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Frame Composites Based On Soluble Glass.

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ABSTRACT

The history of production and use of products with the use of soluble glass shows their high efficiency in construction. The development of new types of composite building materials based on soluble glass is of priority. This article focuses on the development of composites based on soluble glass. A detailed analysis of the use of silicate and silicate polymer materials in the construction industry was performed in the paper. The issues of their structure formation and the features of the manufacture of products based on these technologies were considered. In the studies referred to in the article, the methods for forming products based on silicate and polymer silicate binders were considered, the feasibility of the use of vibration-free methods of manufacturing products allowing to effectively seal the rigid concrete mixes was proved. The mechanism of the formation of the frame materials structure was described, the frame composites manufacturing process using soluble glass binder was considered taking into account the optimization of granulometric composition of composites, and the assessment of the frame and matrix components consumption.

Keywords: frame composite, soluble glass, matrix, binder, granulometric composition, manufacturing process.

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INTRODUCTION

During the design of buildings and structures for production and agriculture, the problem of choosing materials for the manufacture of building products and structures is topical. Aggressive environments, in which all constructions work, are essential factors. That is why, the task to produce durable and efficient materials capable of providing long-term and reliable operation of structures and buildings in aggressive environments is extremely important. The use of composites on a polymer binder is one way to improve the durability of materials and products. At the same time, it is known that the use of, for example, silicate and polymer-silicate composites under aggressive impact of most organic acids is 2-3 times more economical than the use of polymer-penetrated concrete [1-2]. A wider application of these composites in aggressive environments is constrained by the fact that they have insufficient strength and poor resistanceto water and diluted acids.

The study of framework structure materials is one of the effective directions of further improvement of construction composites. The production technology of such materials includes preliminary creation of a frame by gluing aggregate grains to each other followed by cavity filling with matrix compositions. This technology makes it possible to obtain concrete with coarse aggregate. Now there is effective framework concrete on polymer cement and sulfur binding [3-4]. In the development and manufacture of high density frame concrete, material efficiency can be achieved through the use of highly filled matrix compositions using a binder based on soluble glass while filling frame cavities [5-8]. The difficulty in obtaining high-density silicate solutions and concrete is determined by their considerable viscosity even if soluble glass contains a substantial amount of water. Thereat matrix compositions fill frame cavities rather hard. We think that the way of filling frame cavities with matrix by the method of vibration-free roller compaction is promising, as it will be possible to increase density and improve physical-mechanical and operational characteristics of the obtained materials and products [9].

The purpose of these studies was the experimental and theoretical justification of the techniques and methods for the receipt of frame composites using vibration-free roller compaction with binders of soluble glass.

METHODS

In the manufacture technology of large-cement concrete technology there is a method developed in the study [10], in which the filler is first mixed with knowingly large mass of cement paste, then the mixture is subjected to short-term treatment in the vibrating screen for separating the excess binder.The mixture left on the vibrating screenis used to obtain coarse pored concrete. Thus, the carcass mix is obtained with the optimal binder content. Crushed stone was used as filler. It was mixed with knowingly large mass of binder and then subjected to vibrating on screen for 10 seconds, following which the remaining mixture was weighed and the desired amount of binder was determined.

The frames and matrices compounds are shown in Tables 1 and 2.

Table 1: Compounds of frames with various binders

Components	Consumption of components on frames with various binders, wt%				
	Formulations No.				
	1	2	3	4	5
Cement M400	100	–	–	–	–
Soluble glass	–	100	–	–	–
Epoxy resin (ED-20)	–	–	100	–	–
Bitumen (BN 60/90)	–	–	–	100	100
Water	40	–	–	–	–
Sodium fluosilicate	–	18	–	–	–
Polyethylenepolyamine (PEPA)	–	–	10	–	–
Dibutylphthalate	–	–	–	–	–
Diesel oil	–	–	–	–	10
Ballast stone	1,500–1,700	2,700-3,000	2,000-2,300	1,100-1,300	1,200-1,500

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Table 2: The structures of matrix compositions with various fillings

Matrix composites	Consumption of components in a matrix with various fillers, wt%			
	Formulations No.			
	6	7	8	9
Soluble glass	100	100	100	100
Sodium fluosilicate	18	18	18	18
Perlite	100	–	–	–
Diatomite	–	40	–	–
Pyrite cinder	–	–	50	–
Quartz sand	–	–	–	100

The process of the hardening of various binders takes place ether in low-temperature processing, or in vivo. The concrete with the use of such binders is also efficient in vivo.

