Effective polystyrene concrete using glass cullet and liquid glass

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Abstract. Polystyrene concrete blocks are effective structural and thermal insulating wall material, but the matrix structure of the clinker reduces thermal properties, and long hardening of the cement leads to a long cycle of their manufacture. To solve these problems is propose to use instead of the cement composite binder with liquid glass and cullet, which has low thermal conductivity like a material in amorphous phase. The high electrical conductivity of liquid glass makes it efficient to use the method of electric heating. Electric heating and self-compacting energy of polystyrene granules allow to accelerate the hardening of the compound, to increase the strength of the structure, to reduce the technological cycle and energy intensity of the production. In this case the absence of prolonged high temperature treatment allows to efficiently recycle waste glass as a main component of the mixture, improving the properties of the product and reducing its cost.

1. Introduction

Every year in Russia produce more than 1.2 million tons of waste glass and cullet. It is around 4-7% of total quantity of solid waste. In addition, in Russia was adopted new rules of usage glass bottles. It is greatly restrict the opportunity to their reuse and will increase in the amount of glass wastes. However, existing technologies of production materials from glass cullet based on the using the energy intensive methods of heat treatment are significantly complicate and expensive [1].

Traditional recycling of waste glass like raw material for production of glass bottle consists in its re-melting but requires sorting glass by color and chemical composition, because to ensure a high quality of the product is necessary to avoid using a large amount of cullet other colors and composition. It’s greatly limit the possibility of using usual waste glass. So in Russia more common is using waste glass from large factories which can provide glass with a constant chemical composition and not glass from household waste. One of the effective ways of using cullet is the production of foamglass being efficient heat insulation material. But production of foamglass requires a long heat treatment during 6-8 hours at temperatures over 600°C. The high energy intensity of production is too expensive, which makes this material less common. For this reasons, research of low-temperature and high-speed methods of production new materials based on waste glass is actual problem.

Increasing requirements to energy efficiency of buildings and the growth of suburban low-rise construction has shown high efficiency application the polystyrene concrete as wall heat-insulating construction material.

Replacement of clinker binder by composite based on cullet and liquid glass, which has low thermal conductivity like a material in amorphous phase, will improve thermal properties of the
product and high electrical conductivity of liquid glass will allow to use effectively a method of forced electrical warming up to reduce the time of hardening.

In the works [2,3,4,5,6] proved high efficiency of materials with using method of forced electric heating of the self-compacting polystyrene mass, but production of polystyrene concrete based on the composition of liquid glass cullet were not previously considered.

2. Description of the methods
In work were used: unsorted glass (bottle) cullet (> 3000 cm²/g); liquid sodium glass (silicate module 2.7-3.0; 1.42-1.46 g/cm³); pre-foamed for 8 minutes polystyrene granules (bulk density - 30 kg/m³); sodium silicofluoride. The material made in special perforated forms from textolite, equipped with two plate-like steel electrodes. For electric heating used AC current 50 Hz. For voltage regulation used laboratory electrical transformer. To determine electro-physical characteristics was used sensors of pressure, temperature, electrical voltage, amperage. Research of physical and mechanical properties done in compliance with standard methods. The microstructure researched by scanning electron microscopy.

Prepared from the starting components in a mixer plastic composition filled in special form without using of vibration or another methods of sealing, form closed and electrodes connected to electrical transformer and started electric heating during 8 minutes with voltage 50-80V. After that form opened, product removed and send to natural drying.

At a temperature of more 80 °C polystyrene finally foams and creates pressure in a closed space due to sealing mineral component, migrating excessively liquid phase and its exit through the perforated edges of the form. Here with time under the influence of temperature liquid glass polymerizes and matrix hardens.

3. The influence of the electrical heating and self-compaction mass on the properties
Complex thermal effects and energy of the self-compaction in the process of controlled electrical heating of polystyrene concrete mass based on cullet and liquid glass allows to accelerate the hardening of the mixture, to increase the strength of the structure, to reduce the technological cycle and to reduce the energy intensity of production.

Due to the high electrical conductivity of liquid glass during electrical heating the mixture is an intensive and homogenous heating throughout the volume. Cause heat loss through edges and accumulation heat in center of form, temperature in form has reduced from the center to the periphery especially in the initial period, that in beginnings of foaming of polystyrene granules in 60-65°C forms front of the foaming and pressure in the same direction [7].

Finally expanding of polystyrene at a temperature of more 80°C makes excessive pressure to 0.4-0.5 MPa in a closed form. It’s allows sealing mineral component and pressing excess moisture through the perforated edges out the form.

Electrical heating of the mixture is characterized [8] by rapid growth of the amperage to 5A during first 2-3 minutes, but after the beginning of the polymerization liquid glass current gradually decreases and composition hardens. The character of change of temperature, pressure, electrical resistivity and pressing excess moisture during electrical heating is presented in figure 1.

