Investigation of the influence of softening modifiers on the knockout of investment castings

N A Kidalov, N P Zhiltsov, N I Gabelchenko, A A Belov, N V Grigoreva and V F Zharkova
Volgograd State Technical University, 28 Lenin Avenue, Volgograd 400005, Russia

mitlp@vstu.ru

Abstract. The paper considers the problem of laboriousness of cleaning and knocking out investment casting castings from ceramic molds material. The influence of softening modifiers on the structure and residual strength of ceramic samples was analyzed. A magnesium sulfide and copper chloride were selected for the study because of their temperature of destruction, which is in the range of the calcination temperature of the ceramic shells and the temperature of pouring the mold with liquid metal. For comparative studies of particle size distribution after exposure to shock loading the samples were formed from ceramic suspension with introduction of 1.5 and 3 wt.% of softening modifiers. Fractures of ceramics were examined using a two-beam electron scanning microscope "Versa 3D". It was shown that the use of copper chloride as a softening modifier in the composition of ceramics is facilitate the process of knockout the mold of investment casting.

1. Introduction

Currently, one of the casting methods that provide the ability to manufacture high-quality castings of complex configuration, thin-walled castings, castings with low surface roughness, high accuracy class, minimum machining allowances, etc. is a promising method of investment casting in one-time multilayer ceramic forms. However, the materials used in this type of casting are often expensive, scarce and not environment friendly, and the shaping method is characterized by high labor intensity and duration. One of the reasons that increase the production time is the operation of knockout the casting from the shell and cleaning the internal cavities [1-3]. Despite the large number of binders that have already been developed and successfully used in investment casting, there is still no universal composition that makes it possible to obtain high-quality castings from a wide range of alloys with the necessary knockout ability, while meeting the production requirements and world environmental safety standards [4-7].

Thus, improving the technological properties of investment casting in order to reduce the duration and labor intensity of the process (the knockout ability and cleanability of the castings from the remains of ceramic mold) is an urgent problem of the foundry industry.

In the investment casting method, several cleaning methods are known, but each of them has its positive and negative aspects associated with inefficiency, high time and energy costs for cleaning, creating harmful production waste, as well as the high cost of the cleaning process itself [6-8].

The method proposed in this work for improving the process of cleaning castings from ceramic molds is free from these disadvantages.
2. Materials and methods
For the formation of easily knockout and easy-to-clean ceramic molds a suspension of the following composition (wt.%) was used: ethyl silicate (ETS32) - 51.0%, acetone - 40.0%, distilled water - 8.5%, hydrochloric acid – 0.5 % and pulverized quartz refractory filler – the rest. Copper chloride (CuCl₂) and magnesium sulfate (MgSO₄) in amounts of 1.5 and 2.5 % (wt.) were added as technological softening modifiers [9]. The choice of these technological additives for introduction into the composition of the suspension is based on the principle – the temperature of calcination of ceramic shells (usually 900°C) < the additive temperature of destruction < temperature of pouring liquid metal [2, 9, 10].

In order to determine the residual strength of ceramic samples from the proposed suspension, control (without modifiers) and experimental bar-shaped samples were made with a cross section of 8×25 mm and a length of 120 mm, containing as modifiers – copper chloride or magnesium sulfate in amount of 1.5 or 3 % above weight (table 1). The amount of additive introduced into the suspension was determined based on preliminary studies [9, 10]. Before testing, the samples were heat treated up to a temperature of 1250°C in a "SNOL 80/12" chamber electric furnace, which corresponds to the temperature of pouring a ceramic mold with liquid iron.

The studied samples of ceramics were tested on a laboratory impact pendulum machine with a falling weight of 6.35 kg (± 0.015 kg) and a drop height of 50 (± 0.25 mm) [11]. The hammer was reequipped so that during the impact it was in full contact with the surface of the sample mounted on the plate. Control weighing of samples was carried out before testing. After three tests of the laboratory impact pendulum machine [11], the samples were sent for further study to the device for determining the particle size distribution, which includes a set of sieves with different mesh sizes [12].

The knockout of the ceramic mold was judged by the granulometric composition of the destroyed ceramic. For the study a set of sieves with a mesh size of 2.5-0.63 mm, as well as a tray – a pallet of a laboratory device was used. The ceramics were placed on the top sieve of the set, in which the sieves are arranged in descending order depending on the mesh size of the sieve. Sieving was carried out for 5 min, after which the remains of ceramics were transferred separately from each sieve onto glossy paper, weighed and the mass fraction of the remainder of ceramics on the sieves was calculated.

3. Results and discussion
The test results and calculations of the mass fractions of ceramic residues on sieves are summarized in table 1.

| Sample number | Modifier | Modifier content, in mass parts per 100 mass parts of suspension | Sample weight before testing m, g | After sieving | Sieve mesh size, mm | Sieve residue weight m₁, g |
|---------------|----------|---------------------------------------------------------------|---------------------------------|--------------|--------------------|--------------------------|
| 1             | —        | —                                                             | 46.1                            |              | 2.50               | 28.2                     |
|               |          |                                                                |                                 | 1.60         | 10.4               |                          |
|               |          |                                                                |                                 | 1.00         | 3.4                |                          |
|               |          |                                                                |                                 | 0.63         | 2.5                |                          |
|               |          |                                                                |                                 | Tray         | 1.6                |                          |
Comparative analysis of the granulometric composition of the control sample (without a modifier) and samples containing softening modifiers in the amount of 1.5 and 3 % after destruction on a laboratory impact pendulum is shown in figure 1.