The properties of the matrix in composition materials can be adjusted using fillers of different nature and diffraction composition in the material[11]. In order to optimize the composition of the matrix in frame concrete on the basis of soluble glass binder, the effect of the following microfillers was studied: diatomite powder, pyrite cynder, ceramsite dust, limestone dust, perlite flour, ground quartz sand. The test composition consisted of sodium silicate solute – 100 wt%, sodium fluorosilicate –18 wt%, and microfillers in various combinations. We used the method of mathematical planning of experiment, which allowed us to determine optimum compositions and significantly reduce the number of tests. We have developed the plans and selected the components making up the material and assigned their varying levels. Preliminary experiments were performed to establish the variation limits. The compressive strength was selected as optimized setting. The tests were conducted on samples, which represented the cubes with the edge size of 2 cm.

The varying factors were: X_1 – the amount of quartz sand with the fraction 0.315-0.16; X_2andX_3 –the amount of microfillers. The samples of the following formulations were prepared and tested: Formulation 1 X_1 – quartz sand(0.16-0.315 mm), X_2 – quartz sand (0.08-0.16 mm), X_3 – ground limestone (<0.08 mm); formulation 2: X_1 –quartz sand (0.16-0.315 mm), X_2 – pyrite cinder (0.08-0.16 mm), X_3 – diatomite (<0.08 mm); formulation 3: X_1 –quartz sand (0.16-0.315 mm), X_2 – pyrite cinder (0.08-0.16 mm), X_3 – ground limestone (<0.08 mm); formulation 4: X_1 – quartz sand(0.16-0.315 mm), X_2 – pyrite cinder (0.08-0.16 mm), X_3 – gravels dust (<0.08 mm).

After the statistical processing of the experimental results, theregression equation describing the dependence of the optimized parameter onvaried factors wasobtained.

$$R_1 = 14.6x_1 + 13.63x_2 + 14.55x_3 - 22.07x_1x_2 + 9.07x_1x_3 - 15.873x_2x_3 - 18.5175x_1x_2(x_1 - x_2) + 48.1725x_1x_3(x_1 - x_3) + 1.226x_2x_3\,(x_2 - x_3) - 55.18125x_1x_2x_3$$

The interpretation of the obtained dependence is shown in Figure 1.

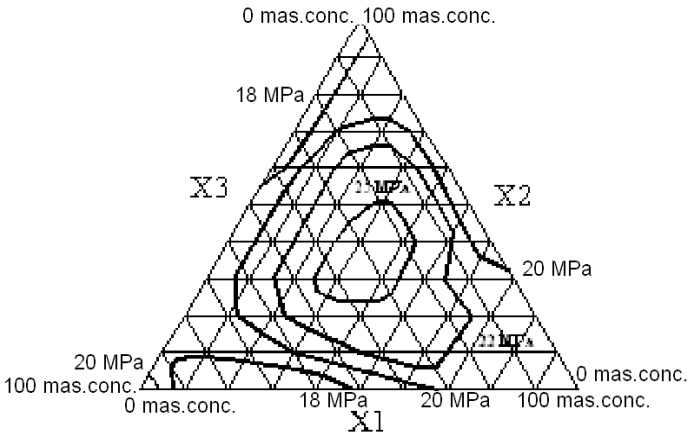

Figure 1. Dependence of the change of the composites compressive strength onthe percentage of 3 fillers, formulation 1

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$$R_2 = 14.6x_1 + 13.67x_2 + 20.125x_3 - 16.36x_1x_2 + 4.4x_1x_3 - 2.53x_2x_3 - 25.72x_1x_2(x_1 - x_2) + 40.51x_1x_3(x_1 - x_3) + 4.196x_2x_3\,(x_2 - x_3) - 208.125x_1x_2x_3$$

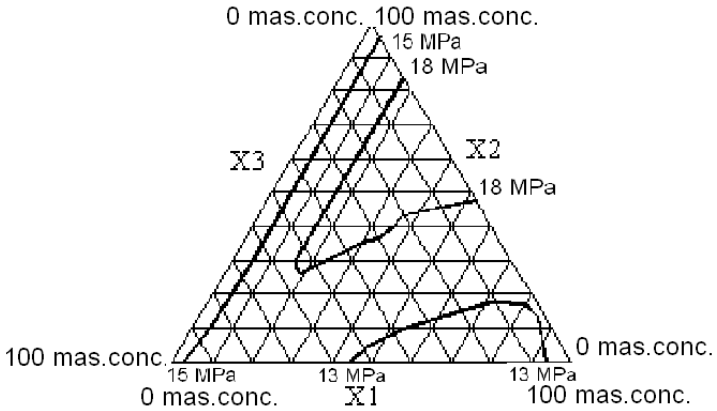

Figure 2.Dependence of the change of the composites compressive strength onthe percentage of 3 fillers, formulation 2

$$R_3 = 14.6x_1 + 13.67x_2 + 14.55x_3 - 16.4x_1x_2 - 9.1x_1x_3 - 0.765x_2x_3 - 25.72x_1x_2(x_1 - x_2) + 48.17x_1x_3(x_1 - x_3) + 1.17x_2x_3\,(x_2 - x_3) - 74.43x_1x_2x_3$$

