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Porous fillers for light concrete from technogenic raw materials

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Abstract. The actual question of the production of porous aggregates for lightweight concrete is to increase their resource base through the use of materials of anthropogenic origin. While porous aggregates should be obtained taking into account the reduction of energy consumption, while addressing issues of disposal of industrial wastes.

The purpose of this study - obtaining foam-glass-crystal porous aggregates for lightweight concrete, according to the technology of low-temperature foaming. The object of study was industrial waste production in Central Kazakhstan that contains silica and aluminosilicate components as the main component (slags, ashes of thermal power plants, tailings).

The results of experimental investigations showed the possibility of obtaining foam-glass-crystal porous aggregates for lightweight concrete based on two-component and multicomponent mixtures composed of one kind of man-made materials, their mixtures in different ratios, and corrective additives. The paper discusses the two stage technology for obtaining foam-glass-crystal porous aggregates for lightweight concrete based on powder method, and includes two main stages: obtaining of will stekloagregat in terms of low-temperature synthesis and preparation of the foaming mixture of glass powder with blowing agent, conducting a foaming process obtaining a final aggregate. The processes of formation of structure occur at lower temperatures (not above 900^0C) compared with the process of obtaining foam glass and expanded clay with a significant reduction in the overall time of the technological process, which significantly reduces the energy consumption.

The resulting porous aggregates are characterized by high physical and mechanical properties: density 200-220 kg/m^3; strength of 3.1-4.0 MPa; water absorption of 1-2%. Samples of lightweight aggregates are characterized by a high degree of homogeneity of the pore structure and is preferred for strength and conductivity pore sizes up to 1.2 mm and interporous partitions is 50 microns.

Confirmed that the obtained porous fillers for light concrete unlike traditional fillers (agloporit, expanded clay), can withstand higher loads without degradation due to the presence of the crystal structure of interporous partitions. The material has a low water absorption compared to concrete block, that indicates the ability to maintain their thermal performance over time, and has virtually unlimited lifespan. For production of porous aggregate for lightweight concrete can be used in conventional industrial heating equipment used in the manufacture of bricks and ceramics.

The results for obtaining foam glass crystal materials from industrial waste, allow us to conclude on the possibility of developing technological schemes for the production of porous

aggregates with high physical and technical properties.

Established in principle the possibility of using technogenic waste of the industry, that allows us to solve the environmental problems of waste disposal and to expand the raw material base for the production of porous aggregates for lightweight concrete.

1. Introduction

The actual question of the production of porous aggregates for lightweight concrete is to increase their resource base through the use of materials of anthropogenic origin. While porous aggregates should be obtained taking into account the reduction of energy consumption, while addressing issues of disposal of industrial wastes.

The world has accumulated a huge amount of various industrial wastes. One of the ways of their utilization is using as a main component in the form of a porous foam-glass-crystal aggregates for lightweight concrete.

Resource conservation involves the use of waste and by-products of enrichment of mineral raw materials, which is available in significant volumes [1 - 4]. Studies have shown that for obtaining foam-glass materials are preferred fine silica materials with a high proportion of amorphous component. Industrial waste that can be used for the synthesis of glass granulate and production of foam-glass-crystal porous aggregates must have a high content of silicon oxide, and containing glass-forming components such as oxides of aluminum, calcium, oxides of alkali metals.

The purpose of this study – obtaining foam-glass-crystal porous aggregates for lightweight concrete according to the technology of low-temperature foaming. The object of the study was of technogenic wastes from the production, containing silica and aluminosilicate components as the main component (slags, ashes of thermal power plants, tailings).

2. Materials and methods

The technology of obtaining foam-glass-crystal porous aggregates based on powder method, and includes two main stages. The first stage – obtaining of glass granulate in the low-temperature synthesis conditions. Will glass granulate is an intermediate product, based on which the preparing a foaming mixture to obtain a filler. Synthesis of glass granulate is carried out at relatively low temperatures not exceeding 950^{o}C (in comparison with the classical melting, which occurs at temperatures of 1300 – 1400^{o}C) standard for building materials industry equipment, without the use of expensive and power consuming glass furnaces. The presence of the crystal phase has a positive effect on physical and mechanical properties of the finished porous aggregate, the particle size of the crystalline phase and its quantity must meet certain requirements.

