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Strength of liquid glass ceramic shell mold

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Abstract
Objective is to establish how the layers drying regime and the composition of refractory slurry when using coarse dusting quartz sand as the cushioning layer influence the strength of not pre-calcinate and calcinate liquid glass ceramic shell mold.
The original *methodology*, standard and generally accepted research methods including a methodology to determine the relative viscosity of suspension, mass, time, temperature, relative humidity and air velocity were used in the work.

The results of studies of the effect on the strength of liquid glass ceramic shell mold of various conditions of its production are shown.
The greatest strength of the liquid glass ceramic shell mold acquires when duration of drying of the 2nd ... 4th layer in an air stream with a temperature of 33 ... 34 °C, speed 2.2 ... 2.5 m / s for not less than 3 hours using water glass with a specific gravity of 1.28 ... 1.29 g / cm^3 and a specific viscosity of liquid glass slurry of 31 ... 32 s.
The data obtained allow us promptly decide on the necessary adjustment of the composition of the refractory slurry under conditions of a cast shop (Fig. 4., Table 6).
Keywords: SHELL, LIQUID GLASS, SAND, STRENGTH, DRYING, SUSPENSION, CALCINATION

The state of the problem

The ultimate strength in the static bending of the molds material in the uncalcined (raw) state, as well as in the calcined state (at calcination temperature and room temperature) is among the characteristics of ceramic shell molds (hereinafter CS).

The level of strength of uncalcined CS predetermines the integrity of the CS when melting its model composition from it and during subsequent manipulations with it before calcination. The strength level of the CS in the calcined state (as a rule, at temperature of 950±15°C) partly characterizes it from the point of view of the probability of destruction under the influence of a dynamic impact at the moment of filling the CS with melt, and also if the CS is poured with a melt without a supporting filler by the ability of the CS to withstand the metallostatic head in it. The level of strength of pre-calcined and cooled to room temperature CS indirectly characterizes it and from the point of view of the probability of destruction under the influence of a dynamic impact at the moment of filling the CS with melt, the ability to maintain integrity in manipulations and to resist the metallostatic head in it.

Among the factors that predetermine the strength of CS both the regime and conditions of drying of CS and the composition of the refractory slurry for the second and subsequent layers of CS are included. Nevertheless, currently such data are not available for liquid glass CS (hereinafter LCS).

The task of the research is to determine the effect of the regime on the strength of the raw and pre-calcined LCS and the drying conditions of its layers, as well as the composition of the refractory slurry when using quartz sand with a predominant particle size of 0.4 mm as a cushioning layer of LCS.

Results of the research

The effect of the above factors was investigated for a quartz LCS produced on the basis of sodium liquid glass. Refractory layers of tested LCS were formed on glass plates with dimensions of 2×100×150 mm. The determination of the mass was carried out by weighing the test samples with an accuracy of 0.01 g. Drying LCS layers has been carried out for 3 hours in a stream of air with a temperature 32± 1 °C, motion velocity of 0.1 m / s and relative humidity 65± 1 %. The melting of the model composition from the LSC was carried out in hot air, calcination – in an oxidized gas atmosphere at 950± 15 °C during 1 hour.

The composition of the refractory slurry for the first and subsequent layers of the LCS is shown in Tables 1 and 2.

Table 1. Composition of the refractory slurry for the first LCS layer

Water, l	Liquid glass, l	Powder quartz, g	SAS, g	Clay admixture, g
0.375	0.187	1120	0.005	0.001

Table 2. The composition of the refractory slurry for the first and subsequent layers of the LCS