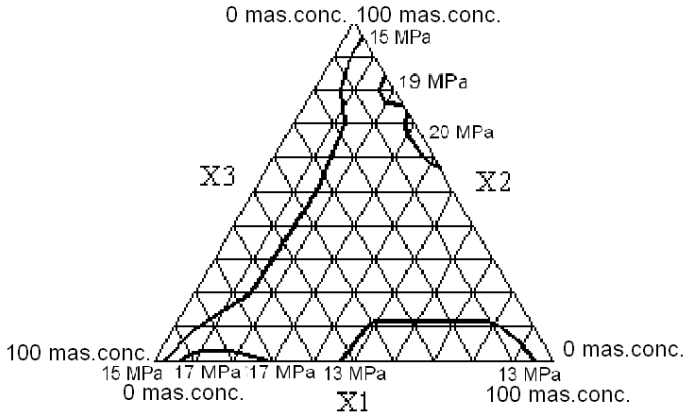

Figure 3.Dependence of the change of the composites compressive strength onthe percentage of 3 fillers, formulation 3

$$R_4 = 14.6x_1 + 13.67x_2 + 13.17x_3 - 16.4x_1x_2 - 7.6x_1x_3 - 4.88x_2x_3 - 25.72x_1x_2(x_1 - x_2) - 20.94x_1x_3(x_1 - x_3) + 21.35x_2x_3\,(x_2 - x_3) - 95.05x_1x_2x_3$$

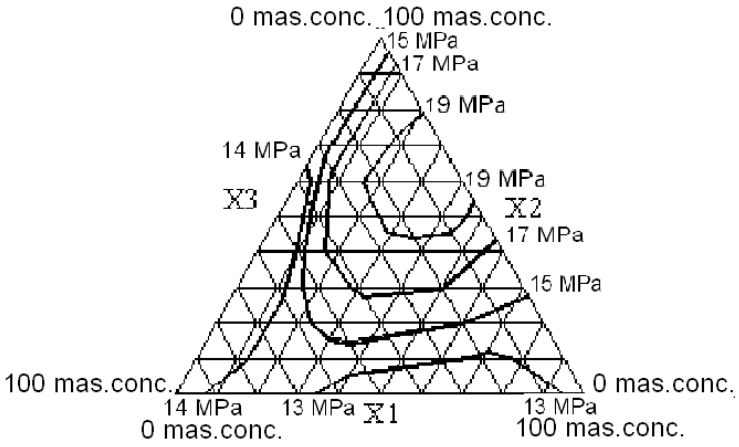

Figure 4.Dependence of the change of the composites compressive strength onthe percentage of fillers, formulation 4

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Analyzing equations and graphs, it can be concluded that the use of several fillers in the system positively affects the increase of strength characteristics of the material. The studies have shown that the best strength characteristics have matrix compositions, filled with a mixture of fillers based on quartz sand, pyrite cinders and diatomite.

Physical and mechanical properties of carcass structure materials depend on many factors, and primarily on the degree of curing of the adhesive composition, nature of the aggregates and binders, the ratio of elastic-strength properties of the binder and the aggregate, and on the linkage value between them [12]. Aggregate gradation also affects the properties of frame concrete. The work [7] shows that the greatest strength of frames on the basis of cement and polymer binders is achieved by optimal combination of granules with different fractions. We have conducted an experiment to determine optimum granulometry for frames on sodium soluble glass. The research was implemented using mathematical methods of experimental design. The factors of variation included the volume content of different aggregate fractions: X_1– fraction 5-10 mm; X_2– fraction 2.5-5 mm; X_3– fraction 1.25-2.5 mm.

According to the planning matrix there were approved the following compounds: soluble glass – 100 wt%; sodium silicofluoride – 18wt%; chip of different fractional composition – the amount was approved taking into account qualitative coating of grains. The indicator of the compression breaking strength (R_{comp}) was considered as the objective variable. The samples were formed into cubes with a size of facets 40 × 40 × 40 mm, kept at normal temperature and humidity conditions for 28 days, and then tested for compression. In order to conduct the experiment there was used a matrix in the form of a plan consisting of 10 experiments (Table 3).

