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Cellular glass obtained from non-powder preforms by foaming with steam

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ABSTRACT

Cellular glass, or foamed glass, has been obtained as a result of the heating (to 700–800 °C) of heavy and strong preforms formed due to the binding properties of the silicate additives. Durability of the preforms reached 6 MPa at the density of 1.8 g/cm^3. The main expanding agent in the composition is steam, which can also be a carbon oxidizer and increase the amount of the evolved gases and decrease the density of the foamed glass obtained. As a result of changing the initial composition structure, the density of the obtained foamed glass varied from 0.14 to 0.6 g/cm^3, its breaking strength - from 0.6 to 5.0 MPa. and heat conductivity – from 0.045 to 0.15 W/(m·K), respectively. The speed of expansion of the preforms had an extreme character with the induction period typical for topochemical reactions. The obtained cellular materials possessed a distinct crystalline structure. The experiments showed the possibility of obtaining cellular materials with acceptable properties from different types of glass for the solution of environmental tasks. Various technological methods of obtaining cellular material blocks from preforms of various forms were tested to use them for thermal insulation and facing materials.

1. Introduction

Processing of glass wastes is an urgent task not only from the environmental protection point of view, but also in connection with the economy of natural resources. Glass wastes contain not only concentrated natural raw materials, but also considerable power stocks which are lost forever while burying wastes at landfill sites. However, not all glass wastes can be successfully recycled because of the difference in their chemical composition and complexity of the cullet sorting, especially in case of small fractions. Besides, there are some types of glass which cannot be processed using the existing technologies, for example, lead-bearing glass from the cathode-ray tubes (CRT).

It is considered that glass wastes can be recycled to produce foamed glass and thus to solve environmental problems. It is shown that cellular glass possesses a complex of unique consumer properties and can be successfully applied in various areas of construction and other applications [1]. The production of cellular glass was mastered in the early thirties of the last century when they started to manufacture the material widely [2]. Extensive researches in this field were carried out and generalized by B.K. Demidovich [3,4], but the process was based on processing special sulfate-containing glass.

In the process of foaming, glass acts as one of chemical reagents. Successful foaming at the temperatures of thermoplasticity of glass requires availability of a sulfate ion in the initial glass, which acts as an oxidizer of the carbon added to the powder composition.

The reaction is described as follows:

$$Na_2SO_4+2\,C+SiO_2+H_2O=Na_2SiO_3+2\,CO_2+H_2S \quad (1)$$

In case of low content of steam in the composition, the sulfate ion changes into a sulfide ion according to the reaction:

$$Na_2SO_4+2\,C=Na_2S+2CO_2 \quad (2)$$

As a result, the obtained foamed glass of such kind preserves sulfide during all its lifetime, and with the slightest damage of the material it is exposed to hydrolysis by steam from air to produce a typical smell of hydrogen sulfide, even when the foamed glass product is aged enough.

Therefore, many researches were involved to solve the problem of finding ecologically safe gasifier for the foamed glass and to develop the technology of foaming independent of the composition of glass cullet. Many researchers propose using lime carbonate and other substances as gas developing agents. However, it is known that silicate glasses can give off water up to the temperatures of a pyroplastic condition of glass and even above. Therefore a number of investigations were concentrated on the use of steam as a gas developing agent in the process of obtaining cellular glass. Besides, steam is known to react as an oxidizer of carbon at the

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temperatures of foamed glass formation, this property being used in the processes of steam conversion.

That is why, an assumption concerning the possibility of using steam present in the composition of preforms for carbon oxidation, increase of the volume of the evolved gases and control over the properties of the foamed glass obtained, seems to be quite perspective.

In case of using gas developing agents with the components being not a part of glass, for example, lime carbonate, the chemical constitution of glass is not so important any more. The glass powder in that case only needs to be able to form gas-tight and plastic mass at the temperature of thermal decomposition of the gas developing agent. It allows us not only to use different types of glass (including wastes) as a raw material and thereby to solve the glass recycling problem, but also simplifies the technological process.

Actually, it is significantly simpler to operate decomposition of one gas developing agent, than interaction of two solid components, as it happens in the case of the sulphatic mechanism. It is lime carbonate that is most widely used as a source of carbon dioxide which foams the silicate composition in a pyroplastic state and promotes crystallization of the obtained foam [5]. For example, the use of lime carbonate from calcite, dolomite [6] or from eggshell [7] enables us to produce qualitative cellular materials.

