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Investigation of the Physicochemical Properties of Borosilicate Glasses for the Preparation of Glass-Fiber Materials

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Abstract—Borosilicate glasses of two compositions are synthesized and investigated with the aim of preparing glass microspheres from them. Using the Appen and Okhotin additive methods, the physicochemical properties of the glasses and melts are calculated, their crystallization ability and water stability are experimentally studied, their intrinsic temperatures are determined using dilatometry and differential scanning calorimetry, and their TLCE values are obtained.

Keywords: borosilicate glass, hollow glass microsphere, viscosity, surface tension, crystallization ability, mechanical and chemical strength

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INTRODUCTION

At present, demands on designing new composition materials capable of long-term operation in severe conditions, such as high temperatures, large mechanical loads, aggressive media, and various radiations, have grown due to the intense developments in engineering. Most engineering problems where a loss of weight is required under low heat conductivity, a high level of strength and economy in terms of volume, and increased resistance to erosion and aggressive media can be solved using glass-fiber materials [1].

There are two types of glass microspheres: glass microbeads and hollow glass microspheres (HGMs).

Glass microspheres are multifunctional materials, which possess some valuable physicochemical and operational properties. Due to their unique combination of shape, size, low density, relatively high uniform compression strength, and high levels of heat- and soundproof and dielectric properties, they are used as a filler in the production of composite polymer materials of various applications, lacquers, and paints; in the fabrication of light-reflecting coatings and various lighting signaling units; in designing medical products; and in other industrial fields.

Construction has recently been developing quickly. During the construction of buildings and facilities, nonhomogeneous solutions are often employed resulting in less robust buildings. To solve this problem, ultralight-weight cement grouts with a stable average density should be used. This is also related to grouts that fill oil wells, where the strength of the entire construction is necessary. For this purpose, HGMs are introduced into the solution. Walls of microspheres should possess a theoretical strength of 800 to 2000 MPa and a specific strength of over 150 MPa according to [2, 3], which is 3–4 times as large as the analogous values of other light-weight fillers.

The aim of this work is to choose the chemical composition of borosilicate glass, which fulfills the requirements for light-weight fillers of building mortars. The glass-fiber material from this glass should be light and strong. The introduction of HGMs into a concrete system would ensure a thick, highly homogeneous material with low average density [3].

EXPERIMENTAL

The glasses were synthesized in a silicon carbide heater at 1350–1450°C. Local raw materials were used as the main materials, such as quartz concentrate, feldspar mixture, limestone, soda, boric acid, and sodium sulfate. Glasses of two compositions were investigated (wt %): in composition 1, there are oxides of alkali and alkaline-earth metals along with silicon, boron, and aluminum oxides at equivalent ratios, while composition 2 not contains CaO and MgO.

	SiO_2	Al_2O_3	B_2O_3	Na_2O_3	CaO	MgO	SO_3
1	74	1.2	5	8.6	8.9	1.7	0.6
2	72	1.9	7	18.8	–	–	0.3

The content of Na_2SO_4 in glass was varied during the experiments. The specimens were molded into a

Table 1. Physicochemical properties of glasses

Composition no.	Theoretical calculations				
	surface tension, σ, N/m	elasticity modulus *E*, mPa	density ρ, kg/m^3	TLCE $\alpha \times 10^7$, °C^{-1}	ultimate compression stress, σ_{comp}, Pa
1	306.02	74765	2490.62	67.80	1048.12
2	276.28	71436	2473.43	94.32	1065.36

Table 2. Experimental data

Composition no.	Surface tension, σ, N/m	Viscosity of glasses η, Pa s	Water stability (dimming class)	Crystallization ability
1	193.2 (*T* = 860°C)	13×10^9	3/98	+
2	160.1 (*T* = 820°C)	15×10^9	4/98	–

graphite mold from the glass melt and, then, the specimens were annealed.

The crystallization ability of the glasses was determined using the gradient method in a pipe furnace. Viscosity was measured using an indenter on a viscometer at a temperature of 620 to 640°C at various loads. The water stability of the glass powders was determined according to GOST (State Standard) 10134.0-82 using the powder diffraction technique.

The theoretical properties were calculated for various compositions (Table 1), among which two were chosen with high values of density, compression strength, and the elasticity modulus, because glass microspheres should resist high pressure. Composition 1 is characterized by a low TLCE value, which is favorable for thermal stability. To prepare a strong microsphere, the initial glasses should possess, in our opinion, a high ultimate stress (from 1030 MPa), a surface tension of higher than 270 N/m at 1300°C, and a low TLCE value (less than 90×10^{-7}°C^{-1}).