Table 3: Planning Matrix and the results of the experiment

No.	Index	Mixture composition,%			Compressive strength, MPa	Coef.	Coef. value
		X_1	X_2	X_3			
1	η_1	100	0	0	0.56	β_1	0.56
2	η_2	0	100	0	1.04	β_2	1.04
3	η_3	0	0	100	0.80	β_3	0.8
4	η_{122}	33	67	0	0.58	β_{12}	-0.09
5	η_{133}	33	0	67	1.10	β_{13}	1.845
6	η_{233}	0	33	67	1.00	β_{23}	1.1025
7	η_{112}	67	33	0	0.98	γ_{12}	3.78
8	η_{113}	67	0	33	1.08	γ_{13}	0.405
9	η_{223}	0	67	33	1.33	γ_{23}	1.6875
10	η_{123}	33.3	33.3	33.3	1.04	β_{123}	-2.0925

The regression equation describing the dependence of the optimized parameter onvaried factors was obtained after the static processing of the experimental results.

$$R_{comp} = 0.56x_1 + 1.04x_2 + 0.8x_3 - 0.09x_1x_2 + 1.845x_1x_3 + 1.1025x_2x_3 + 3.78x_1x_2(x_1 - x_2) + 0.405x_1x_3(x_1 - x_3) + 1.6875x_2x_3\,(x_2 - x_3) + 2.0925x_1x_2x_3$$

Interpretation of the obtained dependence is shown in Figure 5.

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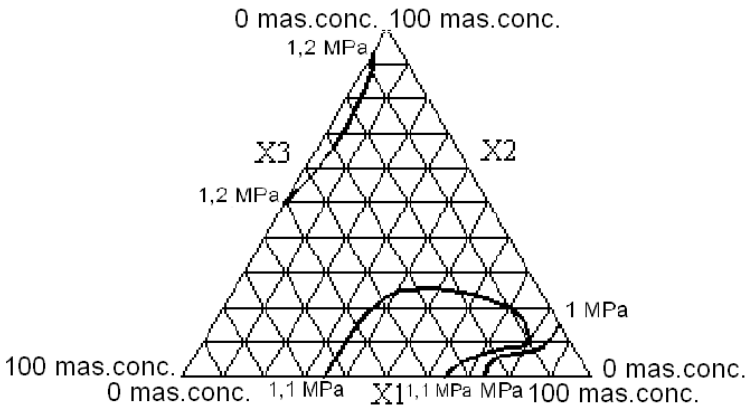

Figure 5. The impact of fractional composition of coarse filler on the strength of frames

The greatest strength of the frame is achieved with the use of the filler fractions 5-10 mm in an amount of 7 parts by weight; 2.5-5 mm – 23 parts by weight; 1.25-2.5 mm – 70 parts by weight.

The analysis of the equation and the characteristics graph makes it possible to conclude that the use of several fractions of filler in the system has positive effect on increasing the strength characteristics of the material. In the correlation of filler fractions 0.1:1:0.4 (X_1:X_2:X_3)the formulation showed an increase in strength of 15% compared with the composition where the fraction formulation X_2 is 100%.

The tensile and compression strength of frame concrete depends on the binder used, the nature of the filler and the aggregate, and the intensity of adhesion interaction between them. The frame composites can be produced on the basis of complex binders when different, and sometimes incompatible binders in the direct mixing are used for the frame and matrix [13]. A significant effect is achieved due to such integration of various binder in the composite. For example, when using the frames on cement binder in combination with a silicate matrix a creep reductionand strength increase is achieved [14-16]. The strength and durability of materials can be improved through the use of polymer frames. The use of the asphalt frames improved the dielectric properties and decreased the cost of the resulting material.

In this regard, optimization and study of frame composites properties, made up on frame with different binders and soluble-glass matrices, are important.

For each binder-fillerpair, their optimal ratio in the frame must be maintained. If the content of the binder is more than the optimal amount, the excess will flow off the aggregate to the bottom of the mold, as well as fill the pore space and, thus, make it difficult to fill cavities with matrix composition; in case of its insufficient amount, poor-quality coating of grains of the coarse aggregate takes place which leads to a decrease in the strength characteristics of the carcass.

Treating frame composite matrices should follow the requirements for relation between the aggregate size and the size of carcass fillers, as well as the mixture viscosity.

