Porous filler from foam-zeolite and light concretes based on it for conditions of the Arctic and the North

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Abstract. Vitreous porous aggregates and light concretes based on them undoubtedly have a great future in construction in the harsh conditions of the North and the Arctic. This article presents the results of experimental studies of the properties of similar porous aggregates and light concretes based on them, produced for the first time during semi-production tests from zeolite-containing rocks of the Khonguruu deposit in the Republic of Sakha (Yakutia). It has been established that porous fillers made of foam rubber with a density of 150-300 kg/m$^3$ have a rather high strength of 1.0-3.9 MPa. It is shown that with the optimal selection of the composition and fractions of granules of GFG there is a real possibility of obtaining a class of concrete B2.5 and B3.5 for low-density structural and heat-insulating concrete D500 and D600, thermal conductivity coefficients under operating conditions A are 0.14 and 0.16 W/(m×K), respectively. Such characteristics of a new type of lightweight concrete make them competitive with traditional wall materials such as wood concrete, expanded clay foam concrete, cellular concrete, etc.

1. Introduction

For the construction of energy-efficient buildings, lightweight concrete is one of the most efficient and economical wall materials. The main physicomechanical properties of lightweight concrete are determined by their highly porous structure, which is obtained by forming the structure of concrete using gas and foam formation processes [1,2], by introducing porous aggregates [3] or by a combined method [4]. As is known, in low-rise construction, effective wall materials should have a low density and sufficient strength characteristics, almost like wood, so that you can build a one- and two-story building without a frame [5].

In the rank of effective wall materials, cellular concrete is a priority. However, they have some drawbacks. So, blocks of non-autoclaved hardened concrete concretes according to the requirements of GOST 21520-89 (2003) are recommended to be used in masonry walls of a single-storey house with a mark of average density D700 and a concrete class not lower than B2 (M25), for a two-story house - D900 and B2.5, respectively (M35). Similar requirements for the strength characteristics of B2 and B2.5 are imposed for structural thermally insulating autoclaved aerated concrete with a grade of average density D500. But such wall materials, mainly autoclaved aerated concrete, are available only for industrialized centers like Moscow, St. Petersburg, Novosibirsk, etc.

The northern cities - the strongholds of the Arctic - Murmansk, Arkhangelsk, Vorkuta, Norilsk, Tiksi, Pevek and Magadan were originally built in stone, where the main building material was...
claydite. Single-type residential buildings up to 5 floors in large-block and panel versions were built from porous concrete with a density of 1200–1600 kg/m$^3$ without additional insulation on a claydite aggregate with a density of 450–500 kg/m$^3$ [6].

2. Relevance
To obtain lightweight concrete with a density of 500 kg/m$^3$ according to the traditional technology, it is necessary to have expanded clay gravel with a density of 200 kg/m$^3$ with an appropriate grade for strength P25, which today is a difficult task [7]. Therefore, there is a need to produce lightweight concrete using granulated foam glass. – GFG, having a low bulk density of 150-300 kg/m$^3$ and sufficient strength of 0.5-2 MPa [8]. In Russia, GFG is mainly produced on the basis of broken glass [9]. Of practical and scientific interest are the results of research into the possibility of using natural (flask, tripoli, diatomite, perlite, zeolite, etc.) [8-15] and man-made [16-17] raw materials in the production technology of GFG. The reserves of sedimentary and volcanic rocks containing active silica and alumina are huge and are available in all regions of the country. In this regard, it is relevant to study the properties of granulated foam glass from local raw materials and the possibility of its use in the production of effective wall materials for low-rise construction in the Arctic and North.

3. Materials and methods
In experimental studies used the following source materials:
- porous aggregate - GFG - granulated foam glass, obtained during half-factory tests, fraction 3-10 mm [18];
- portland cement CEM I 32.5R produced by «Yakutcement»;
- sand according to GOST 8736-2014 from the Lena open-cast mine near Yakutsk;
- technical water according to GOST 23732-2011.

The main physicomechanical indicators of GFG samples were determined in accordance with the requirements of GOST 9758-2012, the quality indicators of the porous aggregate were evaluated according to GOST 8736-2014. Selection of the composition of lightweight concrete with GFG was carried out in accordance with GOST 27006-86, tests of the basic properties of lightweight concrete were conducted in accordance with GOST 12730.1-78 and GOST 10180-2012. To analyze the microstructure of the foam glass, a JEOL JSM-7100F scanning electron microscope was used. Statistical processing of experimental data was carried out using the program MathCAD 2001i.

