Alternative possibilities for application of foamed silicate materials

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Abstract: *In summary form, some trends in the production and application of foamed silicate materials obtained from recycled waste materials are presented. The existing possibilities for the use of different fractions of foam glass granules for the preparation of various products (lightweight concrete, colored decorative panels, etc.) are considered. Experimental samples are prepared in which the average value of the thermal conductivity coefficient λ=0.24±0.13 W/m. K was established. The main technological factors determining the operational characteristics of the material and the existing potential prospects for their optimization are analyzed.*
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1. Introduction

The development of new materials and technological methods allows the production of products with different functional characteristics and application [1-10]. Due to the growing quantities of household and industrial waste products, the development of ecological technologies for cost-effective recycling of waste raw materials and production of competitive ware is of interest. The presence of glass waste materials that are not fully utilized is a prerequisite for finding suitable opportunities for their recycling. The possibilities for obtaining various silicate foam products from glass waste raw materials of different origin have been studied. The effect of the introduction of various foaming agents in the compositions and the role of the applied thermal treatment on the processes of foaming and pore formation have been established [11,12]. Based on the obtained data, recipe compositions and an adequate technological regime (for obtaining products) have been developed, in accordance with the specifics of the used waste silicate raw material and the foaming agent [12].

Various foam glass products are used in the insulation of buildings, equipment, facilities, pipelines and other objects [12]. At the same time, foam glass gravel is applicable in the field of road construction and landscape design.

The foaming ability of deep-water organogenic-mineral sediments and their use as a foaming agent for the preparation of foam glass samples from waste glass are studied [13].

A promising approach for obtaining silicate foam products is the utilization of waste raw materials obtained from various production activities. The foaming ability of amorphous-crystalline polyphase waste product from the energetics, characterized by the presence of different phases: glass phase, $Al_6Si_2O_8$, $CaAl_2Si_2O_8$, α-SiO_2, Fe_3O_4, α-Fe_2O_3 and other phases was studied. Thermal treatment (up to 1100°C) of the raw material without the introduction of foaming agent resulted in polyphase foam products with the presence of alumosilicates (mainly mullite $Al_6Si_2O_8$) and other crystalline phases [14].

An insulating material has been developed with the participation of foam glass granules (obtained from waste glass raw materials), inorganic hydraulic binder and technological additives. The material is applicable for the production of various profiles, non-bearing panels and others [15].

Thermal insulation material is obtained by thermal treatment of samples prepared from deep-water organogenic mineral sediments and foam glass granules distributed in the volume of the material [16].

Due to their specific characteristics, some foam glass materials can be considered as alternative substitutes to a number of classic lightweight aggregates. In this aspect, it is of interest to study the possibilities for the application of foam glass granules in the preparation of lightweight concrete [17] for construction.

Another approach for the application of foam glass materials is the production of foam silicate granules with different color characteristics and their use for the preparation of panels.

The aim of the present work is to establish the coefficient of thermal conductivity of experimental samples obtained from foam glass granules and Portland cement. The technological factors determining the operational indicators of the material are analyzed and the possibilities for application of foamed silicate materials for the production of lightweight concrete and colored decorative panels for cladding of buildings are considered.

2. Experimental procedures

For the preparation of the necessary experimental samples, foam glass granules were obtained using a technological method of several stages: grinding of waste silicate glass, obtaining initial batch from glass powder and a suitable foaming agent, preparation of primary granulate, foaming of the obtained product up to form foam glass granules by applying thermal treatment to 900^{o}C (with an soaking of 15 min) and sorting the granules by fractions. The necessary thermal treatment for foaming of the obtained primary granulate was performed in a programmable muffle furnace, equipped with an electronic programmer, providing determination of the speed (5-10^{o}C/min) of increase and decrease of the temperature values and the time of soaking.

A mixture of foam glass granules (fractions up to 20 mm in diameter) and pre-prepared Portland cement (CEM I 52.5 R) solution and water was prepared. At using compositions of several fractions of foam granules (of different sizes), the smaller ones are localized in the cavities formed between adjacent granules with a larger diameter. The bulk density of the samples increases with growing the introduced amount of granules with smaller sizes. The molding of the samples was done by laying the mixture in pre-prepared formwork forms. The obtained test specimens were stripped after 24 hours and after additional technological downtime were subjected to final machining to form cylindrical experimental specimens applicable to the present study.

The comparative method is used to measure materials with a low thermal conductivity, using comparative samples with a cylindrical shape [EN1225]. A comparative sample (h_R=12 mm, D =120 mm), test material (L=65 mm, D=120 mm), a second reference sample (h_R=12 mm, D=120 mm) and a cooler are placed successively on the heater. The diameters of the comparative samples and the test sample are the same (D=120 mm). The system is insulated with a material with a low coefficient of thermal conductivity. Figure 1 shows a scheme for implementing the comparative method for measuring the coefficient of thermal conductivity.