Using certain sizes of frame fillers and film thickness of the binder on the surface of grains, it is possible to define the permissible value of fillers fineness for the penetrating matrix [17].

Maximum permissible viscosity determined by viscometer VP-3. In case of a frame on a crushed stone with a fraction of (5–10 mm) matrix viscosity should not be less than 15-20mm^2; otherwise the matrix will hover in the upper area of the frame. For frame composites it is important to decrease the viscosity of the filled matrices that allows increasing the degree of filling of penetrating compositions, and thereby reducing the consumption of expensive binders. The viscosity of the penetrating matrix can be reduced using known methods of filler surface modification, and the introduction of various plasticizers.

The penetration quality is increased by using different penetration methods. For example, the paper [4] shows that the frame immersion in the matrix composition can improve the quality and shorten the penetration time.

Studies of various binders for frames with a constant silicate matrix allowed obtaining frame concrete on complex binders. The studies were conducted on samples with the beams size 40 × 160 × 40 mm in order to establish the dependence of the strength of concrete frames.The frame compound was compacted by vibration and roller compaction. The results showed that the compressive strength and tensile strength in bending in formulations compacted by rollers is more by 10-15%, than in vibrocompaction. This is because in this method the binder (matrix) more qualitatively fills the gaps in a frame, thereby forming a more dense structure. Moreover, the use of roller compaction during penetration of frame with matrix compositions carcass promotes additional densification of the matrix composition.

The expansion of properties of frame composites and the field of their use can be made using the compositions acquiring strength upon material backing for the adhesive binder and the penetrating matrix composition, i.e. by production of frame ceramic building materials.

Heat-resistant materials, slightly varying during firing, may be used as the filler in such materials. Thus, the frame technology of production of ceramic material provides for a preliminary bonding of frame made of large heat-resistant filler grains with the binder agent with subsequent filling of the frame cavities with the matrix composition, gaining strength by the backing of the matrix material at high temperature treatment [18].

Receipt of ceramic materials according to the frame technology has several advantages. When using heat-resistant materials, slightly varying during firing, as coarse aggregate in the carcasses, it becomes possible to reduce the shrinkage of the product during drying and firing. Then, the rigid frame of coarse aggregate received in the beginning, after adhesive cord curing, can be used as a solid load bearing element, perceiving the weight of the penetrating matrix and dry treated carcasses without molds. In turn, the increased strength of the semi-finished product, achieved during the drying of the carcass treated by matrix, makes it possible to solve the problem of large-sized products transportation to the calcining furnaces. In addition, frame technology makes it possible to get lightweight coarse pored materials with improved thermal properties.

The properties of the frame composite are largely determined by the properties of the filler. In order to reduce weight and thermal conductivity of products it is appropriate to use porous lightweight fillers. By increasing the surface porosity of fillers the consumption of binder (glue) in the frames increases. Therefore, to reduce the binder flow rate it is preferable to use gravel-like porous fillers. The granules of such fillers have a round shape with a melted surface having a lower porosity as compared with grains having the form of crushed stone.

The artificial fillers occupy the first place in the production of porous fillers. The development of artificial porous fillers is directed mainly to the lightest of their varieties used for concretes in production of protective structures. Currently a number of large (with a grain size of 5 to 40 mm) artificial porous gravel-shaped fillers resistant to high temperatures are produced for sale. These include such types of gravel as ceramsite, shungite, agloporite, gravel of siliceous rocks (Termolit) [9]. Such kinds of artificial porous aggregates like azerite gravel, dacizit, and granulated foamed glass passed pilot production tests and were put into production.

The main technical characteristics of the porous gravel are: bulk density, strength, durability, grain composition, porosity, nature of the grain surface, water absorption, thermal conductivity. Further improvement of properties of lightweight fillers wends the way of creation of ultra-light fillers with a bulk density of 200 kg/m^3 and less, having uniform fine porous structure and increased strength. In particular, the development of such fillers based on glassy waste has worked out.

