Foamed slag glass – eco-friendly insulating material based on slag waste

E.A. Yatsenko, B.M. Goltsman, V.A. Smolii, A.S. Kosarev
"Technology of ceramics, glass and binding materials" dpt.
Platov South-Russian State Polytechnic University (NPI)
Novocherkassk, Rostov region, Russia
e_yatsenko@mail.ru

***Abstract* — The technology for the synthesis of eco-friendly thermal insulating glass material on the basis of thermal power plants slag waste – foamed slag glass – has been developed. Batch compositions and temperature-time synthesis modes have been studied using various foaming agents. Technological properties such as density and thermal conductivity have been defined. The developed material has almost unlimited lifetime at a 2-3 times lower cost in comparison with market counterparts. The application of this material allows solving a number of environmental problems, such as energy resources saving and improving the environmental situation through industrial waste management.**

Keywords— slag waste, thermal insulation, building materials, foam glass

I. Introduction

The environmental deterioration in the modern world is one of the most urgent problems of the mankind. This deterioration is due to both thoughtless pollution by various waste (domestic and industrial) and excessive consumption of natural resources.

The most numerous types of waste are slag wastes produced by various industries. The largest producers of slags are metallurgical manufacturing and thermal power plants (TPP) that produce heat by coal burning.

The problem of waste management is particularly relevant to the countries and regions with developed mining and processing industries. Therefore, the Novocherkassk SDPP – the coal TPP that produces more than 90% of the Russian Southern Federal District's electricity – which is located in 15 km from Novocherkassk, could be a good example. Slag waste produced from coal combustion by this TPP is stored in dumps. The volume of accumulated wastes is more than 40 million tons on an area of 250 hectares, and 800-1000 thousand tons are produced annually. The ratio of waste generation and recycling is presented in Fig. 1.

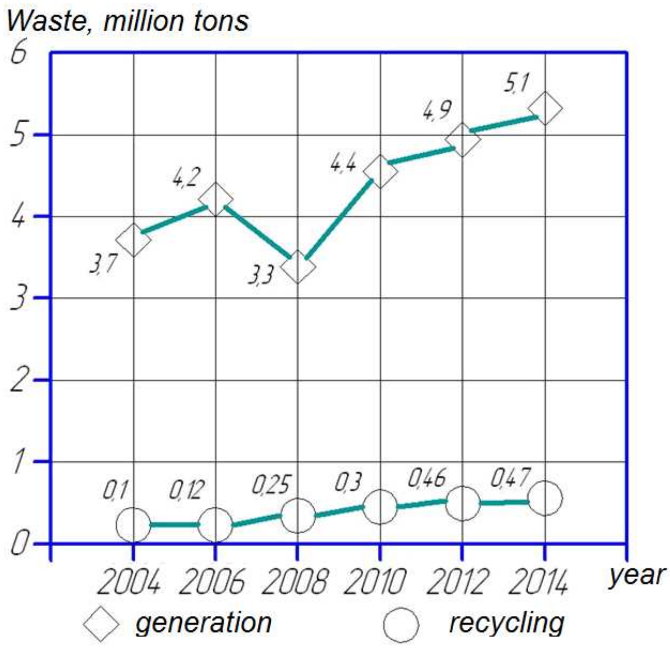

Fig. 1. The ratio of slag waste generation and recycling.

Fig. 1 shows that consumption of slag does not exceed 10% of its production, and most of it is used as a filler in the road construction. At the same time slags are perfect secondary raw materials that passed through primary heat treatment, with stable chemical and mineralogical composition. Therefore, the development of technologies of thermal power plant slag utilization to produce various materials and products is relevant, especially to the countries with the developed coal industry.

II. Energy Saving in Buildings - Current Situation

The problem of over-consumption of natural energy resources is primarily associated with large heat loss in buildings due to the low thermal insulation properties of the used construction materials. Thus, it is necessary to use high quality thermal-insulating materials in order to minimize heat

Research work was performed with the financial support of the Ministry of Education and Science of the Russian Federation under the Federal Target Program "Research and development on priority directions of scientific and technological complex of Russia for 2014-2020".

Agreement №14.574.21.0124 (RFMEFI57414X0124)

loss through the building envelope in civil and industrial construction, as well as in transportation systems.