4. Results and Discussion
The main characteristics of the GFG were determined: bulk density and true density, water absorption by mass and volume, compressive strength (Table 1).

| №  | Name of the indicator             | GFG fraction (mm) |
|----|----------------------------------|-------------------|
|    |                                  | 3-5               |
| 1  | Bulk density (kg/m$^3$)          | 297.53            |
| 2  | True pellet density (kg/m$^3$)   | 593.52            |
| 3  | Crushing strength in cylinder (MPa) | 4.84            | 3.51          | 1.44          |
| 4  | Water absorption by weight (%)   | 32.92             |
| 5  | Water absorption by volume (%)   | 19.62             |

According to the analysis of the quality of granules of GFG in accordance with GOST 32496-2013, the resulting porous aggregate has a bulk density mark of M200-M300 depending on the grain fraction (figure 1), a high strength grade of at least P50 at a low density of no more than 250 kg/m$^3$, low water absorption is not higher than 20% by weight.
Low water absorption of GFG granules, as well as for all types of vitreous porous aggregates [8-20], characterizes closed porosity and the presence of thin interporous partitions, the formation of which is due to the specificity of foam glass production. The microstructure of the cleaved GFG is shown in figure 2.

Thus, according to the basic physicomechanical characteristics, the granules of GFG significantly exceed the indicators of expanded clay gravel (table 2) and can be used to produce lightweight concrete and effective products based on them.

**Table 2.** Comparative characteristics of claydite and GFG.

| Aggregate   | Durability at squeezing in the cylinder (MPa) | Durability in accordance with GOST 32496-2013 (MPa) | Strength grade according to GOST 32496-2013 | Brand by bulk density |
|-------------|-----------------------------------------------|---------------------------------------------------|---------------------------------------------|-----------------------|
| Expanded gravel | 1.46*                                      | 1.0-1.5                                            | P50                                        | M400                  |
| GFG         | 1.44                                         | 1.0-1.5                                            | P50                                        | M200                  |
|             | 3.51                                         | 3.3-4.5                                            | P150                                       | M300                  |
|             | 4.84                                         | 4.5-5.5                                            | P200                                       | M300                  |

* - according to the authors [5]

It is known that lightweight concrete based on GFG is made in two ways:

a) foamglass concrete [19] is made by introducing granulated foam glass into a foam concrete mix;

b) GFG-concrete or light concrete [20] is made by introducing granulated foam glass into cement-sand or cement mortar.
Comparative analysis of research results [8-20], that at the same density, foam glass concrete is inferior to GFG-concrete according to strength characteristics, water absorption and frost resistance. So, in foam glass concrete with a density of 500 kg/m³, the class of concrete does not exceed B1 [21], and in GFG-concrete, depending on the strength characteristics of foam glass granules and the amount of cement, the class of concrete can be from B1.5 to B2.5 [5,8]. In our studies, light concrete samples were made on cement mortar with high filling with foam granules of different fractions of 3.5–5, 5–7.5 and 7.5–10 mm granules.

Table 3. GFG-concrete characteristics.

| №  | Fraction (mm) | Average density (kg/m³) | Brand on average density in accordance with GOST 25820-2014 | Compressive strength (MPa) | Class of concrete for compressive strength according to GOST 25820-2014 |
|----|---------------|-------------------------|----------------------------------------------------------|-----------------------------|---------------------------------------------------------------------|
| 1  | 3-5           | 596.93                  | D600                                                     | 2.86                        | B2                                                                  |
| 2  | 5-7.5         | 536.24                  | D500                                                     | 2.18                        | B1.5                                                                |
| 3  | 7.5-10        | 445.78                  | D400                                                     | 1.27                        | B1                                                                  |

As can be seen from the table 3 received samples of lightweight concrete D500 and D600 for strength meet the requirements of structural thermally insulating concrete according to GOST 25820-2014.

Positive results were obtained with a rational combination of different fractions of GFG granules according to Table. 2 at a ratio of 1: 2: 1 for the design density of concrete D500 and 1: 1: 2 for concrete D600. When testing samples of lightweight concrete it has been established that there is a possibility of increasing the strength characteristics to the level of class B2 concrete, (3,3 MPa) and B3.5 (4,6 MPa) respectively for structural thermal insulation concrete D500 and D600.

In this case, the calculated thermal conductivity of lightweight concrete D500 and D600 on the basis of GFG was 0.14 and 0.16 W / (m × K), which correspond to the previously obtained indicators for concrete with vitreous porous aggregates [8].

Thermophysical properties of structurally insulated concrete D500 and D600 on vitreous porous aggregates, including lightweight concrete on GFG, surpass most of the known analogues (autoclaved aerated concrete, wood concrete, claydite foamed concrete, non-autoclaved aerated concrete) used in low-rise building, which means it can be effective, low-energy concrete, non-autoclaved aerated concrete, used in low-rise construction, it is possible to work with effective energy-efficient concrete, non-autoclaved aerated concrete, used in low-rise building, it is possible to use energy-efficient concrete (figure 3).

5. Conclusions
The organization of production of GFG - foam-zeolite from zeolite-containing rocks of the Khonguruu deposit is a real project designed to provide the north-western and arctic regions of the Sakha Republic (Yakutia) with effective porous aggregates.
According to research results, structurally thermally insulated concrete D500 and D600 with porous filler from GFG will increase the level of thermal protection of exterior walls by 2-2.3 times as compared with walls made of claydite-concrete D1200 of typical buildings of the Soviet period with significant savings in materials and energy resources.

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