Physical properties of low-temperature casting moulds

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Abstract
With this paper we pursued the objectives to define the rational value for the moisture in the moulding compound applied for manufacturing low-temperature moulds (hereinafter referred as LTM), to determine the impact of moulding compound density on the mould strength properties, and to define vacuuming impact on LTM hardness while its freezing. All these have been successfully achieved with this research. In order to evaluate the research results, we applied the standard

methods for defining the compound fluidity, compound density and vacuuming effect on hardness. In the course of the research, we revealed the dependences, which had not been reported before. These dependences show how the moulding compound manufacturing parameters and the process parameters impact the principal manufacturing properties of low-temperature moulds. This allows us to forecast low-temperature moulds properties or to obtain them with the desired properties and also to ensure manufacturing high-quality castings of aluminum and iron-carbon alloys.

Key words: LOW-TEMPERATURE CASTING MOULD, DENSITY, HARDNESS, MOISTURE, THE FLUIDITY

Problem to solve

The problem of manufacturing casting moulds with the desired strength at the minimal expenditures for labour, energy and material consumption remains to be quite urgent. One of the paths towards the problem solution is in applying LTM with water as a binder material. Moreover, the use of water as a binder material permits 80-90% reduction in labour-consuming process for forming, mould knockout and core knockout as well as it significantly reduces the volumes of hazardous gas emissions into the environment.

The research goals

With our research, we pursued the objectives to define the rational value for the moisture in the moulding compound applied for manufacturing low-temperature moulds (hereinafter referred as LTM), to determine the impact of moulding compound density on the mould strength properties, and to define vacuuming impact on LTM hardness while its freezing.

Introduction

The quality of casting mould, which, in its turn, defines the quality of castings to a significant extent, depends on a number of moulding compound properties. Moreover, its plastic properties have the paramount importance in the process of forming, they allow us to assess the reaction of the moulding compound to an external stress, in other words, its capability to be formed. Furthermore, the deformation capability of the moulding compounds is defined by their fluidity.

According to [1], the fluidity characterizes the capability of moulding compound to tolerate plastic deformations under external effect without either changing its volume or filling in the relevant mould cavity or core box. This property defines the even distribution of moulding compound throughout the moulding form at ramming. Taking into account that LTMs possess low green strength, which does not depend on the ramming technique or the ramming effort, it becomes obvious that the most rational ramming technique for moulding compounds is vibroramming.

Moreover, the phenomenon of the increased fluidity, which the moulding compounds show at the mould vibration, also evidences in favor of this technique. In this case, the fluidity in the moulding compounds has overwhelming influence on density distribution, and, therefore, it affects the mould mechanical properties as well.

Furthermore, the impact of the fluidity or the shear resistance depends on the internal friction of the moulding compound and on the mutual adhesion forces, which, on the one hand, act within the moulding compounds and, on the other hand, are conditioned by molecular and capillary forces. Eventually, in the LTM compounds, consisting mainly of sand and water, the mutual adhesion forces depend on the moisture content and the share of the clay constituent in the sand.

For the research, we are reporting below, we took into account the fact that the mechanical properties of the LTMs are sufficient if the latter are produced without clay additions and do not bear the clay adverse impact on the mould gas permeability. Thus, the research of the fluidity was conducted on the moulding compounds without clay additions.

The course of the research

For the current research, we used the sand of Ukrainian 3K02A grade (grain-size composition is 0315-02-016 with the grain average value of 0.24 mm and the fineness of *N*=67.08 (GOST 2138-91). The moisture content in the test moulding compounds was defined in complete agreement with GOST 23409.5-78.

We were varying the water content in the test moulding compound from 0 % to 15 %. The results on the fluidity data for LTM compounds, which we have obtained, are shown in table 1 and Figure 1.

Table 1. The moulding compounds fluidity data

Water content, %	0	2	5	7	10	15
fluidity, %	62	47	53	54	55	55

The analysis of the obtained results shows that dry sand possesses the fluidity of 62 % that is explained by the absence of any binding components. By introduction of a small portion of water (2 %), we reduce the moulding compound fluidity down to 47 %. The further increase in the water content in the moulding compound facilitates the increase in the fluidity value. It is also worth noting, that at the water content within the range of 5 and 15 %, the difference in this value is small and amounts 2 %. The lesser fluidity value at the water content of 2 % is obviously caused by hydration of the clay constituents in the sand and effect of the capillary forces acting with adhesion forces. The latter can reach high values.

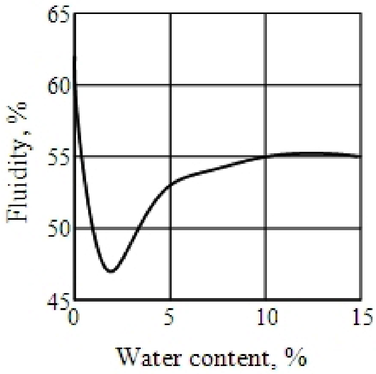

Figure 1. Impact of the water content on the fluidity in moulding compounds

The increase in the fluidity of the moulding compounds due to the water content more than 2 % can be explained by appearing excess water in the form of gravitationally or mechanically held moisture and the moisture adsorption on the surface of the sand particles, which subsequently reduces frictional forces between them.

The moulding compounds with the water content of 5 % and the higher possess nearly the same values of fluidity. Thus, for the purpose to achieve the sufficient level of mechanical properties, gas permeability and the fluidity, we can consider that optimum value of LTM compound is 5 %.

Moreover, the data on two mechanical parameters (rammability and hardness) are presented together, as the hardness and strength of LTM depend on the density of the compound in the mould.