The most widespread insulation materials now are organic polymers (polystyrene foam, polyurethane foam, products based on it), that have several advantages: low cost, good insulation properties, low density. However, this type of materials also has many significant drawbacks - extreme flammability, emission of smoke and toxic compounds when burning, impossibility of recycling, low chemical resistance and lifetime, etc.

Thus, the search for effective eco-friendly non-flammable thermal-insulating materials is very important. One of such materials is a foam glass - cellular glass with a foam structure. Its lifetime is almost unlimited, and physical properties do not change with time, as in conventional glass products. The main disadvantage of foam glass is its high cost associated with the use of glass cullet as the main raw material. Studies on the replacement of glass with other materials are conducted all over the world [1-3], and special attention is also given to various industrial wastes.

III. Foam Glass: Features of Production

As stated above, foam glass is a cellular glass with a foam structure. Its production is based on the ability of glass to form plastic mass when heated, which congeals when quenching.

Production of foam glass is performed by powder method. Semi-finished products (granules, plates, and blocks of any shape) are molded from a mixture of glass powder and the material-foaming agent with moisture of 5-10%, and then loaded into a furnace for heat treatment. During heating the foaming agent decomposes to form a gas which foams the softened glass. Then the foamed material is quenched, the glass solidifies and the porous structure is fixed. The averaged foam glass synthesis schedule is shown in Fig. 2.

The received product is an essentially clear glass. As a consequence, it has all advantages of the glass: moisture- and vapor-permeability, complete fire safety, dimensional stability at high temperatures, resistance to rodents, pests and bacteria, the simplicity of installation works, eco-friendliness, and many others.

Thus, the influence of each raw component on the structure and properties of the foam glass has been studied.

Fig. 2. Foam glass synthesis schedule: 1 - calefaction, 2 - foaming, 3 – quenching (rapid cooling) with structure stabilization, 4 – annealing (gradual cooling).

A. *Glass Cullet*

The main raw material for the production of foam glass is different types of glass cullet. The samples based on three most common types of glass: white (colorless) (Fig. 3a), green (Fig. 3b), brown (Fig. 3c) – have been obtained to determine the influence of the glass type on the structure of the foam glass.

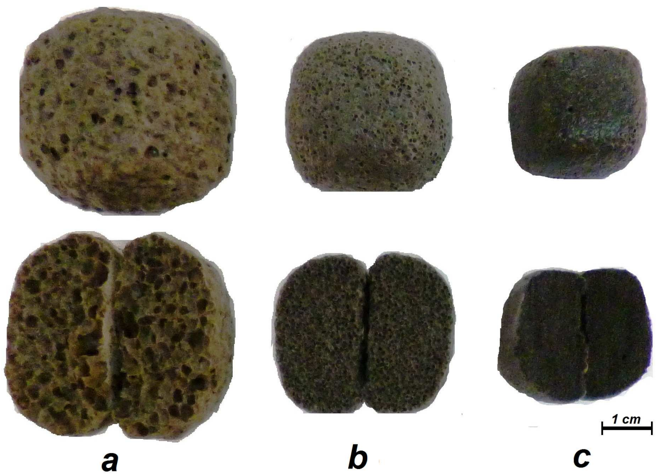

Fig. 3. Foam glass based on various glasses.

Fig. 3 shows that the sample based on the brown glass has foamed the worst of all (density 460 kg/m^3), and the best of all has been the sample based on the white glass (density 110 kg/m^3), but the pore size and distribution here is extremely uneven. The sample based on the green glass has had an average indicator of density (210 kg/m^3) at a substantially uniform porosity.

Thus, the green glass is the best type of glass for the production of foam glass. In some cases, the white glass additives are possible to reduce the density.

B. *Foaming Agents*

Traditional foaming agents in foam glass technology are divided into two groups: carbon and carbonate. Carbon foaming agents include graphite, anthracite, soot and other carbon-based materials. The pore formation during the synthesis occurs due to the oxidation (combustion) of carbon (1). Resulting gas foams the material.

$$C + O_2 \rightarrow CO_2\uparrow \quad (1)$$

Carbonate foaming agents most commonly presented by limestone and chalk, as the least expensive of carbonates. Also they could be presented by marble or even dolomite. The pore formation during the synthesis occurs due to the gas produced by thermal decomposition of carbonates according to (2).

$$CaCO_3 \rightarrow CaO + CO_2\uparrow \quad (2)$$

Moreover, some organic compounds could be used as foaming agents, wherein the principle of pore formation is similar to the reaction (1).