|   |   |   |   |   |   |
|---|---|---|---|---|---|
| 2 | Copper chloride | 1.5 | 44.5 | 2.50 | 18.1 |
|   |               |     |     | 1.60 | 7.3  |
|   |               |     |     | 1.00 | 6.3  |
|   |               |     |     | 0.63 | 6.1  |
|   |               |     |     | Tray | 6.7  |
|   |               |     |     | 2.50 | 16.0 |
|   |               |     |     | 1.60 | 6.7  |
| 3 | Copper chloride | 3   | 46.3 | 1.00 | 8.1  |
|   |               |     |     | 0.63 | 8.1  |
|   |               |     |     | Tray | 7.4  |
|   |               |     |     | 2.50 | 22.1 |
|   |               |     |     | 1.60 | 8.8  |
| 4 | Magnesium sulfate | 1.5 | 45.2 | 1.00 | 7.1  |
|   |               |     |     | 0.63 | 4.0  |
|   |               |     |     | Tray | 3.2  |
|   |               |     |     | 2.50 | 19.4 |
|   |               |     |     | 1.60 | 8.1  |
| 5 | Magnesium sulfate | 3   | 44.7 | 1.00 | 7.0  |
|   |               |     |     | 0.63 | 5.4  |
|   |               |     |     | Tray | 4.8  |

**Figure 1.** Results of the samples particle size distribution study.
Studies have shown that the control samples after testing on a laboratory impact pendulum collapsed partially – the mass fraction of large particles with a size of 2.5 mm and more was 61.17 %, which significantly exceeds the proportion of large particles in the samples with modifiers. Samples with modifiers softened more – the mass fraction of fine particles with a size of 0.63 mm and less in samples with copper chloride and magnesium sulfate in the composition exceeded the fraction of particles in control specimens without additives. The distribution of the remains of the experimental ceramics sample with the addition of copper chloride in an amount of 3 % (wt.) is mainly dispersed on sieves with mesh sizes from 1 mm to the tray. This indicates an easier knockout process for investment castings. Therefore, for comparative studies, fractures of ceramics with the addition of 3 % (wt.) copper chloride and ceramics without additives were selected.

The microstructures of the studied samples are shown in figure 2.

![Figure 2. Microstructure of fractures of ceramic samples: (a) – control sample (without modifier), (b) – experimental sample with 3 % (wt.) of copper chloride.](image)

It is shown that the microstructure of the experimental sample with the addition of 3% (wt.) copper chloride (figure 2 (b)), has microcracks in the binder film and the separation of the binder film from the surface of sand grains, in contrast to the continuous film of the binder in the control sample (figure 2 (a)). This is due to the fact that during pouring the liquid metal, the additive disintegrated with the release of gas, which, under its own pressure, softened the ceramics, creating internal stresses that contribute to the separation of the binder film from the sand grains. This improves the process of cleaning the castings from ceramic molds. The presence of such modifiers in the composition of the ceramic suspension makes it possible to facilitate the operation of knockout and cleaning the castings manufactured by the method of investment casting.

4. Conclusion

During the research, the following results were obtained:
- The granulometric composition of ceramics with the introduction of 3% (wt.) copper chloride is mainly concentrated on sieves with mesh sizes from 1 mm to the tray, which indicates that ceramic molds were knocked out with less effort.
- In the microstructure of ceramics modified with copper chloride, microcracks were revealed, which are serve as concentrators of internal stresses in the mold, as well as separation of the binder film from the surface of sand grains. This indicates a positive effect of the modifier on the softening of the ceramic mold during finished castings knockout.

References

[1] Gini E Ch, Zarubin A M and Rybkin V A 2005 Foundry technology. Special types of casting (Moscow: Academy) p 352
[2] Zhiltsov N P, Kidalov N A and Grebnev Yu V 2017 Research of knockout of ceramic moulds for investment casting Procuring production in engineering (press-forging, foundry and other industries) 7 pp 291-3

[3] Vertsyukh V A 2014 Resource-saving technology of shaping using aluminoborophosphate concentrate in investment casting Dissertation of the candidate of technical sciences (Chelyabinsk: Nosov Magnitogorsk State Technical University) p 126

[4] Vasil'ev V A 1996 Ceramic Mold Manufacture. Pattern Removing. Mold Roasting and Pouring. Finishing Metallurg 12 pp 35-7

[5] Znamenskii L G, Ivochkina O V and Varlamov A S 2019 Acceleration of the formation on the sodium silicate binder in investment casting Mater. Sci. Forum pp 673-7

[6] Dydak A, Kurdziel P, Zaba K, Puchlerska S and Szwachta G 2017 Influence of ceramic molds parameters on the quality of small-scale casts produced by the investment casting METAL 2017 - 26th Int. Conf. on Metallurgy and Materials vol 2017 (Czech Republic/Voronez: IBrno) pp 151-55

[7] Beckett B 1983 Cleaning investment castings the chemical way Foundry Trade J. 155 p 3270

[8] Wiese-Nielson K 1977 High pressure water cleaning of precision castings Fonderie 373 pp 397-403

[9] Kidalov N A and Zhiltsov N P 2018 Suspension for the manufacture of easy-to-clean ceramic casting molds Patent for invention 2673873

[10] Kidalov N A and Zhiltsov N P 2018 A method of manufacturing easy-to-clean ceramic casting molds for investment casting Patent for invention 2673872

[11] GOST 23409.7-78 1986 Moulding sands, moulding and core sand mixtures. Methods for determination of compressive, tensile, bending and shearing strength (Moscow: Standardinform)

[12] GOST 29234.3-91 2008 Moulding sands. Methods for determination of medium size of seed and coefficient of homogeneity (Moscow: Standardinform)