Besides the use of carbon dioxide which is evolved in the process of thermal decomposition of carbonates, oxygen formed as a result of thermal decomposition of oxides is also known to be used. For example, the decomposition of manganese oxide MnO_2 to Mn_2O_3 is used [8,9]. In general, oxidation-reduction couples can be probably offered in quite a wide range, especially when changing composition and temperature. For example, the transition of Fe^{3+} into Fe^{2+} can be a basic reaction for gas development at higher temperatures than normally used in the foamed glass production. For this purpose basalt is probably added to the composition [10].

Another option of foaming the pyroplastic glass composition is dissolution of gas in a melt under pressure with further sharp relief and cooling of the formed foam. In this method physico-chemical properties of the system are not much important; it is actually based on the dissolution of gas in a melt under pressure. The obtaining of cellular boron and silicate glass by dissolution of argon in the glass melt under pressure can be an example of the method [11]. But, despite the quality of the obtained material and technical simplicity of the method, it is difficult to organize high-performance and profitable production, based on such a model.

It is also necessary to consider available raw materials for cellular glass. In most cases authors propose using sodium - calcium silicate glasses. But along with this raw material, there is also lead-bearing glass from utilized cathode-ray tubes and boron-bearing glass, received as wastage of medical and electronic equipment. Therefore, the technology of processing mixed glass cullet and even glass-like slag from the waste-burning plant would be very promising, the example of it being the technology described in [12], when the authors used vitreous slag formed after the plasma gasification of municipal solid wastes.

Nevertheless, it is a well known fact that silicate glasses as anhydrous silicates can be obtained by fusing silicon oxide in various forms with salts of sodium and calcium, so that acid radicals are removed from the melt in the form of gases. One can suppose that it is possible to choose such conditions and reagents that the gases formed would foam the composition. Sodium hydroxide can be one of sodium oxide sources in the glass. In this case heat treatment of the mixture results in sodium oxide being bound with silicon oxide to form silicate, and the rest of the hydroxide forms steam withdrawn from the melt.

Therefore, the presence of silicon oxide and sodium hydroxide in the initial composition leads not only to formation of some additional glass, but also forms an ecologically safe gas developing agent – steam [13]. Steam can be a gas developing agent in a silicate system when the composition contains not a mixture of amorphous oxide of silicon and sodium hydroxide, but also the solution of liquid silica glass. In this case light weight cellular silicate structures are formed [14].

It is also necessary to pay attention to the fact that in the course of forming cellular material the glass powder is surely to be baked into a gas-dense composition to prevent gases from leaving the mixture. Therefore, it would be necessary to obtain such a gas-dense composition at the lowest temperature possible. However, it is known that under certain conditions powders of glass can possess binding properties favorable for preservation of gases inside the composition even at low temperatures. Finally, one more feature which is characteristic of silicate glasses is the possibility of their synthesis from amorphous oxide of silicon at rather low temperatures. Therefore, to solve the problem of recycling glass wastes and independence of gas generation on the composition of glass cullet, the process of gas generation should be carried out in some matrix binding the glass particles. Besides, such matrix should transform into a glassy state at the temperatures of the material foaming.

The suggested method of obtaining foamed glass possesses three distinctive features [15]. First, the gas developing agent is not a part of initial glass, and in a raw composition it is located in the space between grains of glass powder, being a part of a binder. Second, the binder between the grains of the glass unites the grains of the primary glass into a uniform body which is a preform for the production of glass. Third, in the course of heat treatment the binder is to form the material indistinguishable from the mass obtained from the glass powder.

When all the conditions are fulfilled, the finished cellular products can be obtained not from the powder mixture, but from the preforms of an irregular shape formed with the help of the silicate binder, which is technologically much safer and easier to work with. The foamed glass products obtained from such preforms do not differ from the analogs made by the traditional powder method.

In this paper we report a novel technique to prepare a low density foamed material using non-powder preforms as a raw. The preforms were obtained using binding properties of glass powders of various compositions. In the course of heating the preforms, steam evolved, foaming the composition and forming a cellular structure. Addition of carbon to the composition changes characteristics of the obtained silicate foam in a wide range. Technology of the process, as well as application of the obtained materials are discussed.

2. Experimental procedure

Powders of glass and silica gel were prepared by bead milling with ceramic spheres. Soda-lime-silica container glass and coarse-granulated silica gel with large pores were used. The powders for all the experiments were screened through a bolter with the cells size of 100 μm. Liquid silica glass had the density of 1.42 g/cm^3 and the silica modulus of 2.6. Food sugar was used as a carbon-bearing additive.

For the preparation of preforms from paste, glass powder was mixed with 0.2 wt% silica gel powder. The solution was prepared by mixing distilled water and liquid silica glass in a volume ratio of 1:1. In some cases the amount of sugar needed for the experiment was dissolved in water beforehand. The obtained solution was added to the mixture of powders with the mass proportion of 0.43:1.00, and the mixture was stirred to form homogeneous