A qualitative analysis of the influence of the foaming agent type on the porosity of the foam glass has been conducted. The following materials have been selected for the study: anthracite (Fig. 4a), chalk (Fig. 4b), glycerol (Fig. 4c). The results are shown in Fig. 4.

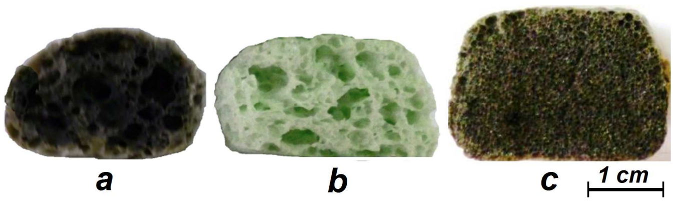

Fig. 4. Foam glass based on various foaming agents.

The sample “c” (the foaming agent - glycerol) has the most uniform porosity and density among all samples. In addition, the sample “b” has channel-like pores inherent to sound insulating materials.

Thus, green and white glass cullet and glycerol-based foaming mixture have been chosen as basic materials. Further studies have been devoted to the search for options to replace glass cullet on the TPP slag waste.

IV. Foamed Slag Glass (FSG)

A. Slag Waste

The choice of slag to replace the glass is not accidental. During the coal combustion in the furnace, incombustible impurities drain under the pot in a form of a melt, where slag is formed due to its rapid cooling. Consequently, slag has a vitreous amorphous structure (Fig. 5), and the chemical composition is quite close to the glass (Table 1).

The chemical composition also shows that the introduction of large amounts of slag will increase the foaming temperature due to the presence of refractory aluminum oxide. So some flux materials must be added into the foamed slag glass to reduce the foaming temperature.

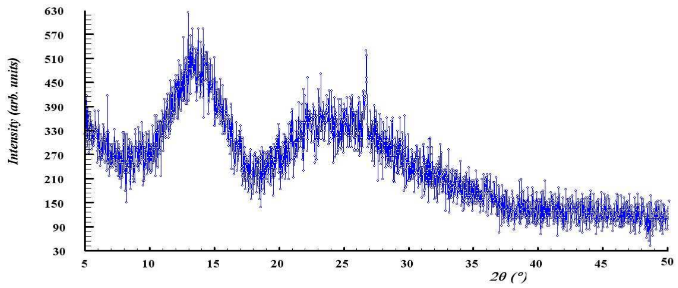

Fig. 5. X-ray analysis of slag waste.

TABLE I. Chemical Composition of Raw Materials

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

a. *Oxides, content of which is less than 0.2 wt.%, are not shown*

B. Replacement of Glass by Slag

According to the studies [4-5], the possibility to replace glass cullet with TPP slag waste has been established. Two series of samples containing slag from 10 to 50 wt.% have been synthesized. The composition of the “A” series samples has included glass, slag waste and glycerol-based foaming mixture. In the “B” series samples the flux material has been introduced to promote better foaming and sintering. The results are shown in Fig. 6.

It can be seen that amount of slag affects the FSG structure and properties. There is a direct correlation between the content of slag and increasing density, strength and thermal conductivity of the material. Thus introduction of slag up to 20 wt.% has virtually no effect on the structure of the material. Introduction of more slag quantity leads to higher density of FSG, and hence to the deterioration of insulation properties. On the other hand, the increased density and strength of the material with slag content of up to 50 wt.% allows using it as a construction material with not only insulating, but also bearing properties.

Introduction of the flux in “B” series samples has had a positive effect on the foaming process. However, in samples with a low slag content it had led to the uncontrolled pore growth and the deterioration of structure uniformity. Thus, the introduction of flux is justified when the slag content is at least 30 wt.%.

Then the main properties of samples of optimal compositions have been determined: density, compressive strength, coefficient of thermal conductivity. The results are shown in Table 2.