The second stage – the preparation of the foaming mixture from a powder of glass granulate with a blowing agent, conducting a foaming process to produce fabricated porous filler.

Two-stage technology of obtaining porous aggregates allows to gradually optimize the structure and properties of the material depending on its purpose. In the first stage solves the problem of synthesis of glass granulate with specified characteristics that can be managed through prescription and technological factors. In the second stage the control of major indicators of macro - and microstructure of the porous filler.

The temperature interval of processing of the batch for low temperature of glass granulate must meet the phase transition of the charge from solid to viscous (with the formation of the melt in an amount of not less than 75 %), which is determined by the composition of the charge and the nature of its main component. The treatment is chosen individually for each composition of the batch.

The result of the heat treatment of the charge in the temperature region from not less than 0.8 of the liquidus temperature in the system is not equilibrium is reached and remains crystalline phase. Mass content in glass granulate should not exceed 25 %. After foaming, the content of the crystalline phase decreases to values from 15 to 4 %.

The obtained granules are milled, mixed with blowing agent and the foaming is carried out. Agents must meet the following requirements: the selection of the gas phase when heated only after full

sintering; a gradual increase in the pressure of the products of decomposition in the temperature interval of sintering.

The main components of the initial charge used industrial waste industry. Depending on the raw material composition of the charge is adjusted by various additives. The charge consists of three components: silica (waste), alkaline (soda ash), carbonate (dolomite).

The main requirements are: to the original siliceous material, its finely dispersion (average particle size less than 100 microns) and chemical composition; material – resistance to glass formation, the amount of generated melt and rheological properties [1].

Analysis of scientific literature showed that the choice of the composition of the batch for obtaining porous aggregates according to the technology of low-temperature foaming should be carried out subject to the following conditions [2 – 8]:

- mass maintenance of glass adjustable and oxides of alkali metals in the mixture should be sufficient for a sustainable glass adjustable, i.e. to be in the range of 60 – 75 and 13 – 22 %, respectively;
- the amount of the melt should not be less than 70 %, which is necessary to ensure pyro plastic the state of mass during the foaming;
- the liquid phase should have an optimum viscosity (103 – 106 PA·s) in the temperature range of foaming;
- the temperature of formation of liquid phase (melt) shall not exceed 950^{o}C to ensure the reduction of energy consumption.

Positive results of experiments for obtaining foam-glass-crystal porous aggregates from industrial waste requires carrying out additional experiments on the influence of various factors on the physico-mechanical properties of the resulting porous aggregates.

Since the process of obtaining porous aggregates is a two-step, the planning of the experimental research involved the study of two independent and consecutive processes:

- getting a glass granulate;
- directly obtaining foam-glass-crystal porous filler.

Decoding the phase composition of the obtained glass granulate, or rather, the definition of the content of the amorphous glass phase, was conducted using the program "Crystallographica Search-Match". Quantitative determination of the ratio of crystalline and glassy phases in the material was determined using a graphical editor and analyzer diffraction patterns – of the "Renex".

For obtaining foam glass crystal filler, the obtained glass granulate was milled to a particle size of 0.1 mm sequentially on a jaw crusher and disk eraser. Then into fine material added the blowing agent, which was used by different reducing agents (carbon black, finely divided coal, hexamine) and a mixture of a reducing agent with an oxidizing agent (coal + potassium nitrate, hexamine + potassium nitrate). The total amount of blowing agent was 1% by weight of crushed glass granulate. The blowing agent and chopped will glass granulate were thoroughly mixed, held the pelleting process to obtain pellets of 3...5 mm. Granules was placed in a porcelain boat and placed in a preheated muffle furnace at a temperature of 850^{o}C. In 30 s. with the boat was taken out and recorded the foaming process, and then the boat was again put in muffle furnace for the desired time period.

The obtained granules were investigated to determine their physico-mechanical characteristics.

