MODELING AND SIMULATION OF DUCTILE-IRON BLANK CASTING PROCESSES FOR AN ELECTROHYDRAULIC POWER AMPLIFIER BODY

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Abstract

The paper describes the process of modeling a casting mold for a body blank of an electrohydraulic power amplifier and the technology of ductile iron melting in small furnaces.

Keywords: electrohydraulic power amplifier, casting, gating system modeling, melting technique.

I. Introduction

The body of the electrohydraulic power amplifier (EHPA) is a unique part; there is no information about the practice of manufacturing similar parts in the technical literature.

The body of EHPA is a parallelepiped, in the center of which there is a stepped hole for placing a spool-sleeve pair in it. A developed system of curved channels of small diameter diverges from the central hole throughout the body, designed for the flow of working fluid with the required pressure, flow rate, and force.

During operation the body is subjected to hydraulic loads under high pressure. The proposed material for manufacturing the body is high-strength cast iron (ductile iron with grades from VCh35 to VCh50 GOST 7293-85); the manufacturing method is casting [1, 2].

Intricate casting elements are internal cavities of developed configuration, which can be obtained using special elements of the casting mold, the so-called cores. Since the casting has small dimensions and is prepared in small-scale production, it is advisable to manufacture it in disposable resin sand molds obtained by 3D prototyping. This method does not require the manufacture of expensive model equipment.

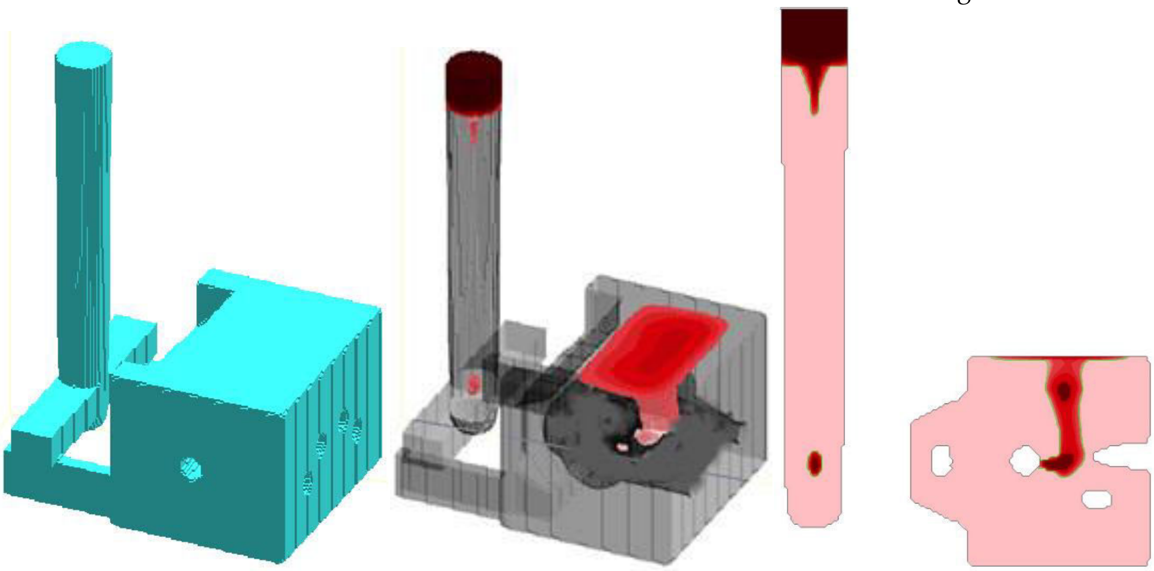
II. Development of the casting mold design

First, it is necessary to design the gating system (GS). Since the casting is small in size and made of cast iron, we select the classic GS type, consisting of a funnel, down gate, sump, slag trap, and feeders.

The calculation is based on determining the optimal time for filling the cavity of the casting mold and calculating the GS bottle neck, which determines this time [3-5].

Ductile iron has significant volumetric shrinkage. To prevent such shrinkage defects as cavities and porosity, it is necessary to provide for a riser, that is, a technological reservoir that feeds the casting with liquid metal during the solidification process.