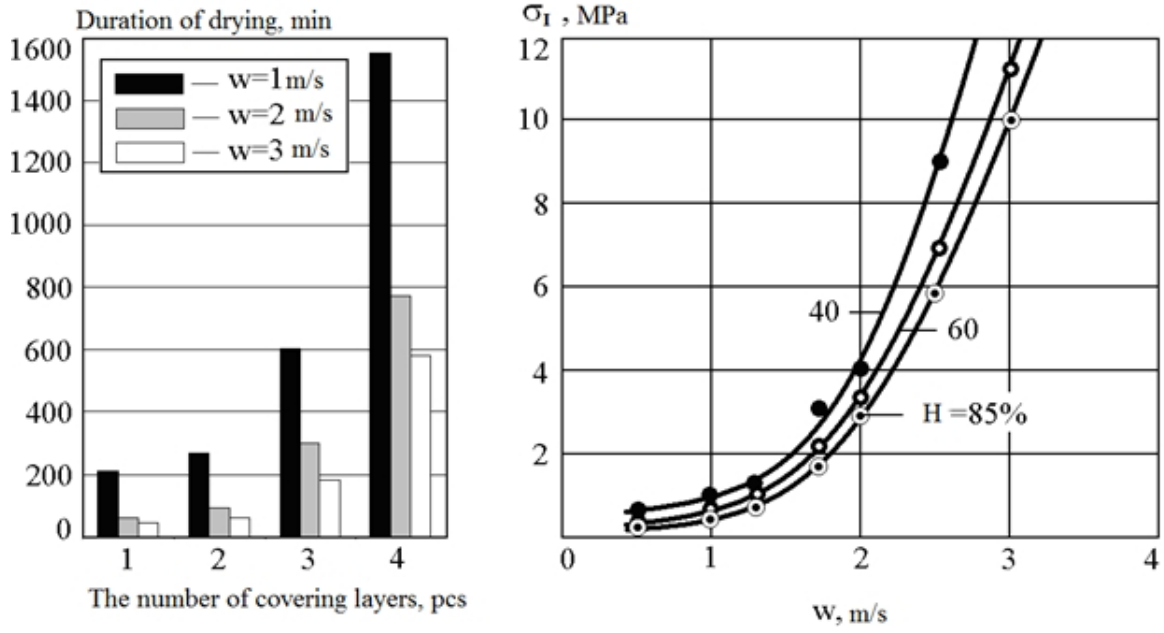
Water, l	Liquid glass, l	Powder quartz, g	SAS, g	Clay admixture, g
0.375	0.340	1120	0.001	0.005

Quartz sand with a primary grain size of 0.2 mm was used as the first LCS layer, and for 2 ... 4 layers – with a predominant particle size of 0.4 mm.

At the first stage of the study, the following characteristics were determined: influence of the air flow rate in the drying chamber of LCS on the drying time

to the relative content of water in them of 1% (by weight) and the strength in the raw state when drying of the first layer of LCS for 1 h, the second layer - 4 h, the 3rd and 4th layers - 16 h. Drying was carried out in an air stream with a temperature of 28 ... 30 ° C and its relative humidity H = 40%, 60% and 85%.

The test results are shown in Figure 1.



a) b)

Figure 1. Dependence of the drying time on the number of layers of LCS and the speed of air movement in the drying chamber (a), the ultimate strength of the raw LCS under static bending from the relative humidity and speed of air movement in the drying chamber (b)

From Fig. 1 it follows that the drying time and the strength of the raw LCS are mainly determined by the speed of its movement in the drying chamber.

In this connection, in subsequent studies drying of liquid-glass CS was carried out in an air stream at a motion speed of 2.2 ... 2.5 m / s.

At the second stage of the research, optimization of the composition and drying temperature of the designed CS was performed at w = 2.2 ... 2.5 m / s.

Optimization of the composition and drying temperature of the developed CS was carried out according to three parameters:

- specific density of sodium liquid glass in the refractory slurry at room temperature (ρrelative viscosity (Vs) of the refractory slurry at room temperature (viscometer VS-4);
- air temperature in the drying chamber, °C (T).

The optimization was carried out by the simplex-planning method of the experiment according to the plan of H. Scheffe with the construction of simplex lattices for:

- ultimate strength at static bending of raw CS;
- ultimate strength at the static bending of the calcinated CS.

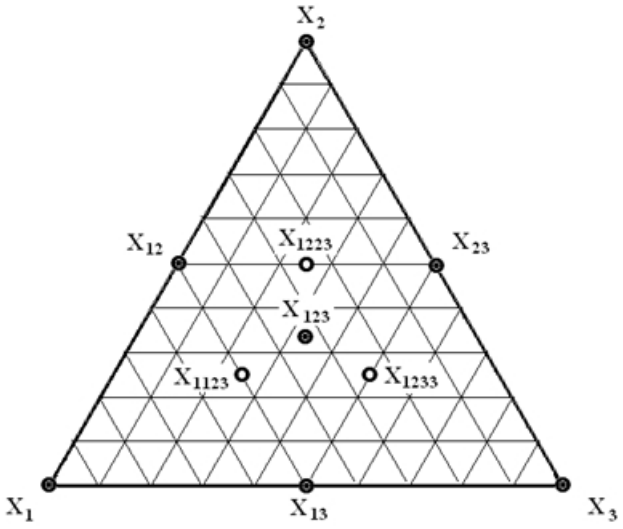


Figure 2. Scheme of the experiments conduct on the plan of G. Sheffe

The developed technology for making CS was considered optimized if its strength in the raw and calcinated state was characterized by the highest values.

We used the scheme shown in Fig. 2 in order to construct a simplex lattice according to H. Scheffe

simplex-lattice plan (a second-order model with a central point).

