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# FOAM GLASS MATERIALS USING RECYCLED RAW MATERIALS AND PRODUCTS BASED ON THEM

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**Annotation.** In this article, the author examines innovative trends in the development of effective building materials and products for thermal insulation of buildings. During the research, a technology for producing thermal insulation foam glass and products based on it was developed. The values and graphs of the properties of the developed materials and products are presented. The author describes in detail the research methods and techniques for producing multilayer building panels based on the developed products, and identified the optimal method for bonding them to form a multilayer building panel. A conclusion is drawn regarding the applicability of the developed technology. The unique properties of foam glass technology allow for the production of a wide range of products: blocks, slabs, shaped products, crushed stone, granules, etc. The gas formed during the decomposition of the pore forming agent forms a porous structure during the softening of the glass mass.

**Keywords:** Energy efficiency, foam glass, thermal insulation, recycled materials, cullet, glass powder.

**Introduction.** One of the main goals of housing construction is to stimulate the efficient development of housing in the regions. The development of prefabricated construction technologies can help address the shortage of affordable and comfortable housing. With increasingly stringent requirements for the safety of building materials and the energy efficiency of buildings, the development of non-combustible, durable thermal insulation materials for the construction of structural elements for prefabricated buildings is becoming increasingly important [1-6].

Practically the only material that meets all these requirements is foam glass – a cellular glass with a combination of insulating and performance properties (durability, resistance to environmental influences and pests, complete fire safety, etc.). The main disadvantage of foam glass is its relatively high price, due to the use of scarce cullet as the main raw material. One of the most promising solutions to this problem is replacing cullet with recycled materials, which reduces both the cost of the material and the environmental impact by reducing waste disposal volumes. The unique properties of foam glass technology allow for the production of a wide range of products: blocks, slabs, shaped products, crushed stone, granules, etc. Slabs and shaped products are used to insulate walls and complex surfaces, while granules and crushed stone are used as aggregate in road construction or for the production of lightweight concrete. Consequently, foam glass products can be used to create both external load-bearing and internal insulating layers of panels for prefabricated buildings. Therefore, research into the development of foam glass products using recycled raw materials is relevant [7-9].

Research into the production of porous thermal insulation materials and products, as well as their structure and performance properties, is being conducted by scientists in many countries [10-13]. Research into the use of foam glass products based on recycled raw materials as the primary materials for creating interior and exterior thermal insulation products has not previously been conducted.

The objective of this study was to develop foam glass compositions and technologies using recycled materials for the creation of interior and exterior thermal insulation products. The research objectives included developing foam glass compositions and technologies using recycled materials and studying their physical and mechanical properties.

**Materials and methods of the study.** The methodological basis is the theory of high-temperature porization of plastic masses. When the charge is heated, solid-phase and liquid-phase sintering processes occur. The gas formed during the decomposition of the pore forming agent forms a porous structure during the softening of the glass mass. The tasks of studying the processes of softening and foaming of foam glass materials, phase composition, macro-, microstructure and properties of the obtained materials were carried out using scanning electron microscopy and physico-chemical testing methods in accordance with relevant building standards. Studies of the structure and properties of foam glass products were performed according to standard methods in accordance with current state standards, as well as using optical and electron microscopy [14, 15].


**Figure 1 – Temperature-time mode of foam glass synthesis:**
**1– heating; 2 – foaming; 3 – abrupt cooling (fixation of the structure);**
**4 – cooling (annealing)**

