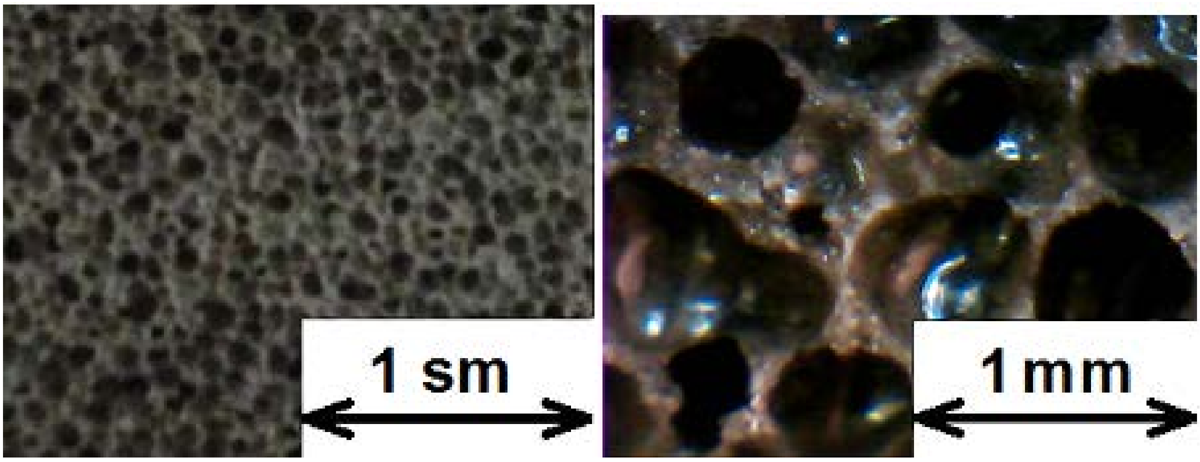


Figure 5 – Photo of foamed slag glass sample (foaming agent – glycerol).

As we can see from the Figure 6, synthesized samples don't consist of any crystal phases. There is only glassy phase in it, so the properties of synthesized materials will be as in glass ones.