Ceramsite, shungite and algoporite gravel shall meet the following requirements in accordance with GOST 9757-90: bulk density – from 250 and less up to 600 kg/m^3 for ceramsite gravel; 400-700 kg/m^3 for shungite gravel; 500-900 kg/m^3 for algoporite gravel. By grains size gravel is divided into the following main fractions; from 5 to 10 mm, from 10 to 20 mm, from 20 to 40 mm. Grain structure of each gravel fraction shall be in the following ranges: full screen residue, % by weight– d – from 85 to 100; D –up to 10; 2D – not allowed

(where D, d – respectively, the largest and smallest nominal diameter of test screen). The strength (at constriction in a cylinder) of ceramsite and shungite gravel for the lowest grade by strength P15 shall be up to 0.5 MPa, for highest grade P400 – over 10 MPa. The strength of agloporite gravel for the lowest grade by strength P50– over 0.7 up to 1.0 MPa, for highest grade P350 – over 3.5 MPa. The weight loss after 15 cycles of alternate freezing and thawing shall not exceed 8%. The structure of agloporite gravel shall be stable against the silicate collapse. The weight loss in determining the resistance to the silicate collapse shall be no more than 8%. The weight loss by boiling shall not exceed 5% and 4%, respectively for ceramsite and shungite gravel.

According to the information in[10] azerite gravel has the following properties: bulk density of fractions 5-10 and 10-20 mm – 490-542 kg/m^3; strength (at constriction in a cylinder) – 4.2-10 MPa; intergranular porosity – 39.8-40.5%; water absorption for 1 h – 16.3, for 48 h – 15.6–-19.8%; softening factor – 0.7–-0.88.

Dacisit– artificial porous material with a closed cell structure with gravel -shape form, obtained by firing of granular powder mass of volcanic dacite rock(75-85%) and clay (15-25%). According to[19], dacisit has the following physical and mechanical characteristics: grain structure – 5-10 mm, 10-20 mm; average density – 350-700 kg/m^3; gravel strength (at constriction in a cylinder) – 1.8-5.9 MPa; frost-resistance– more than 200 cycles; water absorption – 3.8-6.0%.

In recent years the production of porous gravel from finely ground waste glass (construction, container, environmentally friendly and technical) with bloating agents (carbonate minerals, ashes of thermal power plants, black carbon) has developed. The granulated powder mass is burned at a temperature of 790-900 °C, in [20]. The following specifications of granulated foamed glass are provided: bulk density – no more than 200 kg/m^3; mean density of grains–395kg/m^3;porosity of grains – 86%; intergranular porosity – 42%; thermal conductivity in the bulk state at 20 °C– 0.06-0.068 W/(m·°C); water absorption by volume – 1.7-4%; strength (at constriction in a cylinder) – 0.5-1.1 MPa; grains diameter – 5-30 mm; grains shape factor– 1.1-1.28; frost-resistance on weight loss – 15 cycles. This technology of granulated foamed glass involves the use as a binder for forming granules of non-plastic glass powders of soluble glass.

Sodium soluble glass having high adhesion to fillers of different materials can be used as an adhesive for grain fillers in frame ceramic materials.

Sodium soluble glass is aqueous colloidal solution of sodium silicate, having a density of 1.3-1.5 at a water content of 50-70%.

The hardeners are added in its composition for hardening of soluble glass, sodium fluorosilicate, substances containing dicalcium silicate (e.g. nepheline slurry), etc. The hardening of soluble glass binders can occur without curing agents at its drying by polymerization of silicon-containing chemical binders while removing the hydroxyl-hydrogen groups with the formation of polymeric silicone frame having three-dimensional net structure, but this binding is not water resistant. It shall be noted that by adding of portland cement to the soluble glass the adhesive bond in the dried state becomes waterproof.

Thermal conversion of sodium hydrosilicateshasthe following common features listed in[12]. In the initial drying period nucleation occurs in an alkaline aqueous silicate system Na_2O–SiO_2–H_2O, in which the formation of anhydrous sodium silicate and sodium metasilicate Na_2SiO_3 is possible. But anhydrous sodium metasilicate is practically not formed under hydrothermal conditions at temperatures up to 100 °C. Supersaturated metastable solutions with the subsequent transition of sodium silicate hydrate forms by evaporation of moisture in the glassy state appears in these circumstances. The formation of more complex structures needs higher temperatures which require the elevated pressure in the presence of water andare achievable in an autoclave. Upon further heating the removal of water in case of thermal transformations of sodium hydrosilicates can occur in a wide temperature range up to 300–350 °C. The process is usually multistage with intermediate polymorphic phases. Removal of constitutionalwater is accompanied by anionic polycondensation, usually called polymerization. Thus, when heated, the disubstitutedorthosilicates are ultimately converted into Na_2SiO_3 at about 120 °C, monosodium orthosilicates polymerize to $Na_2Si_2O_5$ in the temperature range of 100-300 °C. First, the trisubstitutedorthosilicates are split into two Na_2SiO_3 andNa_2O, and above 400 °C the sodium silicate $2Na_2SiO_3 + Na_2O \rightarrow Na_6Si_2O_7$ is formed.