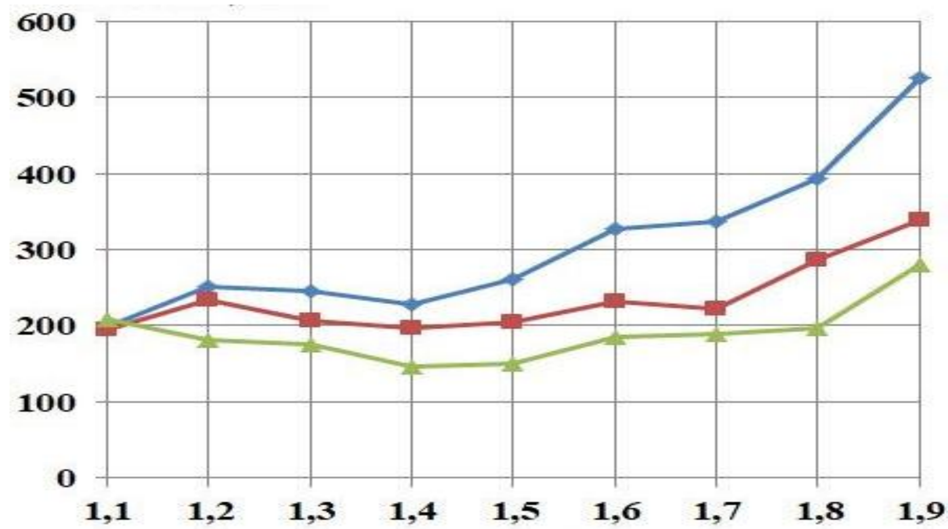
**Results and Discussion.** The optimal ratio of the components of the pore–forming mixture «liquid glass - glycerin – water» was selected. For the study, the model composition, wt. %: BT-1 glassblower– 90; pore–forming mixture - 10. At the first stage, formulations were developed in which the ratio «liquid glass – glycerin» varied. The molded samples were subjected to heat treatment according to Figure 1 at foaming temperatures of 800, 825, 850 °C. The charge compositions are shown in Table 1, and the density of synthesized samples is shown in Figure 2.

**Table 1 – Mixture compositions of foam glass with different ratios of «liquid glass – glycerin»**

| | Content of components, wt.%, in the composition, № | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 |
| BT-1 Glass Cullet | 90 | | | | | | | | |
| Liquid Glass | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
| Glycerin | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |

It was found that with a shift in the ratio of «liquid glass: glycerin» towards glycerin, the formation of large defective pores and a change in the color of the material from uniformly dark to light with dark pores are observed. This is explained by the role of the charge components in the foaming process. The glass powder is in a highly viscous state at the foaming temperature, and individual glass particles fuse to form a silicate frame responsible for the strength characteristics of the material.

Density, kg/m3



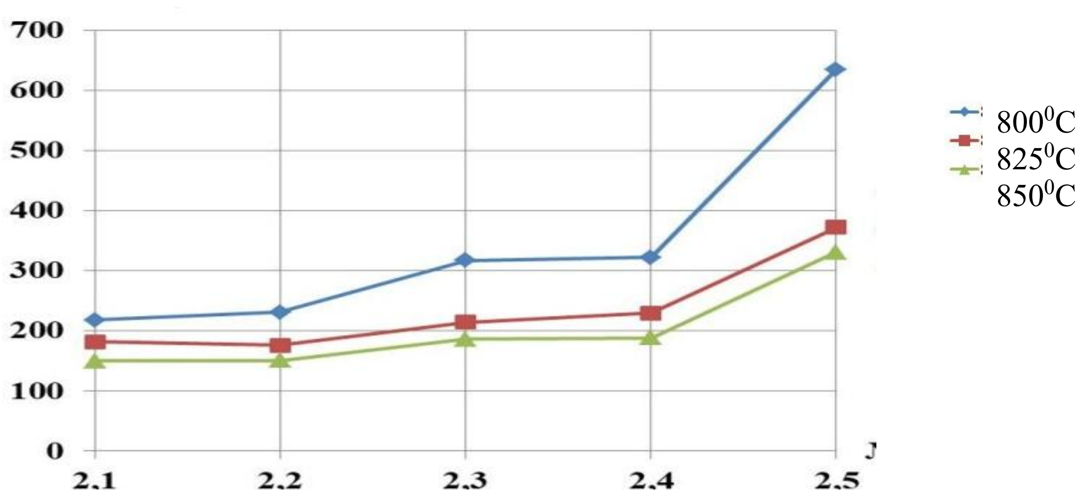

№ composition

**Figure 2 – Dependence of foam glass density on the ratio «liquid glass – glycerin»**

Glycerin acts as a blowing agent; its decomposition creates excess pressure, causing foaming. Liquid glass preserves the blowing agent, promotes more complete contact between the glass powder particles, and accelerates the formation of the silicate framework due to their similar chemical composition.