Alloy codes in accordance with the scheme in Figure 2, their elementary composition and codes of response functions are given in Tables 3 and 4.

Table 3. Code designation of alloys

Number	Symbol	Variables on a natural scale		
		r	Vs, c	T, ^{0}C
1	X_1	1.34	22	20
2	X_2	1.22	32	34
3	X_3	1.34	32	34
4	X_{12}	1.28	27	27
5	X_{13}	1.34	27	27
6	X_{23}	1.28	32	34
7	X_{123}	1.30	28.7	29.3

Table 4. Response Function Codes

Response Function	Code
Tensile strength at static bending of raw CS	Y_1
The strength limit at static bending of the calcinated CS	Y_2

Since the implementation of G. Sheffe's plan involves the construction of a model of an incomplete cube in a ternary system:

$$Y=\beta_1\cdot x_1+\beta_2\cdot x_2+\beta_3\cdot x_3+\beta_{12}\cdot x_1\cdot x_2+\beta_{13}\cdot x_1\cdot x_3+\beta_{23}\cdot x_2\cdot x_3+\beta_{123}\cdot x_1\cdot x_2\cdot x_3 \quad (5.1)$$

where Y is the property of the material; β – regression coefficient; **x** – is the amount of material in the alloy (by weight), then the regression coefficients in formula (5.1) were calculated by the following formulas:

$$\beta_1=\xi_1,\quad \beta_{ij}=4\cdot\xi_{ij}-2\cdot\xi_i-2\cdot\xi_j,\quad \beta_{123}=27\cdot\xi_{123}-12\cdot(\xi_{12}+\xi_{13}+\xi_{23})+3\cdot(\xi_1+\xi_2+\xi_3),$$

where ξ_i, ξ_j, ξ_{123} – the results of experiments at points of simplex lattices.

The results of experimental studies of the properties of materials and alloys listed in Table 3 are shown in Table 5, and the results of calculation of the regression coefficients are given in Table 6.

Table 5. The results of experimental studies

Response Function	Average arithmetic values of tensile strength at bending, MPa						
	x_1	x_2	x_3	$x_1\cdot x_2$	$x_1\cdot x_3$	$x_2\cdot x_3$	$x_1\cdot x_2\cdot x_3$
Y_1	3.3	5.5	14.7	16.8	9.3	24	19.5
Y_2	2.9	5.3	10.2	12.0	7.7	14.1	12.2

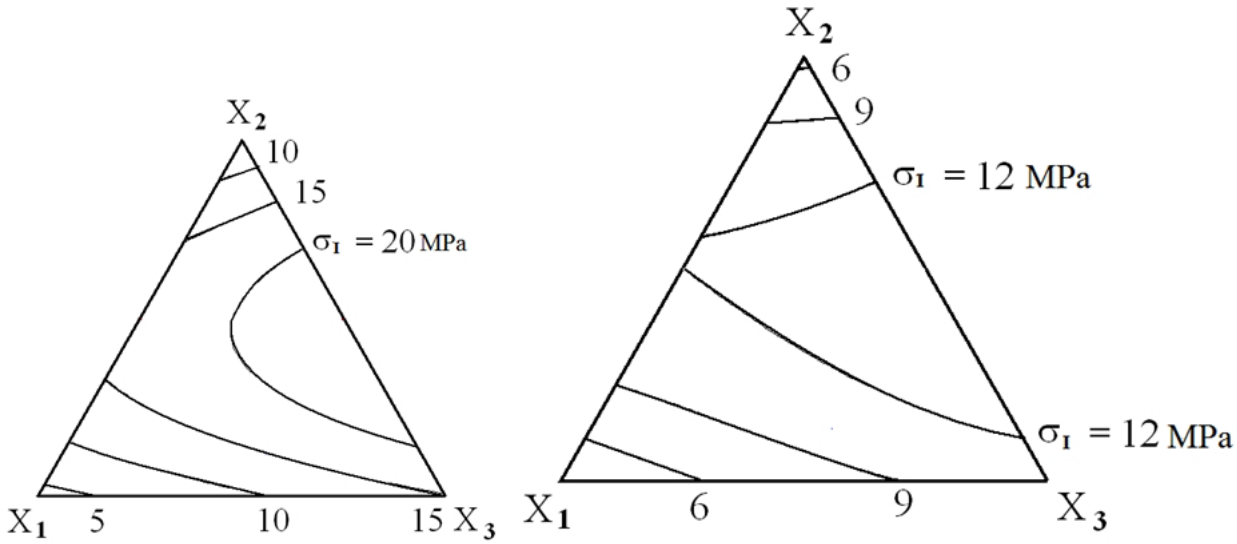
Table 6. Regression Coefficients

Response Function	Regression Coefficients						
	β_1	β_2	β_3	β_{12}	β_{13}	β_{23}	β_{123}
Y_1	3.3	5.5	14.7	49.6	1.2	55.6	-4.2
Y_2	2.9	5.3	10.2	31.6	4.6	25.4	-21.0

The adequacy of the calculated mathematical models was verified by comparing the experimental and calculated values for the experiments with codes x_{1123}, x_{1223}, x_{1233}, and by comparing the tabular and empirical values of the t-criterion for each of the points indicated in Figure 2.