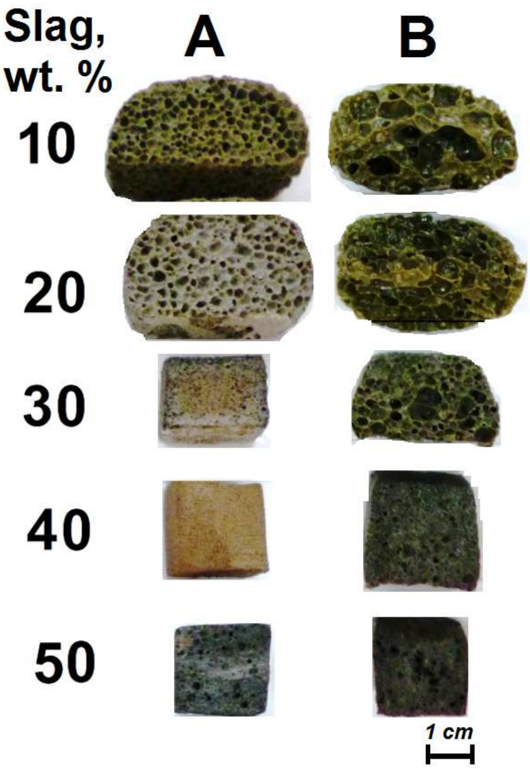

Fig. 6. Foamed slag glass with various content of slag.

TABLE II. PROPERTIES OF SAMPLES OF OPTIMAL COMPOSITIONS

Series	Slag quantity, wt. %	Density, kg/m^3	Compressive strength, MPa	Thermal conductivity, W/(m·K)
A	10	160	1.5	0.061
A	20	240	2.6	0.069
B	30	370	4.1	0.082
B	40	440	5.3	0.093
B	50	500	7.2	0.098

V. PRODUCTS BASED ON FOAMED SLAG GLASS

A. Features of Synthesis

Various variants of products based on received materials have been developed, block and granulated FSG, in particular. Temperature-time modes of the synthesis are shown in Fig. 7. The appearance of these products is shown in Fig. 8.

The differences in the synthesis modes are caused by different sizes of products: an additional stabilization (4), as well as a longer foaming (2) and annealing (5) are caused by the greater thickness of blocks, and therefore, more time is needed for the uniform temperature change in the material volume. Otherwise, the temperature gradient leads to the mechanical strength decrease until the material destruction. At the same time, the ability to break down under the influence of the temperature difference lies in the basis of obtaining the third kind of FSG-based products – the breakstone, which can be obtained as shown in Fig. 5B, by replacing semi-finished granules on blocks.

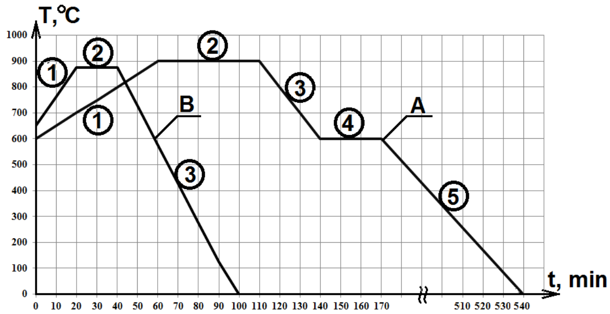

Fig. 7. The optimum temperature-time modes of block (A) and granulated (B) FSG synthesis: 1 - calefaction, 2 – foaming, 3 – quenching (rapid cooling) with structure stabilization, 4 – additional thermal stabilization, 5 – annealing (gradual cooling).

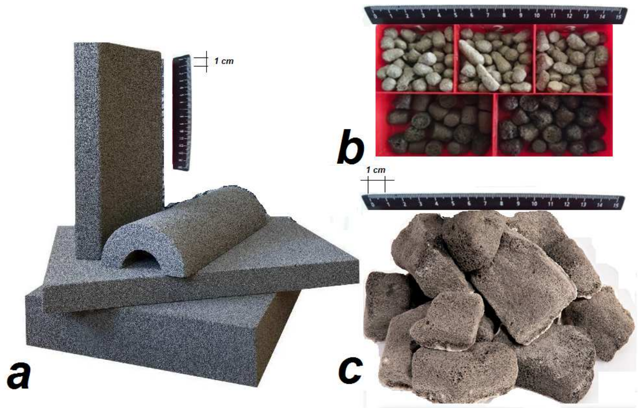

Fig. 8. FSG-based products: a – blocks, b – granules, c - breakstone.

