Control of the Strength Properties of Mixtures Based on Chromite Sand

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Abstract. The paper presents the results of a study into the processing and physical and mechanical properties of mixtures based on liquid glass (LG) with furfuryl oxypropyl cyclocarbonate (FOPCC) for chromite compounds. The patterns of the interaction between triethanolamine-modified liquid glass with furfuryl oxypropyl cyclocarbonate and chromite sand were established. Parameters such as compressive strength, flexural strength, and tensile strength were studied, which were determined using standard methods. Mathematical models of the properties of mixtures on chromite sand with liquid glass and FOPCC were developed based on the planned experiment. Mathematical models represent a system of equations linking the compressive strength, tensile strength, and flexural strength of the mixture with controlled variables of a technological nature for which the contents of liquid glass, FOPCC, and triethanolamine were chosen. Based on the data obtained, it was found that the flexural strength, tensile strength, and compressive strength increase with an increase in the content of LG and FOPCC. The compositions of cold-hardening mixtures on chromite sand were optimized, allowing obtaining high-quality cores with high strength properties. It has been established that FOPCC is a material that has a double effect; it hardens the mixture during preparation and softens it after pouring metal during decoring. The optimum binder content is 4,5 to 5,5%, and the optimum hardener content is 0.4 to 0,6%. A technological procedure has been developed to prepare chromite sand-based CHM. As a result, the surface quality was improved, and the burn-on on the castings was reduced.

Keywords: Chromite sand · Liquid glass · Triethanolamine · Optimization · Mechanical properties · Strength properties

1 Introduction

The quality of castings is strongly influenced by molding mixtures, the properties of which depend on the starting materials [1]. The preparation of mixtures with the desired properties is a traditional task of the foundry [2]. According to existing data, 40 to 60%

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of casting defects are due to the unsatisfactory quality of molding compounds and mixtures [3, 4].

Fillers should have relatively high refractory properties, thermal resistance, inactivity to molten metal, mechanical strength, low coefficient of thermal expansion, uniform grain size distribution, and minimal cost [5]. Quartz sand, chromites, zircon, chrome magnesites are used as refractory fillers [6].

Quartz molding sands are currently most widely used. They account for more than 90% of all sands consumed by foundries. From the point of view of foundry technology, quartz sand has several undoubted advantages: it has a high melting point (1713 °C); high hardness, which contributes to good resistance to abrasion in the processes of preparing mixtures, making molds, and decoring and cleaning castings; chemical inactivity at ordinary temperatures; good mixing properties with various components of mixtures; good wettability with water and with almost all used binders; applicability in the manufacture of castings made of various alloys [7].

Unlike quartz sand, which undergoes allotropic transformations at 575 °C, chromite sand is subject to none of these transformations. It exhibits high thermal shock resistance. With a relatively high melting point of about 1880 °C, chromite sand has a low sintering temperature of 1100 °C. The moisture condensation zone is formed much more deeply in a chromite-based green-sand mold than in quartz sand-based mixtures [8]. The chromite sand is inert to iron oxides at high temperatures in various gas atmospheres. It is also poorly wettable by liquid metal. All these factors improve the conditions for metal solidification and help prevent the formation of the burn-on when manufacturing large steel castings. The high thermal conductivity and thermal storage capacity of chromite sand make it possible to create the directional solidification of casting and prevent solidification irregularities [9].

Therefore, highly refractory and chemically inert Grade AFS45-50 TC U 13.2-35202765-001:2011 chromite sand has become widely used for turbomachinery purposes. The minimum Cr_2O_3 content must be at least 46%. Chromite sand is used as a filler for core and facing mixtures to obtain steel castings. This is particularly advantageous when manufacturing heavy castings where high resistance to ferrostatic pressure is required.

Thus, developing optimal compositions of new chromite sand-based CHM is an urgent task of the foundry.

2 Literature Review

One of the commonly used methods is manufacturing cores and casts on soluble glass (SG), and the technology for their production is used at many enterprises [10]. This is because soluble glass is an affordable, inexpensive and non-toxic binder [11]. The use of SG as a binder for the manufacture of casting and core mixtures allows to obtain more durable casts, reduce the metal consumption of castings by producing thinner products and improve the quality of castings [12, 13].

