THEORETICAL PRINCIPLES AND EXPERIMENTAL STUDIES OF HEAT AND MASS TRANSFER IN ELECTRIC HEATING OF CHAMOTTE-POLYSTYRENE MIXTURES IN A CLOSED PERFORATED VOLUME

V. N. Sokov


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Properties of, special features of, and methods for preparing raw materials for unfired lightweight chamotte refractories are presented. The mechanism of self-absorption of a liquid glass solution in porous chamotte grains in a thermal force field is considered. The laws of filtration mass transfer in chamotte-polystyrene mixtures on a sodium silicate solution in a closed perforated volume are studied.

It has been stressed in [1] that the best results in fabricating refractories by the method of self-burning admixtures are attained using screening of beaded polystyrene that possesses potential energy. The study of the processes in electrically heated self-compacting mixtures conducted at the Moscow State Building University has not exhausted all the possibilities of the method; the possibilities of the thermal force field created in the molded mixture have not been used in full either. In this connection, development of a new process for production of lightweight chamotte refractories based on liquid glass by the method of self-compacting mixtures is an important problem because it should provide articles with high thermomechanical properties at a quite low consumption of power.

The processes was developed proceeding from the following hypothesis. The joint action of the liquid glass binder and the hydrothermal force field on the aluminosilicate glass phase of the molded mixture should result in formation of thin layers of adhesive contacts and active directed synthesis of crystal hydrates that should transform into dehydrated formations upon heating without a substantial change in the volume of the solid phase or loss of strength.

Experience in using molten glass binders and analysis of the special features of the hydration process and the initial stage of structure formation in the system under conditions of the effect of a thermal force allows us to assume that the process of initial self-compaction of a mixture coincides with formation of various amorphous hydrosilicates, aluminum and sodium silicates, and a silica gel. Dissolution of the disperse phase and formation of microscopic crystallization nuclei dominate over the process of formation of coagulation structures, the occurrence of which is hampered by active mass transfer. As the structure compacts, removal of the moisture is decelerated and stops; with further drying of the green preform new crystal formations grow intensely over the whole of the volume both on the surface of chamotte particles and inside them. Thus, the action of the thermal force on the matrix of the hardening material is manifested by mechanical removal of the molding mixture through the liquid phase and by modification of the hydration mechanism and the appearance of strong interpore bridges.

To make the transition from laboratory experiments to industrial tests easier we used raw materials produced by the Podolskogneupor JSC (chamotte and liquid glass). The chemical composition of the chamotte includes 56.86% SiO_{2}, 35.14% Al_{2}O_{3}, 2.97% Fe_{2}O_{3}, 1.07% CaO, 1.23% MgO, 0.6% R_{2}O, 0.4% SO_{3}, \Delta m_{calc} = 0.8. The chamotte contains quartz, cristobalite, mullite, and a considerable amount (up to 50%) of an amorphous substance that is a quite active material and reacts easily with liquid glass, forming viscous systems of a high-modulus glass.

We used chamotte milled in a ball or tube mill. In the ball mill the milling was conducted through screens with cells 1 - 2 mm in size. Then some of the milled chamotte was milled again in a continuous twin-chamber tube mill.

The chamotte milled in the tube mill contained at least 50% fraction finer than 0.088 mm. The mixture of both kinds of chamotte contained (per dry substance) at most 3% frac-
tion coarser than 0.5 mm and at least 30% fraction finer than 0.08 mm.

The burning-off admixture consisted of fine (No. 5) foam polystyrene (FP). The finest fractions, obtained by screening polystyrene No. 5 (less than 0.4 mm), known as polystyrene dust, are waste of foam plastic production. They increase the mean density of the refractories due to a comparatively low expandability, sinter poorly, and have poor adaptability to manufacture [2 – 6]. Beaded polystyrene contains from 12 to 20% fractions finer than 0.4 mm. By data of the Plastpolimer Research and Production Association (Okhta) the annual volume of waste in the polystyrene industry amounts to 3 – 4 thousand tons.

It is obvious that the fine fractions of foam polystyrene can be used as a burning-off admixture for production of lightweight refractories; 3 – 4 thousand tons of fine polystyrene will satisfy completely the needs of the industry of lightweight refractories.

Polystyrene granules are foamed preliminarily by the thermal-force method in a free state in order to attain the requisite mean density. In the process of heat treatment at a temperature of 80°C or higher the material acquires an elastic state, and the foaming agent, which boils at 28 – 45°C, evaporates, which makes the granules expand.