To assess the quality of the obtained granulated material was used as the standard methods, for example [9], and methods developed in the study received new efficient materials [10 -19].

The density of the granular material was determined as the ratio of the mass of granules to volume of pushed out her sand. For this, each pellet is weighed on a laboratory balance with an accuracy of 0.01 g Porcelain crucible with a volume of three to four times larger than the volume of pellets filled with sand, calcined at a temperature of 900–1000 °C. the Excess sand is removed with a metal ruler. Approximately ¾ of the volume of sand poured from the crucible onto a sheet of paper. The test pellet was placed in a crucible on the remaining layer of sand and covered with sand sheet of paper. The excess sand is removed with a metal ruler on a sheet of paper and determine its volume in a measuring glass cylinder with a capacity of 10 see the Shaking of the crucible and the cylinder is not allowed.

The final result should be the arithmetic mean value of results of parallel tests of the three granules.

Bulk density was determined measured according to [9].

The determination of mechanical durability of pellets was performed according to developed at the Department of technology of silicates and nanomaterials TPU technique [10], according to which the strength of granules is determined by compressing them in the mold (fig. 1). The essence of the method is that the measured pressure at which the pellet collapses, the pressure pellet is transferred uniformly from all directions through the surrounding granules of elastic material. Elastic filling (polyurethane) is used to create a volume of pressure on the pellet of test material: the filling has a high elastic and wear-resistant properties and strength characteristics, while in this environment, a granule of the material being tested is in close contact with the granules of the backfill, which are much smaller than the size of the investigated granules.

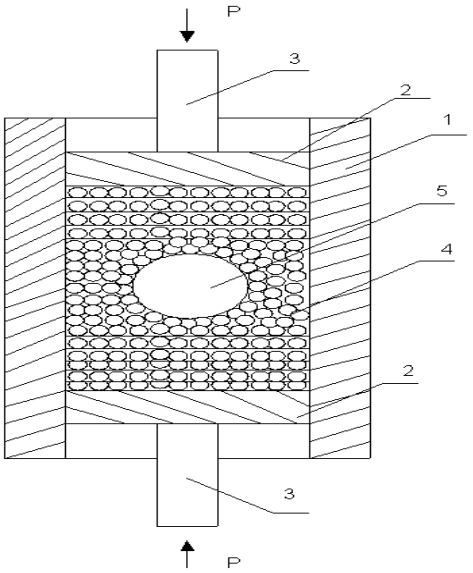

Figure 1. Device for measuring mechanical strength
1 - cylinder, 2 – piston, 3 - rod, 4 – granulated polyurethane, 5 – the sample

In the mold poured elastic filling and place a pellet of the test sample as shown in the figure, determine the form of the hydraulic press on the pistons through the rods served the pressure through the granular backfill is transferred to the pellet of the material.

The time of destruction of the granules is set according to the specific click and a sharp drop in pressure in the hydraulic system of a hydraulic press. The numerical value of the limit of compressive strength of pellets can be described by the formula (1) [10]:

$$R = \frac{MxF_{pis}}{3.14xd_{gr}^{2}}, MPa \qquad (1)$$

Where M is the gauge reading at fracture of granules (MPa); Fpis – the area of the piston of a hydraulic press (50.5 cm^2); *d*p – the average diameter of the pellet (cm).

3. The results of the study

The initial step of obtaining foam glass crystal filler is the synthesis of the glass granulate. To obtain the glass granulate was used the tailings of copper-zinc ore LLP "Corporation Kazakhmys", contains a rather high amount of alumina (up to 17% Al_2O_3). Based on the results of the analysis of phase diagrams, we have defined the basic parameters of the process of obtaining glass granulate and its

subsequent expansion. For the basic composition of the selected glass compositions in which the oxides constituting its base change in the following ranges, wt. %: 62-73 SiO_2; Al_2O_3 5-15; Na_2O 22-23, which requires the addition of soda ash. The pilot batch has the following composition, wt.%: 80 – waste; 20 % – soda ash [1].