The values of the viscosity of the melts were calculated at various temperatures and their graphical dependences are given in Fig. 1.

The results of the experiments are given in Table 2. It is important to obtain a high chemical strength of the glass, because the use of HGMs in mortars assumes their interaction with a weak basic solution.

Composition 2 was weaker and less stable and it is related to dimming class 4. The glass of composition 1 is sufficiently stable for crystallization as compared to composition 2.

The glasses with the mentioned compositions were also synthesized under industrial conditions with the formation of granulate, from which glass powder was prepared. Microspheres were prepared by blow molding at 1300°C and tested for water stability and pressure.

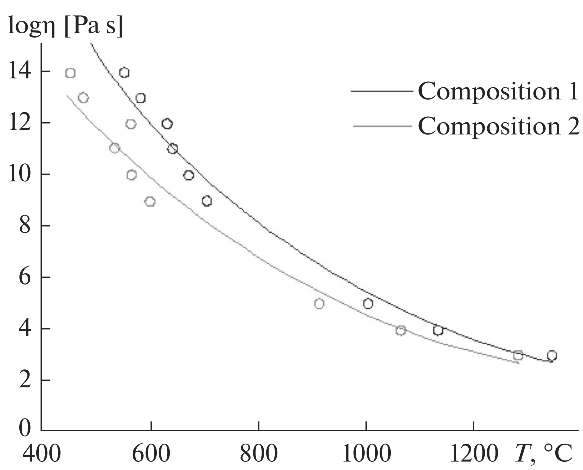

Fig. 1. Graphical dependences of logη vs. temperature according to calculated data for compositions 1 and 2.

RESULTS AND DISCUSSION

The glass of composition 1 is resistant to an aqueous environment. Composition 2 was weaker and chemically less stable; it consists of a large number of alkali oxides and is low-melting, which is important during microsphere formation.

The most important characteristics for sphere formation are the viscosity of the melt and surface tension. As follows from the calculations, at *T* = 1350°C, the logarithm of the viscosity for composition 2 corresponds to 10^3 Pa s. This glass is sufficiently low-melting for sphere formation. In the case of composition 1, significantly higher temperatures, which make it difficult or impossible for a manufacturer, and high energy consumption are necessary. Glass of this composition is high-melting due to the small number of alkali oxides and the strengthening of the structure, and the structures grow from SiO_4 tetrahedra and BO_4 tetrahedra due to boron oxide. In the case of composition 2, the concentration of Na_2O is large, while boron and aluminum are in quaternary coordination and the change of the coordination of boron affects their chemical stability, hardness, surface tension, and other characteristics.

The glass of composition 1 is sufficiently resistant to crystallization. The glasses which are used for the fabrication of HGMs should not crystallize during molding (during the preparation of the granulate) during sphere formation in the course of the blow molding of the glass melt and further cooling. The crystal inclusions distort the homogeneity of the glass and result in the disintegration of the glass shell; therefore, more rejects are observed after the crush tests. The microspheres prepared from glass 1 under blow molding ($T = 1300°C$) were very strong, albeit, in low quantities; consequently, the higher temperatures of the burner are necessary. HGMs made from glass 2 were not strong and did not resist a pressure of 27 MPa.

The glasses for HGMs should possess significant surface tension and sufficient viscosity, as well as chemical and mechanical strength, in order to form a large number of strong and low-density light-weight spheres of a regular shape.

CONCLUSIONS

Analyzing the experimental data, we can state that alumoborosilicate glasses are applicable for the preparation of microspheres; however, the optimal temperature mode of sphere formation must be chosen assuming all the physicochemical properties. In this case, the temperature of blow molding of up to 1500°C and high gas outflow velocities are necessary for glasses of composition 1, whereas low temperatures are applicable for composition 2; however, the employment of this microsphere is restricted.

REFERENCES

1. Guloyan, Yu.A., On the relationship between surface tension and the viscosity of glass melts, *Steklo Keram.*, 2013, no. 10, pp. 6–17.
2. Budov, V.V., Hollow glass microspheres. Application, properties, technology, review, *Steklo Keram.,* 1994, no. 7, pp. 7–11.
3. Oreshkin, D.M., Belyaev, K.V., and Semenov, V.S., High-quality construction and backfill mortars with hollow glass microspheres, *Prom. Grazhd. Stroit-vo,* 2010, no. 10, pp. 56–58.

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