To identify the features of shrinkage processes in the casting, computer modeling was carried out in the LVMFlow finite-difference system. The 3D model of the casting and the simulation results are shown in Figure 1. The dimensions of the sections of the GS elements were as follows: one down gate with a diameter of 19 mm, two slag trap branches of rectangular cross-section 14×18 mm each, and two feeders of rectangular cross-section 6×20 mm each. According to the calculation, each of the two risers was 166 mm high and 30 mm in diameter. The technological yield (TY) with this design and dimensions of the GS was 55.1%. The amount of metal in the mold was 5.525 kg for ductile iron.



a) b) c)

a) 3D model; b) volumetric view; c) cross section of casting

Figure 1: *Casting with a gating system and the results of modeling the formation of shrinkage defects in the casting body*

The simulation results showed that these risers worked inefficiently, and shrinkage defects penetrated into the casting. The end of shrinkage defects in the casting was on the axis of its heating element. To improve the casting feeding process, we decided to use one central riser located above the center (on the axis) of the heating element. The simulation results showed (Fig. 2) that the place of probable formation of shrinkage defects was removed from the casting body. This allowed us to conclude that the volume of this open riser was sufficient to obtain a high-quality casting.

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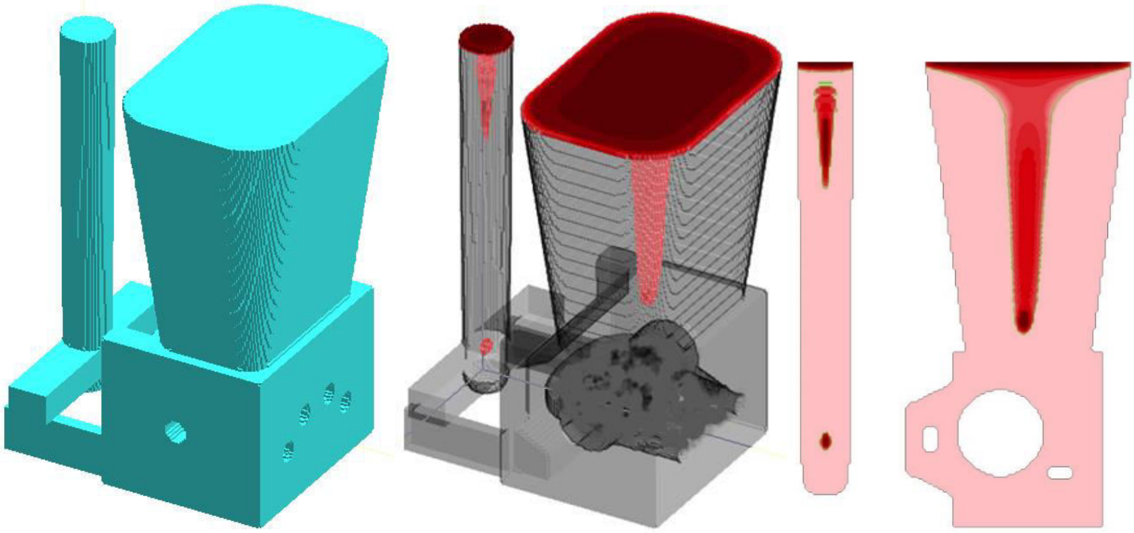

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a) 3D model; b) volumetric view; c) cross section of casting

Figure 2: *Results of modeling the formation of shrinkage defects in the casting body*

However, with such a riser weighing 5376.3 g, the technological yield decreased to 33.6%, and the metal weight in the mold was 9067.2 g. Such a level of TY when producing castings from ductile iron is considered very low. To reduce the weight of the riser, we switched to a closed type of risers to reduce heat loss by radiation and the rate of riser solidification. As a result, we changed the design of the riser: its height was reduced from 116 mm to 86 mm and all sharp corners of the riser, which acted as chillers during riser solidification, were rounded. As the simulation results showed (Fig. 3), the efficiency of such a riser became significantly higher than in the previous version. At the same time we managed to increase TY to 37.4% and reduce the amount of metal in the mold to 8146.8 g. We continued working in this direction.