Depending on the solidifying nature, these mixtures can be divided into mixtures with a solidifier introduced together with a binder during their preparation and mixtures solidified by blowing with a gaseous solidifier during or after filling equipment by them and their solidification [14, 15].

In the CO_2 process, the binding properties of liquid glass are poorly implemented (up to 20%), which leads to an increase in liquid glass content in the mixture and a decrease in the decoring properties; because of this, liquid hardeners are used for liquid glass-based CHM [16]. The consumption of liquid hardeners is very low, amounting to 10 to 12% of liquid glass mass [17]. Heavy organic ethers or aldehydes have proven to be the most advantageous liquid hardeners [18].

The use of liquid hardeners is one of the most advanced methods for hardening liquid glass-based mixtures, which allows [19]:

– Reducing the consumption of liquid glass to 2,5% to 4%;
– Increased in-mold decorative properties and cores by 1,5 to 2 times;
– Improving the quality of mixtures;
– Abandoning the use of CO_2 and thereby simplifying the technological process;
– Reducing defects and waste castings [20].

The paper proposes to use a universal additive, furfuryl oxypropyl cyclocarbonate (FOPCC), developed at NTU "KhPI" as a promising hardener for the manufacture of liquid glass-based molds and cores [21].

FOPCC is an environmentally friendly material, since when pouring metal into a mold, as a result of thermochemical destruction, FOPCC decomposes and releases CO_2 and water vapor in the volume of the formed composition into the environment.

The paper investigates into the properties of cold-hardening mixtures based on a chromite filler with triethanolamine-modified liquid glass and a universal additive, furfury loxypropyl cyclocarbonate.

FOPCC is a material that has a double effect; it hardens the mixture during preparation and softens it after pouring metal during decoring.

The composition (chromite sand – FOPCC – liquid glass) hardens when FOPCC interacts with liquid glass. Any cyclocarbonates (propylene cyclocarbonate, and FOPCC) are unstable in an alkaline medium and decompose with the release of CO_2, which reacts with liquid glass to form polysilicates in the volume of the formed composition. These systems can be referred to nanostructured composite materials, since the interaction processes between FOPCC and LG undergo on the surface of chromite sand in monomolecular layers.

The purpose of the study is to establish the regularities of the interaction between a triethanolamine-modified liquid glass-based binder with furfuryl oxypropyl cyclocarbonate (FOPCC) and chromite sand in the foundry.

3 Research Methodology

FOPCC is a material based on raw materials of plant origin, which was obtained as follows: furfuryl glycidyl ether and a catalyst (2 wt% tetrabutylammonium bromide) were loaded into a three-necked flask equipped with a thermometer, a reflux condenser, and a bubbler. The reaction mixture was heated to 90 °C, and carbon dioxide was introduced through the bubbler. The reaction was carried out for 8 h. The reaction course was monitored according to variations in the epoxy equivalent and using IR spectroscopy (the appearance of an absorption band at 1790 cm^{-1}, which corresponds to the stretching vibrations of the carbonyl group in the cyclic carbonate ring). After the reaction, the catalyst was removed (washed with water), and the product was vacuum distilled.

The reaction for obtaining FOPCC is shown in Fig. 1.

Furfuryl propyl cyclocarbonate is a transparent liquid of light yellow color, with a boiling point of t_b = (192 to 194) °C at 10 mm Hg, refractive index of (n_d^{20}) = 1.4920, density of 1,45 g/cm^3 (at 25 °C) [21].