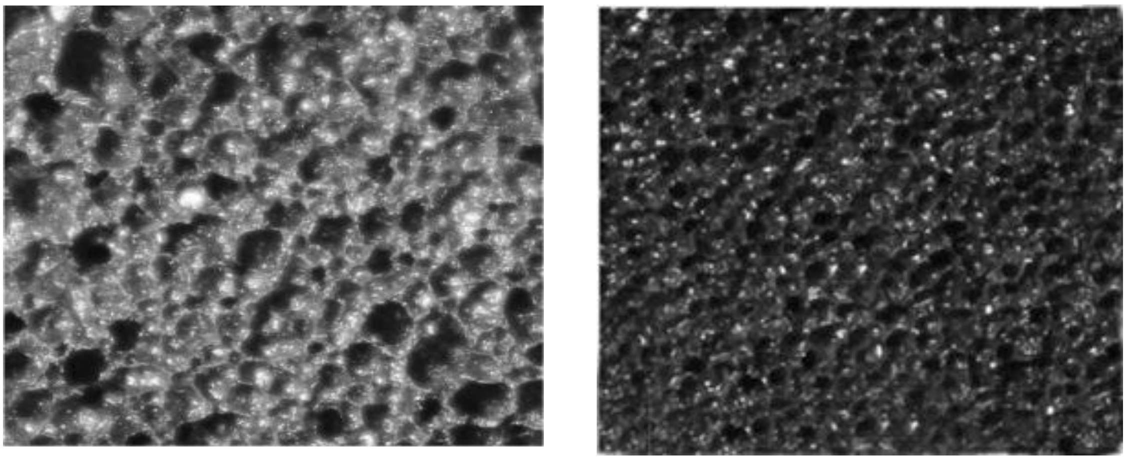
Composition 1.4, with a liquid glass: glycerin ratio of 6:4, was chosen as the optimal blowing agent. Liquid glass and glycerin are viscous liquids, which complicates the process steps of batch homogenization. To reduce viscosity, batch compositions were developed in which the blowing agent of Composition 1.4 was partially replaced with water, with a mixture: water ratio ranging from 9:1 for Composition 2.1 to 1:9 for Composition 2.5. The change in foam glass density depending on the amount of water is shown in Figure 3, and the change in foam glass structure is shown in Figure 4.

Density, kg/m3




№composition

**Figure 3 – Dependence of foam glass density on the water content in the mixture**



- without water - with water

**Figure 4 – Dependence of the foam glass structure on the water content in the mixture**

Studies have shown that even small amounts of water significantly improve the homogeneity of the porous structure, primarily due to a decrease in the viscosity of the mixture and its improved distribution within the batch. Composition 2.2, corresponding to a mixture: water ratio of 7:3, was selected as optimal. As a result, the optimal model composition of the foam glass batch was determined: BT-1 cullet – 90%; liquid glass – 4%; glycerin – 3%; water – 3%.

The influence of synthesis parameters (foaming temperature and time, batch fractional composition) on the structure and properties of foam glass was studied.

To study the effect of foaming temperature, samples were fired at temperatures of 655-880°C in 15°C increments without holding. The dependence of sample density on foaming temperature is shown in Figure 5.

Samples were loaded into the furnace at a temperature of 600°C. Consequently, all low-temperature processes (decomposition of glycerin (≈ 260 °C), evaporation of water (100 °C)) begin to occur simultaneously, and at the same time sintering of the charge begins.