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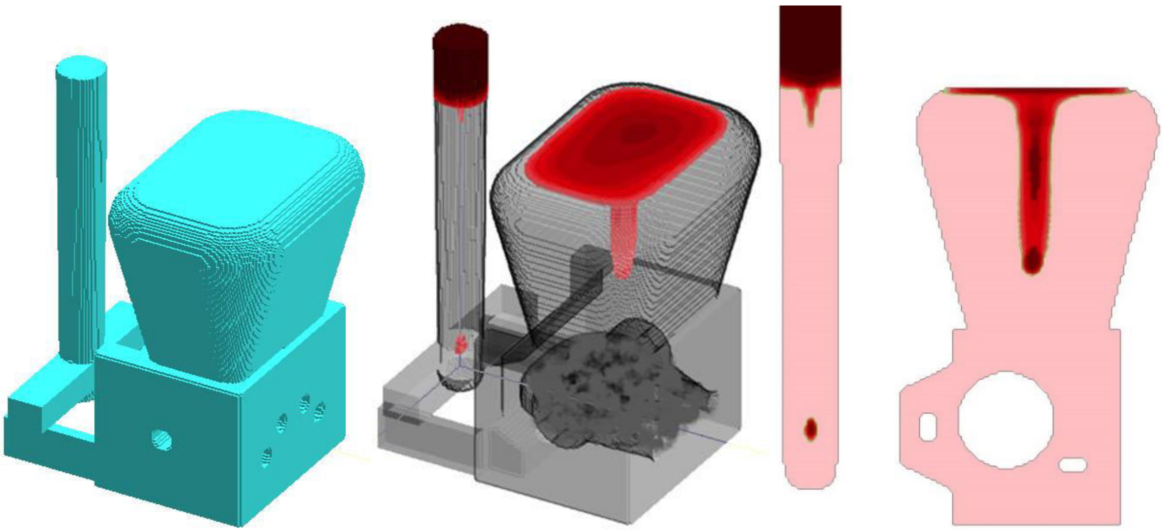
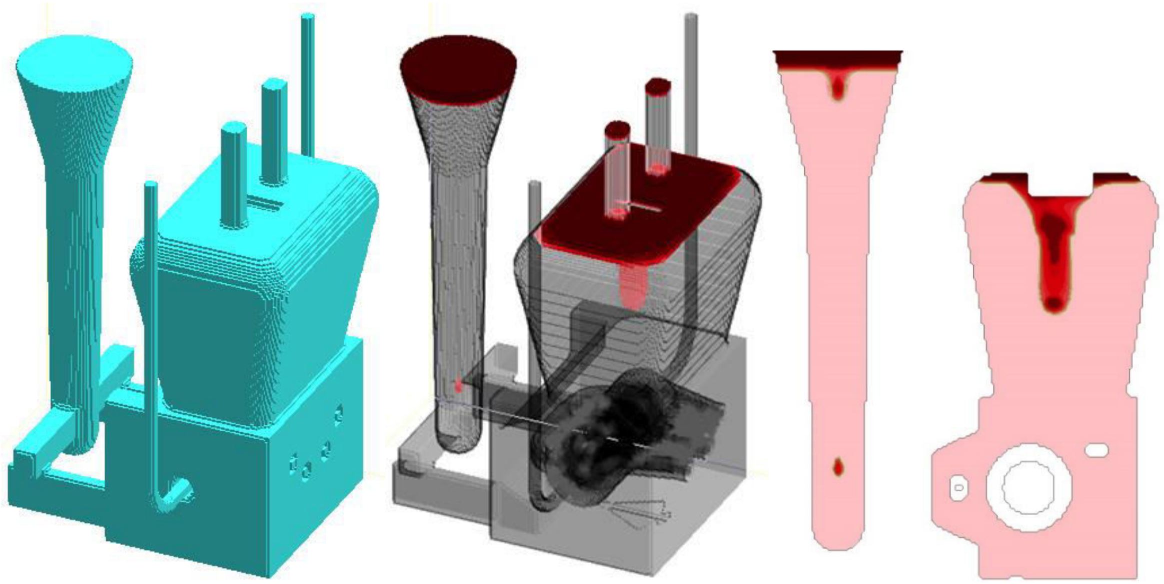


a) b) c)

a) 3D model; b) volumetric view; c) cross section of casting

Figure 3: *Results of modeling the formation of shrinkage defects in the casting body (a variant of the technology with one closed rectangular-sectioned riser with an expansion towards the top)*