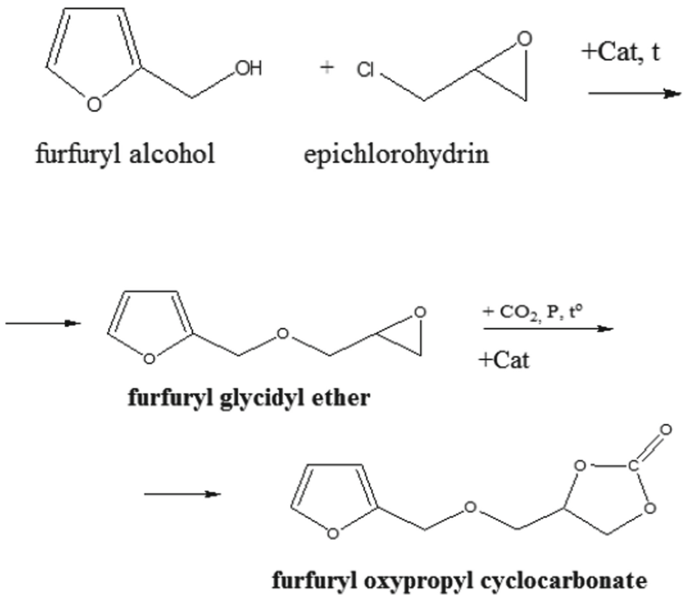

Fig. 1. The reaction for obtaining furfuryl oxypropyl cyclocarbonates.

The mixture was prepared as follows: first, a hardener was added to chromite sand and mixed for 3 min, then liquid glass with triethanolamine was added and mixed for another 2 min. Triethanolamine was introduced into liquid glass. TEA was taken of the total mass of FOPCC. The mixture was molded into a 9-piece mold, which is used to study the properties of CHM. Liquid additive (FOPCC) was added in the content of 0,4 to 0,6 wt%; liquid glass in the content of 4,5 to 5,5 wt%, and TEA in the content of 2 to 10 wt% mass of FOPCC. AFS45-50 quartz sand was used as a filler for molding mixtures.

The mixture was prepared as follows: FOPCC was added per 100 wt% chromite sand and stirred for 3 min, then the triethanolamine-modified liquid glass was introduced into the mixture and stirred for another 2 min.

Testing the compressive strength of the mixtures was carried out under GOST 23409.7 – 78 (strength in the “wet” state) and GOST 23402.9 – 78 (strength in the "dry" state). For this purpose, a set was used to determine the tensile strength of cast and core mixtures of modules 04116У with a device for compressing dry samples up to 15 MPa manufactured by UkrNIILitmash by a particular order of National Technical University "Kharkiv Polytechnic Institute".

4 Results

Recently, a computational and analytical method based on a planned experiment has been widely used to solve the problem of controlling the properties of molding mixtures and their stabilization. This approach opens up new possibilities for controlling the properties of molding mixtures owing to the operational efficiency of process control when modifying the properties of the starting materials.

To establish the regularities of the interaction between a triethanolamine-modified liquid glass-based binder with furfuryl oxypropyl cyclocarbonate (FOPCC) and chromite sand, and the experiment was carried out.

The variation intervals of the factors and their values at the main, upper, and lower levels are shown in Table 1.

Table 1. Experimental conditions for chromite sand-based CHM.

Independent variables	Content of liquid glass, wt%	Content of triethanolamine in liquid glass, wt%	Content of FOPCC, wt%
Factor	$x1$	x_2	$x3$
Main level	5,0	5	0,5
Variation interval	0,5	2	0,1
Upper level	5,5	7	0,6
Lower level	4,5	3	0,4

The experiment planning matrix 2^{6-3} is shown in Table 2.

Table 2. Experiment planning matrix 2^{6-3}.

Experiment no.	Content of LG (x_1)	Content of FOPCC (x_2)	Content of TEA (x_3)	x_0	x_1	x_2	x_3	x_1x_2	x_1x_3	x_2x_3	Compressive strength, MPa (y_1)	Flexural strength, MPA (y_2)	Tensile strength, MPa (y_3)
1	5,5	0,6	10	+	+	+	+	+	+	+	1,4	7,5	0,5
2	4,5	0,6	10	+	–	+	+	–	–	+	1,3	6,25	0,45
3	5,5	0,4	10	+	+	–	+	–	+	–	1,18	6,5	0,43
4	4,5	0,4	10	+	–	–	+	+	–	–	1,08	5,5	0,4
5	5,5	0,6	2	+	+	+	–	+	–	–	1,05	6	0,4
6	4,5	0,6	2	+	–	+	–	–	+	–	1,2	5,75	0,43
7	5,5	0,4	2	+	+	–	–	–	–	+	1,05	6	0,4
8	4,5	0,4	2	+	–	–	–	+	+	+	0,93	5	0,38

The varying factors were as follows: the content of liquid glass (x_1); the content of triethanolamine in liquid glass (x_2); and the content of FOPCC (x_3). As an optimization parameter (y), the following indicators of the physical and mechanical properties of the molding mixtures were chosen: compressive strength after 3 h (y_1), flexural strength (y_2), and tensile strength (y_3).