Model the self-compaction of composition during electrical heating, schema of migration the liquid phase under excess pressure is presented in figure 2.
Figure 1. The character of change parameters of electrical heating

Figure 2. Model of self-compaction during electrical heating

Due to self-compaction mineral components are approached closely, the contact area of glass particles increases and thickness of liquid glass membranes becomes thinner. Meanwhile the adhesive contacts, cohesion, the chemical potentials of the phases and the thermodynamic potential of the system are increase. High wetting of glass cullet, homogeneity of the chemical content of cullet and liquid glass are support to high adhesion in hardened form and cause strength composition.
The intense polymerization of soluble amorphous silica results to formation colloids in the form of a gel of orthosilicic acid, which forms frame and combines fractions of glass in one conglomerate (fig. 3).

Figure 3. The structure of glass polystyrene concrete after electrical heating. a) the location of polystyrene granules (x10), b) the structure of the diaphragm (x60), c) the contact area of polystyrene and mineral component (x60)

Control (not self-compaction) samples natural hardening differ a large quantity of micro-defects like cracks of shrinkage, through holes in diaphragms, large pores and voids (fig. 4).

Figure 4. Microstructure of glass polystyrene concrete a) control sample; b) self-compaction sample

Cause of complex influence of temperature and pressure structure of silica gel is compacted in contrast of control sample natural hardening in which silica gel has loose structure because of slow aggregation of the gel with the gradual evaporation of the coupled moisture (fig. 5).

Figure 5. Structure of silica gel on the surface of the cullet a) natural hardening b) after electrical heating
Thinning of the membrane of silica gel and his pre-compression during self-compaction before hardening allows to reduce the amount of linear shrinkage in 2-2.5 times compared with samples of natural hardening (fig. 6).

The main advantage of the proposed method is the opportunity to get material with 90-95% strength after electrical heating during 8 minutes in comparison with control samples of natural hardening reaching the same strength during 7 days (fig. 7). Self-compaction of composition allows to increase the strength of materials to 10-15% because quantity micro - and macro defects, shrinkage cracks are reduced.

**Figure 6.** The relative linear shrinkage.

**Figure 7.** The changing of strength glass polystyrene concrete after electrical heating (1) and natural hardening (2)

### 4. Conclusions

Received material has density D700-D900, strength B1.5-B2 and coefficient of thermal conductivity in the dry state 0.125-0.146, W/m·°C, that makes it effective as a structural and insulation wall material.

The thermal conductivity coefficient of polystyrene concrete using cullet and liquid glass density D700-D900 is low on 25% and 35% than foam concrete and polystyrene concrete using clinker binder with same density.

The usage method of forced electric heating of the self-compacting polystyrene mass based on cullet and liquid glass allows to intensify the hardening rate of the composition to 8-10 minutes and gets product with 90-95% strength due complex effect of temperature and pressure. In this case the
proposed technology allows to reduce the time of heat treatment from 6-15 hours to 8-10 minutes, technological cycle from 10-24 hours to 70 minutes, to refuse from the autoclave, high temperature and steam curing, and to reduce the energy intensity of production to 13 kW·h/m³.

In addition, the usage of cullet as a main component reduces the cost and allows to efficient recycle the waste glass.

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References
[1] Sokov V, Logunin A 2015 Usage of glass cullet as a primary product for the production of construction Science review 18 pp 108-112
[2] Sokov V, Zhabin D, Zemlyanushnov D, Beglyarov A On the Issue of foam concrete creation in hydro-heat-force field Industrial and civil engineering 3 pp 12-13
[3] Sokov V, Beglyarov A, Zemlyanushnov D, Zhabin D 2011 Teplosilovoy monolitno-sloisty blok Vestnik MGSU 1.5 pp 309-312
[4] Mishin V, Sokov V 2000 Teoreticheskie i teknologicheskie printsipy sozdaniya teploizolyatsionnykh materialov novogo pokoleniya v gidroteplosilovom pole (Moscow: Molodaya gvardiya) p 350
[5] Sokov V 1998 Analysis of physicochemical processes during thermal and force treatment of chamotte-polystyrene system tempered with liquid glass solution Refractories and technical ceramics 2 pp 2-4
[6] Sokov V, Mishina G 1999 Self-compacting gypsum polystyrene concrete (Moscow: MPA) p 128.
[7] Orlova A, Logunin A, Yanina L, Danchina S 2015 Glass-fiber-reinforced plastic concrete based on liquid-glass binder for high-speed technology Science review 18 pp 112-117
[8] Orlova A, Logunin A, Lyamzin F, Yanov M 2015 Electric curing of self-packing masses on the basis of cullet and liquid glass in the manufacture of wall products Science review 18 pp 117-121