At the final stages of computer modeling, we tested the variant of manufacturing a casting with empty spaces in those parts of the mold that play the role of cores and are intended to obtain internal cavities in the casting. This will help to reduce the gas formation from those parts of the mold when obtaining experimental castings. In this version of manufacturing the casting in the mold, we also provided channels coming out to the surface and intended to improve the removal of gases formed from the mold. According to the results of modeling, no places of probable formation of shrinkage defects were found in the body of the casting (Fig. 4) and a calm laminar flow of the melt was noted when filling the casting cavity, and this variant of the technology is recommended for use in obtaining experimental castings.



a) b) c)

a) 3D model; b) volumetric view; c) cross section of casting

Figure 4: *Results of modeling the formation of shrinkage defects in the casting body with the pouring temperature TPOUR = 1420 °C*

Development of technology for melting high-strength cast iron in small-capacity furnaces

Melting was carried out in a PPI-0.02 induction crucible furnace with thyristor converters based on pig iron PL1. The load was 10 kg.

III. First version of melting

After melting the cast iron, ferromanganese was added to the furnace in the amount of 21 g. To obtain spheroidal graphite in the structure, a complex modifier of the following composition was used: a SferoMag 611 graphite spheroidizer in the amount of 200 g and a Sibar 4 graphitizer in the amount of 50 g, which was pre-loaded into the pouring ladle before heating it.

The ladle was heated to a temperature of 600 ° C together with the modifier. After pouring the metal from the furnace into the ladle, a significant flare indicated the processes of spheroidizing modification. Experimental rods were casted into sand-clay molds and samples for chemical composition were casted into a metal chill mold.

The results for chemical composition (Table 1) and structure (Fig. 5) showed the presence of spheroidal graphite of irregular round shape (allowed) and ferrite-pearlite base of the alloy with ferrite content of 50%. The manganese content in the alloy was slightly below the lower limit recommended by GOST 7293-85. We used the DFS-500 optical emission spectrometer to analyze chemical composition and the SIAMS complex to determine the structure.

Table 1: *Chemical composition of cast iron (melting no.1)*

Element	Fe	C	Si	Mn	Mg	Cr	Ni	Cu	S	P
Weight content, %	93.8	3.688	2.085	0.182	0.078	0.014	0.009	0.0026	0.017	0.0097

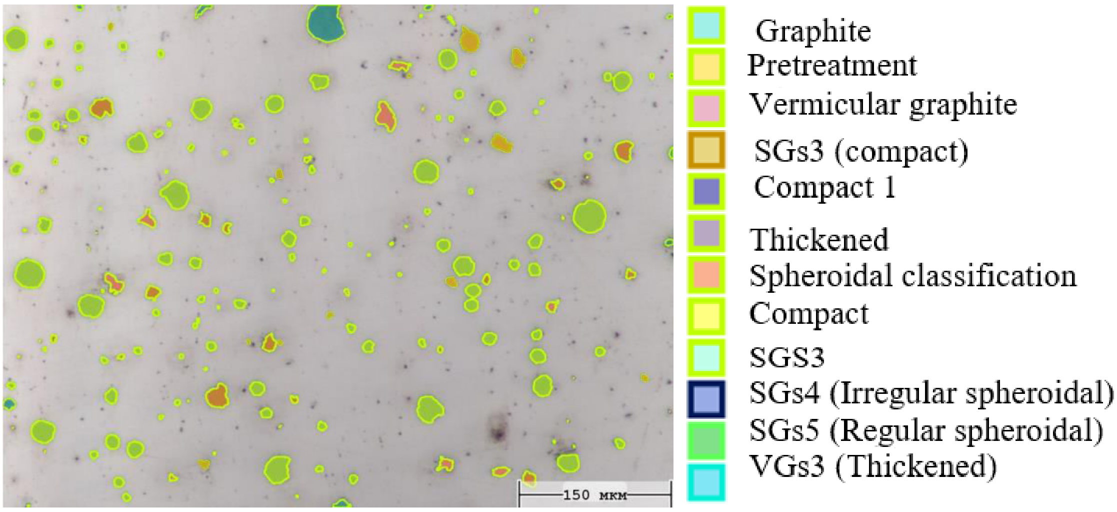


Figure 5: *Structure of cast iron (melting no.1)*

Determination of mechanical properties showed that the strength characteristics corresponded to the VCh50 grade of GOST 7293-85, and the relative elongation was slightly lower than recommended by GOST 7293-85.

We decided to conduct the second melting, adjusting the charge composition.