After processing the data obtained, the following equations in a coded scale were obtained:

$$y_1 = 1,15 + 0,02_{X_1} + 0,09_{X_2} + 0,09_{X_3} + 0,03_{X_{12}} + 0,02_{X_{23}} - 0,035_{X_{13}}, \text{MPa} \quad (1)$$

$$y_2 = 6,06 + 0,44_{X_1} + 0,38_{X_2} + 0,31_{X_3}, \quad \text{MPa} \quad (2)$$

$$y_3 = 0,42 + 0,01_{X_1} + 0,02_{X_2} + 0,02_{X_3} + 0,01_{X_{12}} + 0,01_{X_{23}}, \quad \text{MPa} \quad (3)$$

When experimenting, account must be taken of the need to determine the experimental error, i.e., the variance of reproducibility. The reproducibility is estimated according to the results of parallel experiments. For this purpose, each experiment is supposed to be carried out three times in the planning matrix. The coefficients of the mathematical models were calculated, and their statistical significance was determined. The significance of the coefficients for each investigated optimization parameter was checked using Student's criterion. The hypothesis about the adequacy of mathematical models was checked using Fisher's criterion.

The effect of the content of LG with TEA and FOPCC on the compressive strength of the mixture is shown in Fig. 2.

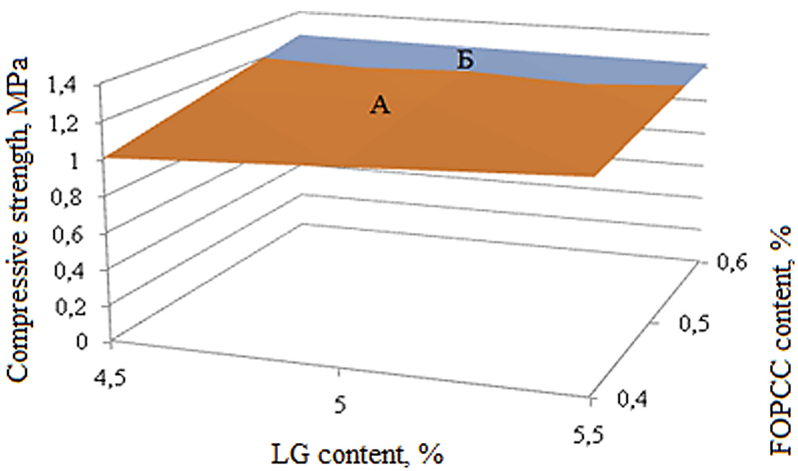

Fig. 2. The effect of the content of LG modified by 6 wt% TEA and FOPCC on the compressive strength of the mixture A: Compressive strength ranging from 1,00 to 1,12 MPa; Б: Compressive strength ranging from 1,20 to 1,40 MPa

Figure 3 shows the effect of LG and FOPCC on the flexural strength of the mixture, and Fig. 4 shows the effect of LG and FOPCC on the tensile strength of the mixture.

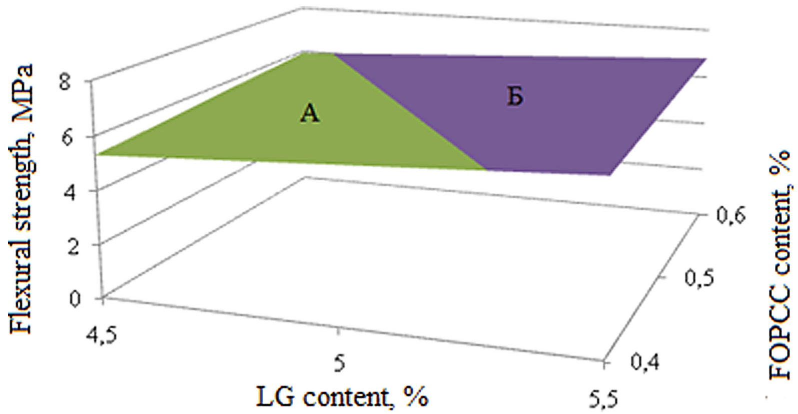

Fig. 3. The effect of the content of LG modified by 6 wt% TEA and FOPCC on the flexural strength of the mixture A: Flexural strength ranging from 4,00 to 6,00 MPa; Б: Flexural strength ranging from 6,00 to 8,00 MPa.