B. Comparison with Counterparts

The comparative analysis of the properties, structure and market prices of FSG-based products and its analogues has been performed. Its results are presented in Table 3 and Fig. 9. Foam glass blocks from "Gomelglass" (Gomel, Belarus) and foam glass breakstone from "ICM Glass Kaluga» (Kaluga, Russia) have been selected as analogues.

TABLE III. 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	0.061	350
FSG	160	1.5	0.062	150
Breakstone				
Foam glass «ICM Glass Kaluga»	220	0.5	0.070	150
FSG	240	2.9	0.072	70

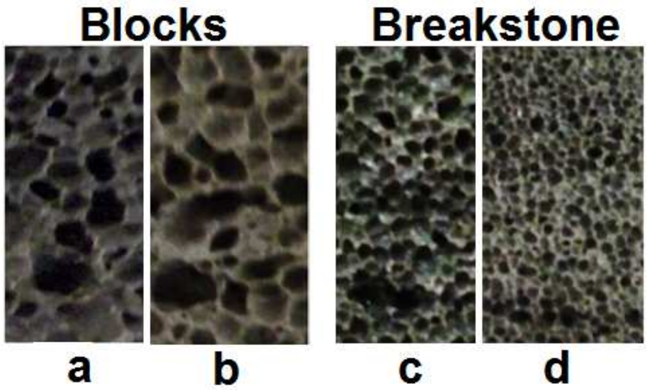

Fig. 9. Photographs of macrostructure of obtained materials in comparison with market counterparts: a - «Gomelglass» foam glass block; b – FSG block; c – «ICM Glass Kaluga» foam glass breakstone; d – FSG breakstone.

Fig. 9 shows that the structure of the developed materials is almost identical to counterparts, and the properties (Table 3) even slightly exceed them. At the same time the price of FSG is about 2-3 times lower than conventional foam glass which is available on the market at the moment through the use of slag waste instead of glass cullet.

VI. Conclusion

Thus, we can conclude that the use of the developed insulation material based on slag waste - foamed slag glass (FSG) - solves a number of important environmental issues, such as energy resources saving by minimizing heat loss through the walls of buildings, industrial waste management and improvement of the environmental situation. In addition, a wide range of FSG-based products with both insulating and constructive-insulating properties can be obtained by varying the ratio of the components and the type of foaming agent. At the same time, the synthesized materials in their characteristics and structure will not yield to market counterparts at a lower cost due to the replacement of the raw materials to the slag waste.

Acknowledgment

Research work was performed in Platov South-Russian State Polytechnic University (NPI) with the financial support of the Ministry of Education and Science of the Russian Federation under the Federal Target Program “Research and development on priority directions of scientific and technological complex of Russia for 2014-2020”.

Agreement №14.574.21.0124 (RFMEFI57414X0124).

References

[1] I. Ponsot, E. Bernardo, “Self glazed glass ceramic foams from metallurgical slag and recycled glass,” Journal of Cleaner Production, 2013, vol. 59, pp. 245–250.

[2] L. Ding, W. Ning, Q. Wang, D. Shi, L. Luo, “Preparation and characterization of glass–ceramic foams from blast furnace slag and waste glass,” Materials Letters, 2015, vol. 141, pp. 327–329.

[3] M. Suzuki, T. Tanaka, N. Yamasaki, “Use of hydrothermal reactions for slag/glass recycling to fabricate porous materials,” Current Opinion in Chemical Engineering, 2014, vol. 3, .pp. 7–12.

[4] E. Yatsenko, V. Smolii, A. Kosarev, E. Dzyuba, I. Grushko, B. Gol'tsman, “Physical-chemical properties and structure of foamed slag glass based on thermal power plant wastes,” Glass and Ceramics. 2013, vol. 70 (1-2), pp. 3-6.

[5] E. Yatsenko, A. Zubekhin, B. Gol'tsman, V. Smolii, A. Kosarev, “Investigation of the Factors Influencing the Properties and Structure of Foamed Slag Glass,” Glass and Ceramics, 2014, vol. 71 (3-4), pp. 111-114.