In fig. 1 the following designations are used: 1 - heater, 2,3 - comparative samples with cylindrical shape from material with high thermal conductivity (steel), 4-test sample, 5,6,7,8 - thermocouples for measuring temperatures type K, 10 - thermometer - registering device for recording the change of temperatures with time (4-channel CENTER 304 type K thermometer).

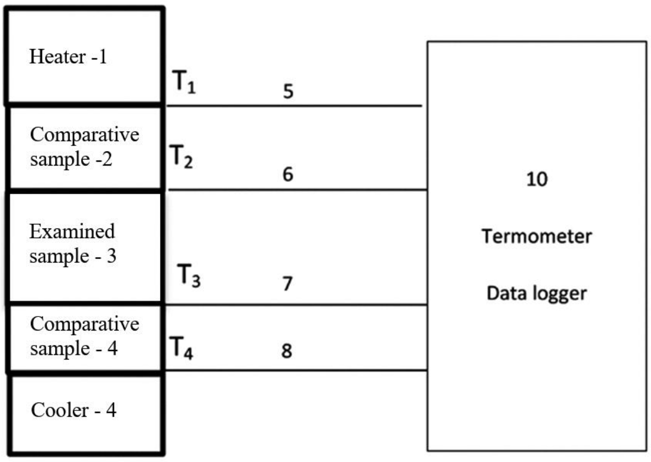

Fig. 1*. Scheme of experimental installation.*

The amount of heat Q that is conducted through a material of thickness h at a temperature difference ΔT at a time interval τ through an area S is determined by the dependence:

$$Q = \lambda.s.(\Delta T/h)$$

where λ is the coefficient of thermal conductivity of the material, and ΔT is the temperature difference of the two opposite surfaces.

At a stationary thermal regime, the amount of heat which passes from the heater through the comparative sample to the test piece and the second comparative sample, which have the same area, is the constant:

$$Q = \lambda_R . \frac{\Delta T_{12}}{h_R} = \lambda_x . \frac{\Delta T_{23}}{h_x} = \lambda_R . \frac{\Delta T_{34}}{h_R};$$

where λ_R is the coefficient of thermal conductivity of the material of the comparative sample, λ_X is the coefficient of thermal conductivity of the test sample, ΔT_{12} is the temperature difference measured on the surface of the heater (1) and the comparative sample (2), ΔT_{23} is the temperature difference measured on the surfaces of the comparative (2) and the measured sample (3).

The coefficient of thermal conductivity λ of the material of the test sample is determined by the expression:

$$\lambda = \lambda_R \frac{\Delta T_{12}}{\Delta T_{23}} . \frac{h_x}{h_R}.$$

3. Results and Discussion

The accuracy of the proposed method largely depends on the accuracy with which temperatures and temperature differences are determined, the accuracy with which λ_R is determined of the geometric dimensions of the samples. Sufficient time is required to create a constant temperature gradient in the studied system. The measurement is repeated many times and the data are processed statistically. The average values of the temperature in the two disks with which the studied material is in contact are determined. In fig. 2, 3 and 4 show the results of the temperature measurements.

At the laboratory tests of the prepared experimental samples, an average value of the thermal conductivity coefficient λ=0.24±0.13 W/m.K was registered.

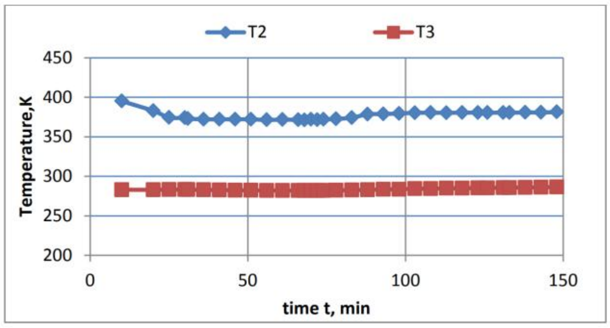

Fig.2. *Change in the surface temperature of the comparative sample (2) and the test sample (3) over time.*