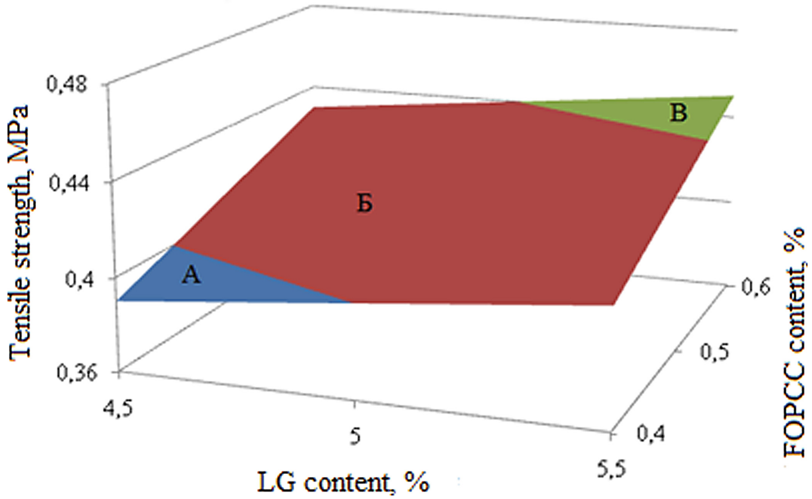

Fig. 4. The effect of the content of LG modified by 6 wt% TEA and FOPCC on the tensile strength of the mixture A: Tensile strength ranging from 0,44 to 0,48 MPa; Б: Tensile strength ranging from 0,4 to 0,44 MPa B: Tensile strength ranging from 0,36 to 0,4 MPa.

Based on the analysis of the equations, it was found that the compressive strength, flexural strength, and tensile strength increase with an increase in the content of LG and FOPCC.

According to the process sample, the compressive strength of the mixture is an average of 1,5 MPa after 1 h; 2,5 MPa after 3 h; 3,5 MPa after 24 h. The tensile strength is an average of 0,2 MPa after 1 h, 0,5 MPa after 3 h, 0,8 MPa after 24 h. The flexural strength is an average of 4,5 MPa after 1 h, 7 MPa after 3 h, 9 MPa after 24 h.

The study has found that the developed additive FOPCC had shown the effectiveness of its use in the foundry. FOPCC has a double effect; it hardens the mixture during preparation and softens it after pouring metal during decoring.

5 Conclusions

To create new technological processes for the preparation of chromite mixtures, using triethanolamine-modified liquid glass with furfuryl oxypropyl cyclocarbonates (FOPCC) is a promising area for facing and core mixtures.

According to the process sample, the compressive strength of chromite mixture is an average of 1,5 MPa after 1 h; 2,5 MPa after 3 h; 3,5 MPa after 24 h. The tensile strength is an average of 0,2 MPa after 1 h, 0,5 MPa after 3 h, 0,8 MPa after 24 h. The flexural strength is an average of 4,5 MPa after 1 h, 7 MPa after 3 h, 9 MPa after 24 h.

In developing a technological process for the manufacture of high-quality castings using CHM with chromite sand based on FOPCC, a planned experiment was carried out.

A mathematical model was built for CHM based on chromite filler with FOPCC. This model is a system of equations linking the compressive strength, tensile strength, and flexural strength of the mixture with controlled variables of a technological nature for which it is appropriate to use the content of triethanolamine-modified binder and the content of hardener. It was found that the flexural strength, tensile strength, and compressive strength increase with an increase in the content of LG and FOPCC. The optimum binder content is 4,5 to 5,5%, and the optimum hardener content is 0,4 to 0,6% for the production of steel castings.

The addition of furfuryl oxypropyl cyclocarbonates a double effect; it hardens the mixture during preparation and softens it after pouring metal when decoring.

A technological process for obtaining chromite sand-based CHM was developed. The result was improved surface quality and reduced burn-in on castings.

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