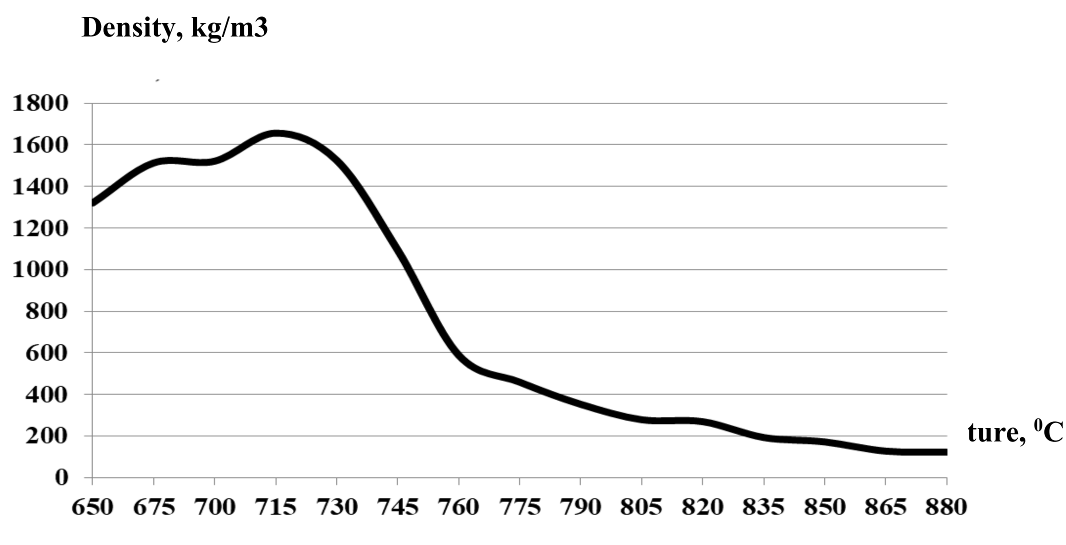
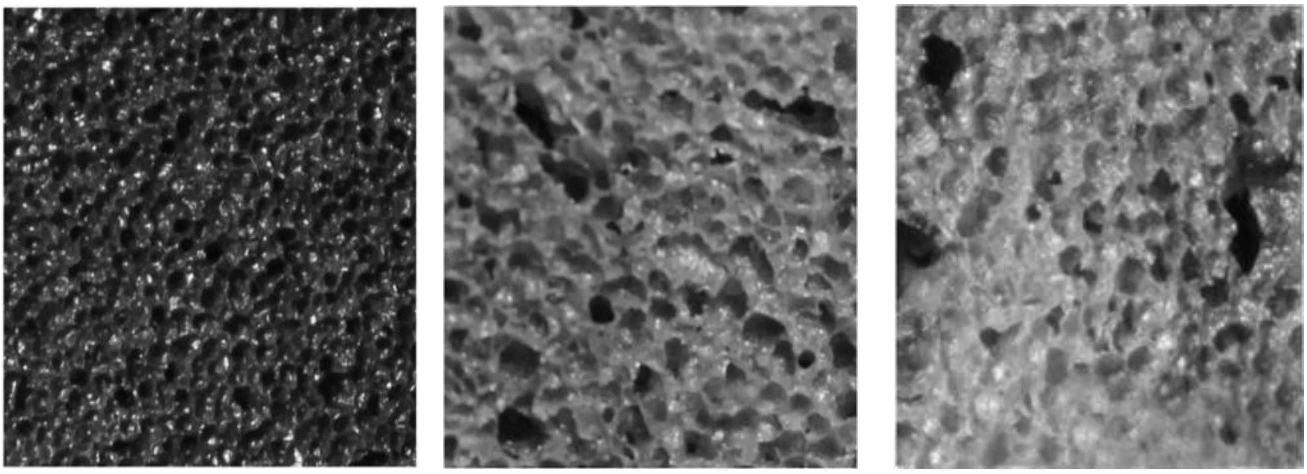



**Figure 5 – The dependence of sample density on foaming temperature is shown**

Therefore, at temperatures up to 730°C, a gradual increase in density is observed, indicating particle convergence during sintering. As the sample is further heated above 730°C, the density begins to decrease due to an increase in the number of gas pores. At temperatures above 850°C, the sample structure becomes less ordered, the pores deform, and defects appear. The optimal temperature range for the formation of the porous structure of the developed material was chosen to be 800-850°C.

To study the effect of foaming time, the samples were heat-treated at a foaming temperature of 825°C for foaming times of 5, 10, 15, 20, 30, and 60 minutes. The dependence of sample structure on foaming time is shown in Figure 6.



10 minutes 30 minutes 60 minutes

**Figure 6 – Microstructure of samples at different foaming times**

It was found that foaming for 5 minutes does not ensure uniform porosity. The structure of samples foamed for longer than 10 minutes is also uneven, with pores becoming irregularly shaped and defects such as isolated channel-like pores appearing. After a 60-minute holding time, the sample noticeably settles, indicating that the gases responsible for the foam glass's volume have largely evaporated from the sample. A 10-minute holding time allows for the average pore size to be averaged and stabilized without causing excessive pore coarsening, making a 10-minute foaming time optimal. To study the effect of the batch fractional composition, the samples were heat-treated at a foaming temperature of 825°C for 10 minutes. The dependence of sample density on the batch fractional composition is shown in Figure 6.