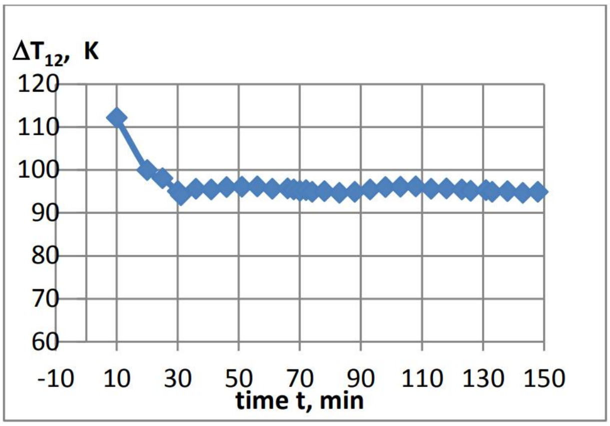

Fig. 3. *Change of temperature differences ΔT_{12} with time t.*

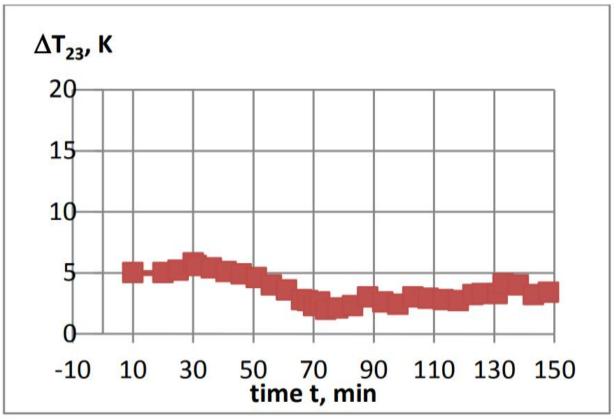

Fig. 4. *Change of temperature differences ΔT_{23} with time t.*

Based on the experimental data obtained from the present and previous studies, the main technological factors determining the characteristics of the product are analyzed: composition of the starting waste silicate raw material (glass waste), used foaming agent, presence of modifiers, used of plasticizers, composition of the prepared batches, heat treatment regime (applied in the preparation of the foam glass granules), degree of foaming of the obtained foam glass granules, granulometric composition of the used foam granules, used Portland cement, weight ratio of cement: granules, application of technological additives (air-entraining agents, water-reducing agents, zeolite, etc.), introduction of other components (river sand, etc.), technological parameters of the cement solution, characteristics of the obtained mixture granular-cement solution, introduction of reinforcing fibers (fiberglass fibers, basalt fibers, steel fibers, etc.), presence in the volume of the material of air cavities formed at the contact of adjacent foam glass granules, etc.

According to the necessary functional characteristics of the product, there are different possibilities for modifying the compositions and changing the technological conditions for obtaining the product. Optimization of the performance of the material can be done by applying different technological approaches: increasing of the degree of foaming of the foam glass granules, appropriate ratio of the used fractions from granules, presence of different reinforcing components according to the used fractions of foam granules, removal of excess liquid phase at the end of the technological process and a number of others.

The applied technological method for obtaining the material has some main advantages: recycling of non-degradable in natural conditions waste silicate raw materials, use of available standard materials (cement, etc.) with a relatively low cost, application of simple technological activities for the preparation of the samples, obtaining sustainable end product with a long service life.

A logical technological approach the use of different fractions of foam silicate granules as alternative substitutes for some classic lightweight aggregates (expanded clay, expanded perlite, vermiculite, etc.). Therefore, foam glass materials can be considered as suitable alternative components applicable to obtain of lightweight concretes and other products. The material is applicable for the production of monolithic products by casting in various formwork forms, as a filler for cavities, in the construction of flooring and various repair and construction activities. The obtained experimental results are a prerequisite for further development of various compositions for lightweight concrete with suitable characteristics.

Another original opportunity for the application of foam glass materials is the preparation of a palette of color patterns. Compositions suitable for the production of foam silicate granules with various color characteristics have been developed by introducing colorants in the initial compositions. From the prepared colored silicate granules and inorganic hydraulic binders prototypes of panels potentially applicable for decorative cladding of buildings and other architectural objects were made.

4. Conclusions

Experimental samples of foam glass granules (obtained from waste silicate materials) and Portland cement were prepared, in which the average value of the thermal conductivity coefficient λ=0.24±0.13 W/m.K was experimentally established by applying the comparative method.

The functional characteristics of the material and the possibilities for their optimization are determined by a number of technological factors: starting prescription compositions, specifics of the foaming agent, heat treatment regime, degree of foaming of the prepared granules, ratio of different fractions of foam glass granules used, Portland cement used, weight ratio cement: granules, introduction of technological additives, application of reinforcing fibers, technological parameters of the prepared cement solution and the resulting mixture of granules-cement mortar and others.

A promising environmental solution is the use of foam glass granules (derived from glass waste) as an alternative component, replacing some standard lightweight aggregates in the manufacture of lightweight concrete and other products.

By introducing colorants to the starting compositions, foam silicate granules with different color characteristics were obtained. From the obtained colored silicate samples and inorganic hydraulic binders are made panels, potentially applicable for decorative cladding of buildings.

5. References

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