In connection with the fact that the difference between the experimental and calculated values for each of the obtained mathematical models in points x_{1123}, x_{1223} and x_{1233} does not exceed 2.4% and in all cases $t_{EXP} < t_{TABL}$, the hypothesis of the adequacy of the calculated mathematical models at 5% significance level has been adopted.

We constructed the corresponding dependences in the form of simplex lattices using these mathematical models (Figure 3).

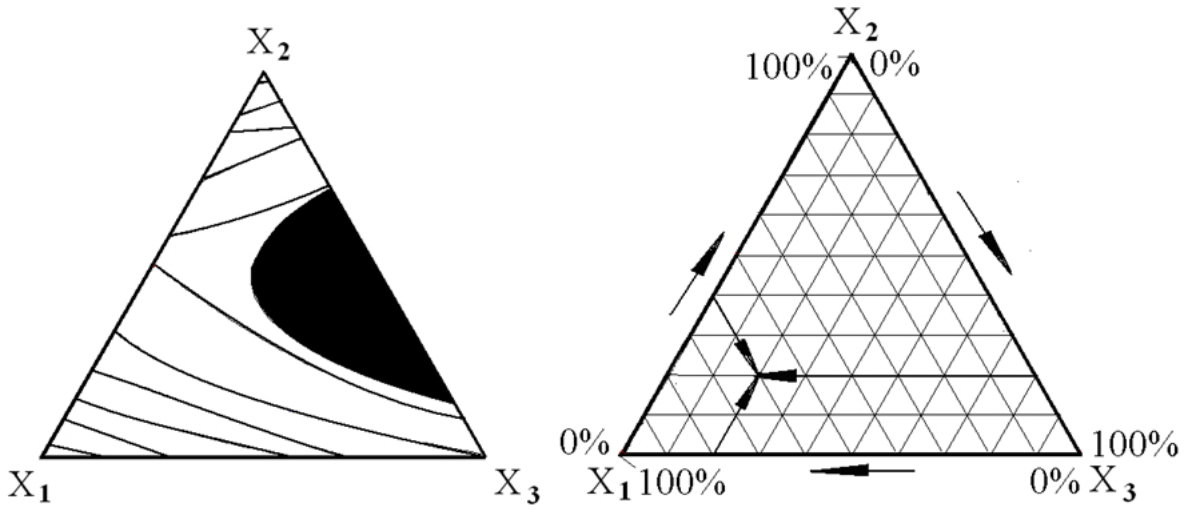


a) b)

Figure 3. Ultimate strength at static bending of raw (a) and pre-glued (b) LCS

The field of optimal contents of initial materials in the developed MS was obtained by hatching on simplex lattices of fields with an unacceptable level of the parameter and subsequent imposition of the obtained images on one lattice.

The result of combining the simplex lattices is shown in Figure 3, where the field of the optimal contents of the tested materials is placed in a concentration grid and is colored with black, and the simplex lattice key is shown in Fig. 4.



a) b)

Figure 4. Optimal area (blackened) of contents of tested materials (a) and the simplex lattice key (b)

Based on the results obtained, the optimal drying parameters for the 2nd ... 4th layers of the LCP are the following: w = 2.2… 2.5 m/s; ρ_{LG} = 1.28 ... 1.29 g/sm^3; Vs = 31 …32 s; T = 33 … 34 °C; τ_D > 3 h, where τ_D – duration of drying of the 2nd ... 4th layers of the LCS.

In this case, it should be noted that the identity of the course of isolines in the values of the ultimate strength of both raw and pre-calcined LCS.

Conclusions

The results of the conducted studies indicate that the LCS on quartz sand by strength parameters can provide the required level to be met by CS in the production of casting for machine-building purposes. At the same time, the optimal drying parameters for the 2nd ... 4th layer of the LCS are the following: w = 2.2… 2.5 m/s; ρ_{LG} = 1.28 ... 1.29 g/cm^3; Vs = = 31 …32 s; T = 33 … 34 °C; τ_D > 3 h.

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