IV. Second version of melting

The loading of pig iron PL1 was also 10 kg. During the melting process, ferromanganese was added to the crucible in the amount of 25 g, ferrosilicon 24 g to the furnace and 25 g to the pouring ladle. The SferoMag 611 modifier in the amount of 180 g, the Sibar 4 in the amount of 120 g, and ferrosilicon in the amount of 25 g were placed in the pouring ladle before tapping the metal from the furnace. The metal tapping temperature was 1500 °C and the ladle temperature was 800 °C. Temperature measurements were made with a VR 20-5 tungsten-rhenium thermocouple. After the metal was poured from the furnace into the ladle, a significant flare occurred, indicating the processes of spheroidizing modification. The holding time in the ladle was 3 minutes and the mold pouring temperature was 1330 °C.

Experimental rods were casted into sand-clay molds and samples for chemical composition were casted into a metal chill mold. After pouring, the experimental rods were separated from the sprues and cleaned of burnt-on deposits. Dumbbell samples were cut from the rods to determine mechanical properties. The results for the chemical composition (Table 2) and structure (Fig. 6) showed the presence of spheroidal graphite of a regular round shape (the best option) and a ferrite-pearlite base of the alloy with a ferrite content of 88.4%, which is typical for cast iron of VCh50 grade.

Table 2: *Chemical composition of cast iron (melting no.2)*

Element	Fe	C	Si	Mn	Mg	Cr	Ni	Cu	S	P
Weight content, %	93.8	3.342	2.464	0.208	0.055	0.017	0.012	0.0074	0.019	0.025

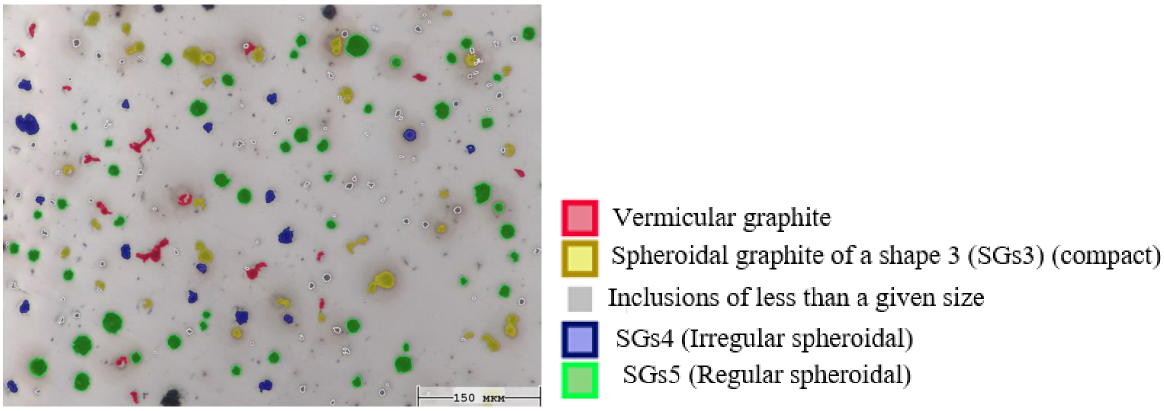


Figure 6: *Structure of cast iron (melting no.2)*

The mechanical behavior test showed that the characteristics averaged over three similar test results corresponded to the grade VCh50 GOST 7293-85 (Table 3).

Table 3: *Mechanical properties of cast iron (melt No. 2)*

Property	Tensile strength, MPa	Offset yield stress, MPa	Relative elongation, % (additional parameter)
Value	504	348	7

When melting and pouring small volumes of metal (10 kg), rapid cooling of the melt in the ladle occurs (approximately 50 ºC/min), which limits the time of graphitizing holding and complicates the production of cast iron with a fully ferritic matrix structure (grades VCh40 and VCh45).

High-strength cast iron VCh50 has a high level of strength properties (tensile strength and offset yield stress), sufficient plastic properties (relative elongation) and vibration resistance, for which there is no need to have high plastic properties. Therefore, for the production of the EHPA cast body, along with cast iron VCh45, high-strength cast iron VCh50 can also be recommended as the main material.

Two cast bodies of an electrohydraulic power amplifier were made of ductile cast iron in accordance with the developed technical solutions and successfully passed hydraulic tests under a pressure of 500 atm.

V. Acknowledgments

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