For the test, we produced the mould samples from the sand of the Ukrainian grade specified above, processing them with the rammer and vibroramming equipment. The density of the samples was determined in accordance to GOST 23409.13-78 and was revealed as the following:

$$\rho = \frac{m}{v} = \frac{0.169}{0.000098} = 1724\ kg/m^3$$

The moulds ramming was carried out on the vibrating table with the oscillation amplitude range of 0.04 – 1.5 mm and the oscillation frequency of 3 000 r.p.m. (Table 2).

Table 2. Oscillation amplitudes of the vibrating table at different modes

Control steps	1	2	3	4	5	6	7	8	9	10	11
Amplitude, mm	0.04	0.06	0.07	0.11	0.15	0.3	0.45	0.6	0.83	1.1	1.5

In Figure 2 and Figure 3, there are shown the dependences for the density values of the moulding compound samples, which are 50-150 mm high, produced at the varying amplitudes but with the constant time of oscillation (2 min) and also for those manufactured with the varying time but the constant amplitude (1.1 mm). The analysis of the dependences in Figures 2 and Figure 3 performed on the density of the moulding compound shows that due to increasing oscillation amplitude, the density of the moulding compound increases. It is the oscillation amplitude of 1.1 mm that allows us to reach the moulding compound density of 1700 kg/m^3 while the further increase in the amplitude does not have any prominent influence on changes in the moulding compound density.

Furthermore, at the samples ramming with the constant amplitude of 1.1 mm, there is observed the density increasing with the time holding of 1 min but after this time period, the density does not crucially change. The changes in the moulding compound height within the moulding box impacts the density sufficiently only at the initial stage of ramming. The further ramming does not show the greater difference in the density, which remains within 1…3 %.

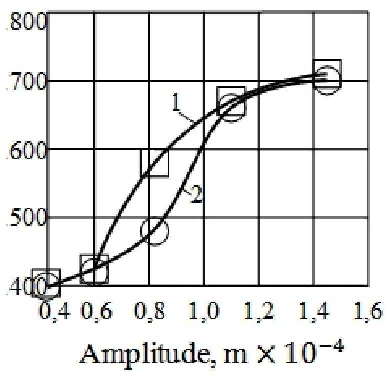

Figure 2. Impact of the oscillation amplitude on the moulding compound density at the constant time of ramming:
1 –the compound in the moulding box is 150 mm high;
2 – the compound in the moulding box is 50 mm high

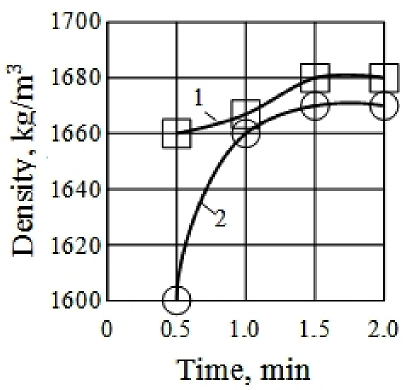

Figure 3. Impact of the ramming time on the moulding compound density at the constant oscillation amplitude:
1 –the compound in the moulding box is 150 mm high;
2 – the compound in the moulding box is 50 mm high.

In order to determine the impact of the moulding compound density on the mould hardness, we conducted the following experiment. The moulding boxes with the volume of 0.003379 m^3 and sizes of 230×115 mm were filled with the green sand and were subjected to oscillations at different modes. This resulted in the moulding compounds with the density of within 1400…1700 kg/m^3. Then, the moulds were frozen and their hardnesses were measured statically directly within the cooling chamber. This experiment has revealed that the difference in the hardnesses of the moulds, rammed at different modes, is conditioned by the differences in the moulding compound densities (1700 kg/m^3 and 1540 kg/m^3) and does not exceed 8…9% while the changes in the freezing temperature cause 25% increase in the moulding compound density. Additionally, LTM hardness is defined by the freezing temperature rather than by the density of the moulding compound at ramming.

The impact of vacuuming on LTM hardness was defined during freezing. The measurements were carried out in the lower part of the test mould, namely in the cavity for vacuuming. The air was evacuated by BBH1-0.75 pump to the vacuum of 0.05 MPa. In the chamber, freezing in the vacuum was performed down to the desired temperature and the hardness was measured there as well. The results of the experiment are in Table 3.

Table 3. Hardness measurement and vacuuming

Temperature of the moulding compound freezing, °C	Hardness		Changes in hardness, Δ %
	Without vacuuming	With vacuuming	
–10	37.5	46.5	24
–20	51	58	14
–25	62.5	67	7

Eventually, with vacuuming procedure, the hardness of the frozen moulding compound increases. However, with the further temperature lowering, the hardening effect of freezing reduces: hardening with freezing becomes the determining factor.

The results and conclusions

The reported study has revealed that the sands with the water content of 5% and higher possess actually the same values of the fluidity. Thus, with the objective to obtain the sufficient level of mechanical properties, the gas permeability and the fluidity we consider that the optimum value of moisture in the LTM compound should reach 5%.

It is also found that the difference in the hardnesses of the moulds, rammed at different modes, is conditioned by the difference in the densities of the moulding compounds (1700 kg/m^3 and 1540 kg/m^3) but does not exceed 8…9%.The changes in temperature towards freezing cause the increase in density up to 25%. LTM hardness is defined by the temperature of freezing rather than by the density of the moulding compound at its ramming.

The research has shown that vacuuming increases the hardness of the frozen moulding compound. However, with the further temperature lowering, the hardening effect of freezing reduces: hardening with freezing becomes the determining factor.

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