**Table 2 – Dependence of foam glass density on fractional composition**

| Composition № | 3,1 | 3,2 | 3,3 | 3,4 | 3,5 | 3,6 |
|---|---|---|---|---|---|---|
| Particle size, mm | 0,71-0,90 | 0,50-0,71 | 0,32-0,50 | 0,16-0,32 | 0,10-0,16 | less than 0.1 0,1 |
| Density, kg/m3 | 506,91 | 487,70 | 435,97 | 344,31 | 176,15 | 178,28 |

The table shows that decreasing batch particle size significantly reduces foam glass density, which is due to better batch homogenization and faster melting of fine particles. A fraction of 0.1-0.16 mm or smaller was selected as optimal. To expand the raw material base for foam glass production and to recycle ungraded glass waste, the feasibility of using various types of cullet was investigated. The most common types of cullet were selected for the study: green container glass cullet grade ZT-1, sheet glass cullet M4, and colorless container glass cullet grade BT-1. Using these types of cullet, the batch compositions presented in Table 3 were developed.

The molded samples were then heat-treated at foaming temperatures of 800, 825, and 850°C for 10 minutes. The density was then determined, and the porous structure of the synthesized samples was examined. It was found that composition 4.1, based on BT-1 cullet, had the lowest density (150-230 kg/m3), while composition 4.3, based on ZT-1 cullet, had the highest density

(300-410 kg/m3). Composition 4.2, based on M4 cullet, was similar in density to that of the BT-1 cullet (280-150 kg/m3). Compositions based on a mixture of different types of cullet demonstrated a direct increase in density with the addition of cullet, with denser samples obtained.

**Table 3 – Compositions of batches based on different types of cullet**

| Component | Content of components, wt.% | | | | | |
|---|---|---|---|---|---|---|
| BT-1 Container Glass Cullet | 4,1 | 4,2 | 4,3 | 4,4 | 4,5 | 4,6 |
| M4 Sheet Glass Cullet | 90 | 0 | 0 | 45 | 0 | 45 |
| ZT-1 Container Glass Cullet | 0 | 90 | 0 | 0 | 45 | 45 |
| Rock-Forming Mixture Composition 2.2 | 10 | | | | | |

A mixture of BT-1 and M4 glass was selected as optimal for use as a thermal insulation material. To replace cullet with a less scarce raw material, the use of slag waste from thermal power plants was investigated. The compositions were developed by replacing cullet in the optimal foam glass composition with slag waste in amounts ranging from 5% (composition 5.1) to 30% (composition 5.6) by weight. Sintering was performed using the powder method at foaming temperatures of 800, 825, and 850°C with a hold time of 10 minutes. The change in foam glass density depending on the amount of slag waste is shown in Figure 7, and the change in foam glass structure is shown in Figure 8.

It was found that with the introduction of up to 25 wt.% slag waste, there is a slight increase in the density of the samples (200-300 kg/m3), however, virtually no changes in the structure of the material are observed. An increase in the synthesis temperature naturally leads to a decrease in density. For compositions with a slag waste content of 30 wt.%, a sharp increase in density and a decrease in the uniformity of the porous structure are observed; the density of the obtained samples exceeds 400 kg/m3. Composition 5.5, containing 25 wt.% slag waste from thermal power plants, was selected as optimal, forming a uniform porous structure with a density of 285 kg/m3 at a temperature of 825°C. Next, using the experimental design method, the composition of the foam glass was optimized, in wt.%: slag waste from TES-22; cullet BT-1 - 34; cullet M4 - 34; Foaming mixture – 10. The resulting composition has a density of 195-220 kg/m3 in the temperature range of 800-850°C. Optimum synthesis conditions: foaming temperature of 840°C, foaming time of 10 minutes.