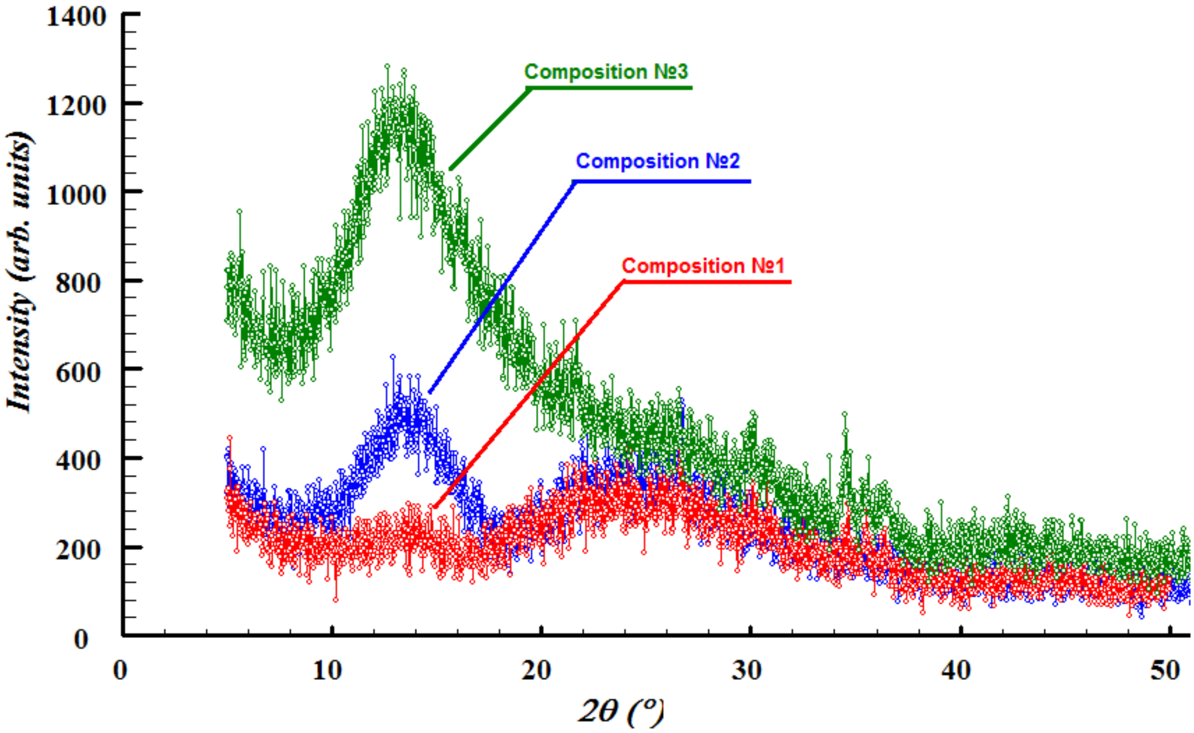


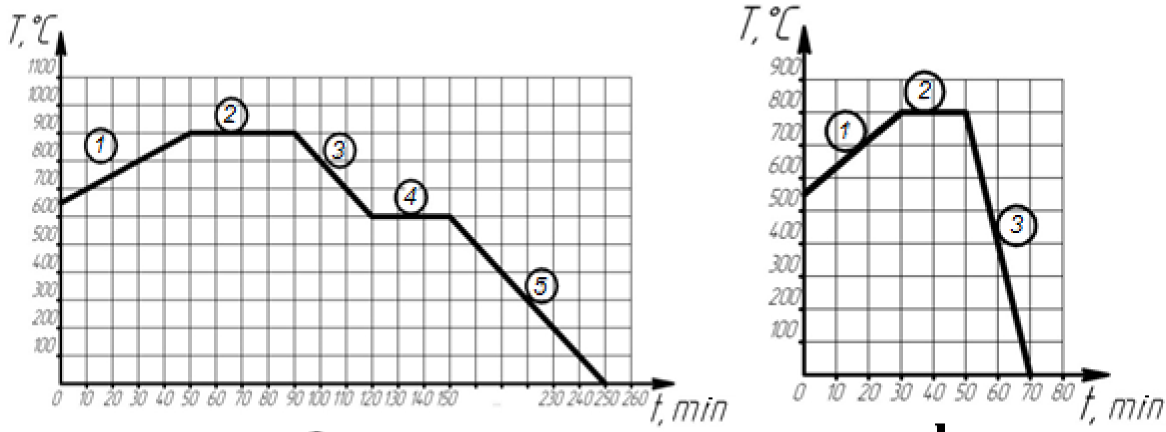
Figure 6 - X-ray analysis of synthesized samples.

Then there were determined the main physical and mechanical properties of these compositions which are presented in Table 4. The Table shows that the properties of developed materials are not inferior to the market counterparts.

Table 4 – Main properties of foamed slag glass

№	Foaming agent	Density, kg/m^3	Water absorption, %	Compressive strength, MPa	Coefficient of thermal conductivity, W/(m·K)
1	Chalk	620	5,3	2,2	0,08
2	Anthracite	480	1,8	6,5	0,07
3	Glycerol	250	0,6	4,6	0,06

Then, there were developed technologies of manufacturing various kinds of products based on foamed slag glass, namely technology of granulated and block foamed slag glass. Their modes of synthesis are given in Figure 7 a, b, and appearance - in Figure 8 a, b.



a b

Figure 7 – Optimal temperature-time modes of block (a) and granulated (b) foamed slag glass synthesis.

a b

Figure 8 – Appearance Designs of block (a) and granulated (b) foamed slag glass.

Empirically it has been found that for the synthesis of block foamed slag glass for volumetric sintering of blocks requires a temperature higher than for granules (≈ 25-30 °C). Differences in modes of synthesis are also due to sample size - Additional stabilization stage 4 (Figure 7 a) and extended annealing step is due to the large thickness of the block, and therefore, the more time needed for uniform cooling. Otherwise, temperature gradients lead to reducing of the material’s mechanical strength up to its destruction.

Then, a comparative analysis of market counterparts’ prices and estimated selling price of foamed slag glass was performed, which shows that due to the use of slag waste selling price of developed material is 3-5 times lower than that of the foam glass, which is currently on the building materials market. So, for example, foam glass production of JSC "Gomel glass" (Gomel, Belarus) is 350 USD/m^3 whereas developed material has a price of 100 - 150 USD/m^3 (depending on the technology and composition).

4. CONCLUSIONS

Slag wastes of thermal power plants can be recycled into a foam glass by partial replacing of initial cullet and adding foaming agents of different types: carbonate (chalk), carboniferous (anthracite), organic (glycerin). Addition of slag increases density of samples and their strength. Different foaming agent provides different porosity so there can be synthesized materials with both thermal and sound insulation: carbonate foaming agent provides open porosity with pore's size from 0,5 to 3 mm, carboniferous – closed porosity with pore's size from 0,3 to 2 mm, organic – closed porosity with the most uniform pore's size about 0,5 mm.

The physical properties of the developed materials are already correspond to the level of insulating building materials. Besides there is an opportunity to produce materials of different densities (up to ultra-lightweight materials – 150 kg/m^3) and strengths by changing developed material's initial composition and temperature-time mode of synthesis

Thus, we can conclude that the thermal insulating glass material on the basis of slag waste – foamed slag glass is a new perspective heat insulator and not only has the widest range of beneficial properties, but also low cost through the use of slag waste as raw material.

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