At temperatures above 600 °C the silicate bonding usually begins to interact with fillers additives to form a variable composition of compounds that are difficult to identify.

Using soluble glass glue without hardeners it is possible to obtain carcass waterproof binder only at heat treatment above 900°C. It should be noted, however, that fire resistance of soluble glass is about 800°C, and softening of the binder during firing causes its flowing and absorption by porous surface of the aggregate, which prevents formation of a binder layer of adequate thickness on the surface of the aggregate grains and firing of products without fire resistant molds arising from products deformation.

In addition to fire resistance, carcasses deformation will be affected by the area of carcass grains contact, depending on the shape and granulometric composition of the filler, the thickness of the adhesive bond layer and presence of modifying additives, changing its properties, absorbency of the filler surface, and surface density of the heat-treated product (static imposed load on the base). When setting up preliminary experiments aimed at studying the properties of soluble glass bind without hardeners at heat treatment, for carcass manufacture was used expanded clay gravel of various fractions, brickbats, manufactured by dry compaction, and breakage of hard-sintered ceramic material (with water absorption of 4.3%) received under laboratory conditions during firing of clay brick in vacuum. The grain size of the filler varies within 5-15 mm. Sodium soluble water glass used for carcass bonding had a density of 1.212g/cm^3.The amount of glue was approved with some excess to ensure qualitative coating of aggregate grains and determined from preliminary experiments. After mixing filler with glue it was laid in a metal cylindrical mold without a bottom to remove glue excess. The diameter and height of the mold were 50mm. The mold was placed on a flat foundation. Before laying the filler, the foundation and the inner surface of the mold were laid with paper to prevent sticking of the adhesive binder to the foundation and the surface of the mold. Having laid the filler in the mold, the glued carcasses were dried at a temperature not exceeding 100°C. The implemented studies have shown that during drying glue bond of the carcasses acquires high strength exceeding the strength of the brickbat grains, but it has no water resistance. Further heat treatment of carcasses at the temperatures above 100°C was carried out in a muffle furnace after the removal of samples from the mold.

With further rapid temperature increase to 140°C and above, the bond of soluble glass rapidly swells at dehydration of the soluble glass products hardening and water removal as vapor; it has foamed structure with a large pore size. We have found out that swelling intensity of the adhesive binder decreases when tripoli is added to soluble glass in the amount up to 8-9% (if you add tripoli in the amount exceeding 9%, glue becomes like sticky dough and is not very well mixed with the filler grains). In case of heat treatment up to 370°C glue from soluble glass with tripoli has a swollen finely porous structure; its strength increases with the increase of tripoliamount.

DISCUSSION AND RESULTS

We have found out that, starting from the temperature of 700°C, the soluble glass bond, both with tripoli and without it, begins to thicken with porosity decreasing. At higher temperatures of heat treatment, deformation properties of glued carcasses appear because of softening of the soluble glass bond.

The introduction of tripoli in the soluble glass binder composition showed a decrease in frames deformability.

At temperatures of burning of 950–1000 °C, the frames on the soluble glass binder without the addition of tripoli showed a reduced resistance to deformation, resulting in their partial destruction. With the addition of tripoli and burning in this temperature range, in case of the use ofexpanded clay gravel grains and brickbats in frames, the formation of a durable adhesive binder layer with the required thickness was not observeddue to the high absorbency of the grain surface used for these types of fillers. As a result, the weak bond between the frame grains was observed. The formation of a durable transparent layer of soluble glass binder occurred when using filler grains of dense ceramic material in the frames. The resulting binding was characterized by high strength and water resistance. During the strength testing of frames, the destruction occurred by the filler grains volume, rather than by adhesive binder. On holding in water for several months the binding strength has not decreased significantly.

Thus, the addition of tripoli in the soluble glass binder of coarse heat-resistant filler grains contributes to binding structure strengthening during heat treatment, resulting in reduced deformation properties of frames. The use of porous fillers, whose surface is characterized by enhanced absorbency in frames, adversely affects the formation of a durable layer of soluble glass binder of the desired thickness during heat treatment.

Under otherwise equal conditions the frame grains in the form of crushed stone are firmly bonded by contrast with the grains having a rounded shape due to the difference in the contact area.