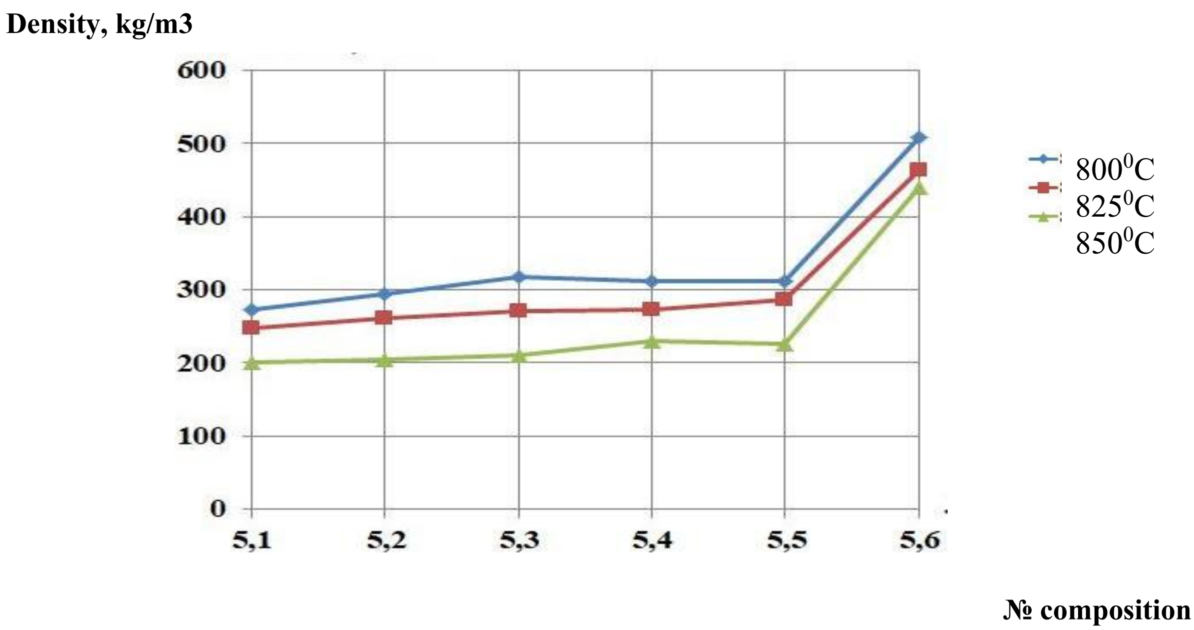
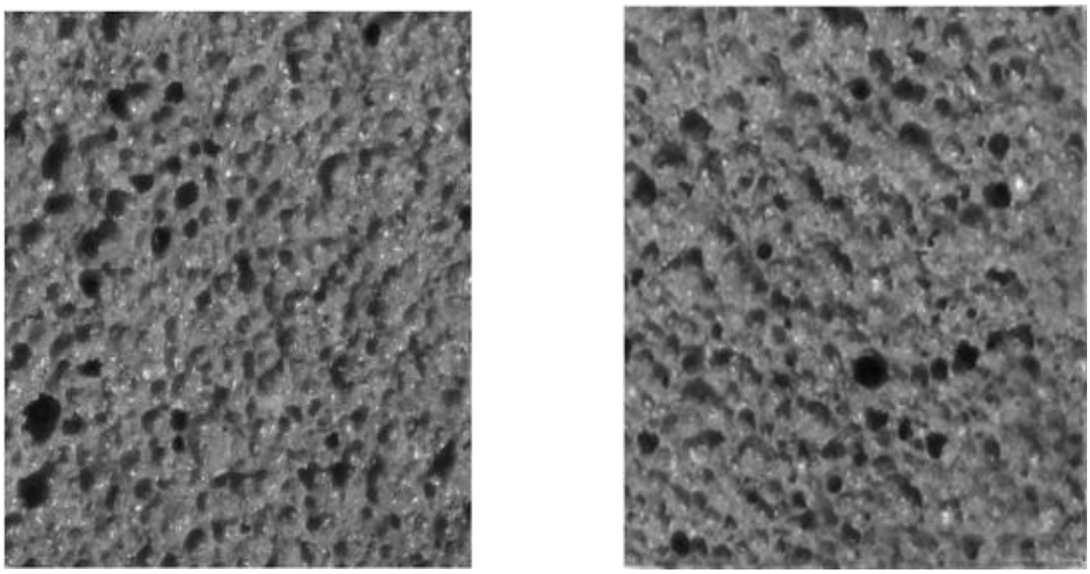