Before heat treatment the mixture was compactibility, providing more rapid uniform heating and growth of chemical activity of the charge compared to powdered. With this purpose, the powder mixture previously moistened with 15%-s ' solution of liquid glass to the mass content in the charge 5 – 7 % and extruded.

Pre-heat treatment of the charge conducted on samples in the form of cylinders with a diameter of 20 mm and a height of 10 mm, which was heated in a muffle furnace at temperatures of 900 and 1000°C. After a thirty minute exposure of the cylinders at a maximum temperature of the samples was completely astelonaris (fig. 2).

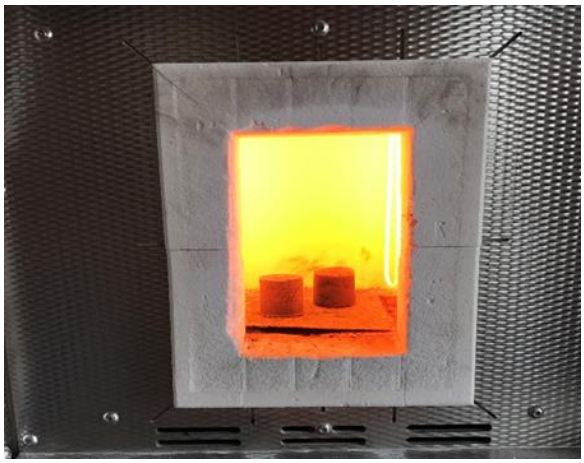

Figure 2. Heat treatment of the samples in a muffle furnace

X-ray diffraction showed (fig. 3) that the crystal phase represented by the residual crystalline quartz and albite. The content of the glass phase (70%) of the obtained glass granulate meets the specified requirements.

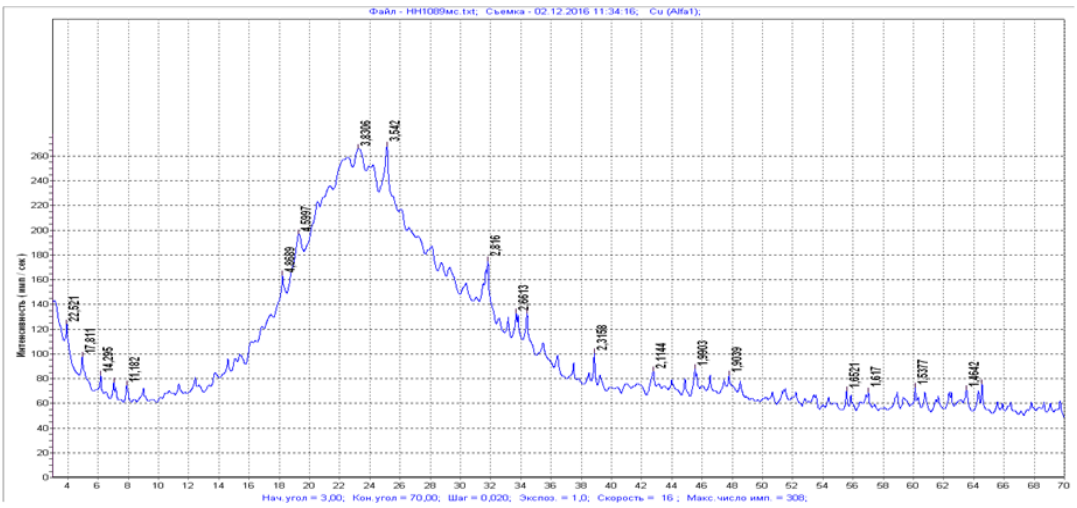

Figure 3. Radiograph of the glass granulate

Samples of the glass granulate in the form of cylinders with a diameter of 20 mm and a height of 10 mm after heat treatment is presented in fig. 4.

Figure 4. Samples of glass of the pellets after heat treatment

Thus, the best option for getting PSCM by low-temperature technology is the synthesis of glass granulate at a temperature of 900°C of a two-component mixture, containing 80 % waste and 20% soda ash.