Shrinkage in the sintered matrix material during firing takes place in the pore volume of almost un-shrinkable hard carcass mostly composed of inert filler grains. In case of exceeding a certain value, such shrinkage can lead to rupture of uniformity of the matrix binder or to its detachment from the surface of the carcass grains. That is why matrix compounds for carcasses penetration must have a minimum ultimate shrinkage after drying and firing of the carcass material. One way to neutralize the negative influence of matrix shrinkage during heat treatment on defect-free formation of the carcass material macrostructure is the use of the matrix compounds swelling during firing [24]. It is intended that expansion of the matrix material in pyro-plastic state duringswelling can compensate its shrinkage occurring during high temperature treatment.

The formation of liquid melt in the material with simultaneous gassing processes is necessary for swelling of thermo-processed material. Swelling occurs in case of the sharp increase in gas pressure in closed pores of the melt [25].

As a swelling matrix binder in carcass firing materials, it is possible to use powders of alkaline lime-silicate glasses, characterized by low softening temperature. The gas-forming factor in heat treatment of glass powders in the proposed methodis water removal as vapor from a water-flooded initial structure of glass particles. Filling of pores of the cured carcass with glass powder is made by carcass penetration with glass aqueous slurry, followed by drying and calcining of the penetrated material. It should be noted that swelling intensity of the penetrating matrix depends on the pyroplastic viscosity of the molten mass appeared at a given temperature, as well as on the beginning temperature and the intensity of the gassing process. One way to control the swelling of the matrix is the introduction of the clay component increasing pyroplastic viscosity.

In the studies on the properties of swelling matrix compositions derived from shredded waste of container glass, the clay gravel with fractions5–10 and 10–15 mm was used for the manufacture of frames. The sodium soluble glass with the addition of tripoli was used for preparation of adhesive binder. Bonding of the filler into the frame, followed by curing of the adhesive binder at temperatures not exceeding 100°C, was performed in rectangular metal collapsible forms with the dimensions of the base of 82 × 82 mm and the height of 40 mm.

After carcass curing, its penetration with glass slurrytook place. The amount of water in the penetration slurry was taken from the condition to ensure its sufficient fluidity providing qualitative filling with slurry of the cavities between the grains of the carcass filler. It should be noted that slurry concentration has a significant impact on shrinkage of the penetrating matrix compound during the subsequent drying. That is why in order to fluidize the slurry at a constant concentration it is advisable to use electrolytes additives.

Penetration was performed by brief immersion of the frame extracted from form in slurry or pouring of the slurry onto the top frame, followed by run-off of excess slurry from the pores in the frame.

Drying and calcining after penetration were implemented in a chamber electric furnace.

When firing at a temperature not exceeding 750°C, from the coating layers was formed a solid water-resistant bundle having a continuous porous structure (pore diameter 0.02-0.5 mm) and strong adhesion to the surface of the aggregate grains. Absence of shrinkage leads to a drastic decrease in the number of defects in the bonding material and at the interface “coarse-grained filler-binder”.

Samples of the material during firing were characterized by resistance to deformation, which made it possible to fire them without molds if laced on a heat-resistant ceramic or metal tray with smooth surface [26-28].

The decrease in the size of the carcass aggregate fraction leads to an increase of such material characteristics as resistance to deformation during firing, macrostructure uniformity and strength.

Under the conditions of two-layer cross-section, the lower coarse pored layer is formed when coating with high-temperature binding the surface of the carcass pores of coarse aggregate as a result of incomplete carcass penetration with matrix glass slurry. Complete filling of carcass pores with concentrated glass slurry to a small depth from the front top surface makes it possible to form a continuous layer which will have a monolithic bond with the coarse-pore layer and perform protective functions.

The use of the two-layer cross-section material with an outer continuous and inner coarse-pore layer is advisable when it is necessary to obtain strong adhesion of materials by the coarse-pore layer with a solution of the interlayer connecting the carcass material to the foundation. The material of three-layer cross-section with two outer continuous layers and inner coarse-pore layer make it possible to use it as a basis to design non-bearing, self-bearing and load-bearing wall enclosures in the form of small-piece blocks or large-size panels.

CONCLUSIONS

Thus, the results of theoretical and experimental studies proved the possibility to obtain, at heat-treatment, composite materials under carcass technology using a complex binder base on sodium soluble and alkaline-lime-silica glass. Coincidence of temperature intervals of water exudation in the form of vapor from the flooded alkaline-lime-silicate glass of the bonder matrix composition and the formation of closed pores in the resultant molten mass, the viscosity of which provides non-rigid carcass stability during firing, makes it possible to obtain a porous binder with strong adhesion to the surface of the aggregate grains. Swelling of the binder during firing compensates its shrinkage caused by material sintering which prevents the formation of shrinkage cracks in the interaction of the binder with a rigid carcass of coarse aggregate.

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