**Figure 7 – Dependence of foam glass density on the content of slag waste**



Composition 5.3 (15 wt.%) slag waste    Composition 5.5 (25 wt.%) slag waste

**Figure 8 – Dependence of the foam glass structure on the content of slag waste**

**Conclusion.** The following are the results of the study:

1. The optimal composition of the foaming mixture was determined, and the effect of the synthesis process parameters on the structure and properties of foam glass was examined. The optimal composition of the foaming mixture, in wt.%, was: liquid glass – 4; glycerin – 3; water – 3. A foaming duration of 10 minutes allows for averaging and stabilizing the average pore size, thereby achieving optimal results. The optimal temperature range for the formation of a porous structure was 800-850°C. It was found that with a decrease in the fractional composition of the batch, the density of the foam glass significantly decreases and the volume increases due to better homogenization and greater heating intensity of the fine particles, which intensifies the melting and foaming processes of the samples. A fraction of 0.16 mm or less was selected as optimal.

2. The influence of various types of secondary materials on the structure and properties of the synthesized foam glass was studied in detail and systematized. It was found that when using glass waste, the composition based on BT-1 container cullet has the lowest density (230-150 kg/m3), and the composition based on ZT-1 container cullet has the highest density (410-300 kg/m3). A mixture of BT-1 container cullet and M4 sheet glass cullet was selected as optimal for use as thermal insulation material. It was found that when using slag waste from thermal power plants (TPPs) in amounts of up to 20 wt. %, virtually no changes in the structure and properties of the material are observed. When the slag waste content is higher than 30 wt. %, a decrease in the uniformity of the porous structure is observed. 3. Using the methods of mathematical experimental design, the optimal composition of foam glass was established, in wt. %: slag waste from TPPs - 22; BT-1 cullet - 34; M4 cullet - 34; Foaming mixture – 10. Optimum synthesis conditions: foaming temperature 840°C, foaming time 10 minutes. The resulting composition has a density of 210 kg/m3.

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**ҚАЙТАЛАМА ШИКІЗАТТЫ ҚОЛДАНА ОТЫРЫП КӨБІК ШЫНЫ МАТЕРИАЛДАР ЖӘНЕ ОЛАРДЫҢ НЕГІЗІНДЕ ЖАСАЛҒАН БҰЙЫМДАР**

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**Андатпа.** Бұл мақалада автор ғимараттарды жылу оқшаулауға арналған тиімді құрылыс материалдары мен бұйымдарын әзірлеудегі инновациялық үрдістерді қарастырады. Зерттеу барысында жылу оқшаулағыш көбікті шыны және оның негізіндегі бұйымдарды өндіру технологиясы әзірленді. Әзірленген материалдар мен бұйымдардың қасиеттерінің мәндері мен графиктері ұсынылған. Автор әзірленген өнімдер негізінде көп қабатты құрылыс панельдерін өндірудің зерттеу әдістері мен әдістерін егжей-тегжейлі сипаттайды және оларды көп қабатты құрылыс панелін қалыптастыру үшін желімдеудің оңтайлы әдісін анықтады. Әзірленген технологияның қолданылуы туралы қорытынды жасалады.

**Тірек сөздер:** Энергия тиімділігі, көбікті шыны, жылу оқшаулау, қайталама материалдар, шыны сынықтары, шыны ұнтағы.

**ПЕНОСТЕКОЛЬНЫЕ МАТЕРИАЛЫ С ПРИМЕНЕНИЕМ ВТОРИЧНОГО СЫРЬЯ И ИЗДЕЛИЯ НА ИХ ОСНОВЕ**

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**Аннотация.** В данной статье автором рассмотрены инновационные тенденции в области получения эффективных строительных материалов и изделий для теплоизоляции зданий. В процессе исследования была разработана технология получения теплоизоляционного пеностекла и изделий на его основе. Предоставлены значения и графики зависимости свойств разработанных материалов и изделий. Автором подробно приведены методы исследования и способы получения многослойных строительных панелей на основе разработанных изделий, выявлен оптимальный способ их скрепления с получением многослойной строительной панели. Сделан вывод о применимости разработанной технологии.

**Ключевые слова:** энергоэффективность, пеностекло, теплоизоляция, вторичные материалы, стеклобой, стеклопорошок.