The foaming process of the foaming mixtures, prepared from the synthesized glass granules ground to a specific surface of 5000 cm^2/g with addition as the blowing agent carbon black in an amount of 0.5 %, assessed on the value of the coefficient of expansion Kv. The coefficient of expansion shows the degree of increase in the volume of the sample during heat treatment at obtaining a porous material.

To determine the coefficient of expansion of the foaming mixture is prepared in the form of cylindrical specimens (with a pressing force of 1 MPa) the height and diameter of 10 mm with subsequent heat treatment in a tubular furnace at different temperatures, with the change of the maximum temperature of foaming and curing time (table 1).

Table 1. Mode and coefficient of expansion

The mixture	T_f, ^oC	$\tau_в$, min	K_v
PS-1	800	10	1.1
PS-2	800	15	2.74
PS-3	850	5	1.54
PS-4	850	10	3.36
PS-5	850	15	2.64
PS-6	900	5	5.19
PS-7	900	10	4.43
T_f – temperature foaming, ^oC; $\tau_в$ – holding at maximum temperature, min; K_v – the coefficient of expansion.			

The maximum coefficient of expansion took samples obtained at the temperature of foaming 900°C with 5 min. exposure, However, the macrostructure of these samples presented pores of large size

(over 5 mm), some of which were connected, obviously, a negative result was to affect the water absorption of the samples. Therefore, for further studies were selected for samples obtained at 850°C with 10 min. The characteristics and structures of these samples are given in table 2.

Table 2. Characteristics and structure of the samples of foam glass crystal porous aggregates for light concrete

The average pore size, mm	The average size of interporous partitions, micron	The macrostructure of the samples
1.2	50	

Thus, the developed temperature foaming during 850^{o}C exposure time of 10 min provides the optimal macrostructure of the porous material with the following characteristics: an average pore size of 1.2 mm, the average thickness of interporous partitions 50 microns [1].
The obtained filler has a porous structure. Some physico-chemical parameters have the following values [1]:
- density – 150...250 kg/m^3,
- thermal conductivity coefficient – 0.1 to 0.125 W/(m ^{o}C),
- compressive strength – 1.5...2.5 MPa.

4. Insights

The results of experimental investigations showed the possibility of obtaining foam-glass-crystal porous aggregates for lightweight concrete based on two component and multicomponent systems composed of one type of man-made materials, their mixtures in different ratios, and corrective additives. The paper discusses the two stage technology for obtaining foam-glass-crystal porous aggregates for lightweight concrete based on powder method, and includes two main stages: obtaining the glass granulate in the conditions of low-temperature synthesis and preparation of the foaming mixture of glass powder with blowing agent, conducting a foaming process obtaining a final aggregate. The processes of formation of structure occur at lower temperatures (not above 900^{0}C) compared with the process of obtaining foam glass and expanded clay with a significant reduction in the overall time of the technological process, which significantly reduces the energy consumption.
The resulting porous aggregates are characterized by high physical and mechanical properties: density 200-220 kg/m^3; strength of 3.1- 4.0 MPa; thermal conductivity of 0.07 - 0.1 W/(m ^{o}C); water absorption of 1-2%. Samples of lightweight aggregates are characterized by a high degree of homogeneity of the pore structure and is preferred for strength and conductivity pore sizes up to 1.2 mm and interporous partitions is 50 microns.

Confirmed that the obtained porous fillers for light concrete unlike traditional fillers (agloporit, expanded clay), can withstand higher loads without degradation due to the presence of the crystal structure of interporous partitions. The material has a low water absorption compared to concrete block, that indicates the ability to maintain their thermal performance over time, and has virtually unlimited lifespan.

For production of porous aggregate for lightweight concrete can be used in conventional industrial heating equipment used in the manufacture of bricks and ceramics.

Results on porous aggregates by low-temperature technology from industrial waste, allow us to conclude on the possibility of developing technological schemes for the production of porous aggregates with high physical and technical properties.

Established in principle the possibility of using technogenic waste of the industry that allows us to solve the environmental problems of waste disposal and to expand the raw material base for the production of porous aggregates for lightweight concrete.

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