However, only 50% expansion of the granules is provided by evaporation of the foaming agent; further expansion occurs due to penetration of the heating agent (steam or air) into the cells of the granules. Despite excess pressure in the cells, penetration of the heating agent into them occurs much more rapidly than removal of the vapor of the foaming agent from the cells.

The degree of expansion of the granules depends on the grain composition of the polystyrene, the content of foaming agent, the kind and temperature of heating agent, and the time of its action. The degree of expansion is evaluated by the expandability, determined as the ratio of the volume of the preliminarily foamed granules to the initial volume of the granules. With growth of the heat treatment time the expandability increases. The most intense foaming occurs in the first 5 min [2].

The preliminary foaming is conducted in hot water (95 – 100°C) with the help of steam and other heating agents. The granules are kept in the water for a certain time with continuous stirring. When heated in the boiling water the polystyrene softens and becomes plastic, the isopentane passes into a gaseous state, expands, and increases the volume of the granules by a factor of 8 – 20, depending on the foaming time. The rate and coefficient of foaming depend on the ratio of the internal pressure of the gaseous isopentane to the viscosity of the softened polystyrene.

The granules should not stick to each other in the process of the preliminary foaming. The molecular weight of the polystyrene to be foamed should lie within 35,000 – 45,000; at lower values the granules stick to each other, at higher values the foaming is not complete. Sticking causes large lumps [2]. After the preliminary foaming the granules are held in air. The surface films of the granules harden and the compressed gaseous isopentane condenses, which causes a marked reduction in its volume and formation of voids (vacuum) inside the cells. The condensed gas precipitates in the form of drops inside the granules because the FP films are not wetted by the liquid isopentane. In addition, air diffuses into the granules during the hold in air; this process is accelerated by the large pressure drop, which increases the foaming capacity of the granules in further treatment. The most intense air absorption occurs in the first 5 h of the hold [3].

In the process of the hold the foaming agent evaporates gradually from the foamed granules. Therefore, the shortest hold time in which the granules absorb air and the longest storage time (up to 5 days) in which loss of foaming agent is not so high as to affect the quality of the product molded from such granules should be determined for a material with a specified mean density [2 – 7]. The final foaming consists in heat treatment of granules preliminarily foamed and put into a press mold, where they expand additionally and melt together.

Liquid glass (GOST 13078-81) is represented by a melt of vitreous alkali silicates of sodium and potassium. Glass containing sodium silicates is the cheapest. According to the hypothesis of A. Rabukhin, liquid glass is an equilibrium solution of inorganic polymers whose properties are determined by the mobility and hydration of the alkali metal and the branching of polymer silicon-oxygen anions of various compositions (SiO₄, SiₓOₓ, and others). Liquid glass contains 26.9% SiO₂, 10.1% Na₂O, 0.2% Al₂O₃ + Fe₂O₃, 0.12% SO₃, its modulus is 2.7, the moisture content is 62.7%, and the density is 1.44 g/cm³.

The gluing and binding properties of liquid glass are widely used in industry. Possessing high adhesive properties, liquid glass glues various materials quite well. The gluing properties of the glass are mostly provided by its dehydration in a dry air medium, i.e., removal of the moisture causes aggregation of the molecules of sodium silicates and formation of a strong solid substance. Soluble sodium glass is a vitreous sodium silicate with a variable composition of Na₂O · nSiO₂ and a certain amount of impurities. The number n is called the modulus of the liquid glass and fluctuates from 1.58 to 3.0. Commercial liquid glass is a thick yellowish liquid with the same modulus range as that of impure sodium silicate and a small amount of admixtures of Al₂O₃ + Fe₂O₃ (less than 0.5%), CaO (less than 0.35%), and SO₃ (less than 2%). Its density commonly corresponds to 44 – 50°Bé.

The higher the concentration the higher the viscosity of the liquid glass and the greater the effect of the modulus on the viscosity. The value of the modulus at which the viscosity is minimum is 2.0 – 2.5. At an Na₂O : SiO₂ proportion exceeding 1 : 1 there are virtually no colloids in the solution and at Na₂O : SiO₂ < 1 : 2 their amount is somewhat elevated. At high moduli the content of colloids increases considerably and a colloidal solution with solvated molecules appears. Liquid glass with an Na₂O : SiO₂ proportion equal to 1 : 4 or 1 : 5 hardens readily in the form of a gel. The viscosity of liq-