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DETERMINATION OF THE INFLUENCE OF THE SURPLUS CONSTRUCTION ON THE PARAMETERS OF THE SHRINKAGE SHELLS IN THE «BODY»-TYPE STEEL CASTINGS WHEN CASTING IN SINGLE SAND MOLDS

The object of research is the technology of manufacturing «Body»-type shaped castings of the from medium carbon steel in one-time sand molds.

The existing problem is that the design of the casting and foundry equipment significantly affect the formation of internal defects in castings. This especially applies to steel castings, the technology of which is more complicated than the technology of cast iron castings due to much worse casting properties of steel.

To determine the influence of the location of surpluses on the «Body»-type steel castings of the on the formation of shrinkage shells, computer modeling was used, in the process of which 5 computer experiments were conducted with different sizes and geometries of surpluses.

According to the simulation results, it was found that with some technological options, there is a risk of the shrinkage shell penetrating into the casting body. The use of a cylindrical surplus of a rectangular cross-section with fillets ensures complete absorption of the shrink shell in the place of surplus installation. Using an excess round section at the installation location does not guarantee absorption of the shrink shell. The determining factor affecting the coefficient of increase in the depth of the shrinking shell is the excess volume. This influence can be described by a functional dependence of the logarithmic type with the coefficient of determination $R^2=0.82$*.*

It was determined that the ratio of the diameter of the inlet to its height does not affect the coefficient of increase in the depth of the shrinking shell. The resulting functional dependence allows to set the excess volume that provides a minimum growth factor while simultaneously preventing excess metal consumption.

The presented study will be useful for machine-building enterprises that have foundries in their structure, where shaped castings are made in one-time sand molds.

Keywords: *steel shaped castings, surplus, shrink shell, design and technological solutions.*

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1. Introduction

The mechanical properties of castings are known to be determined by two main factors: the continuity of the castings and the chemical composition of the alloy. While the influence of the second factor can be estimated based on mathematical models of the «composition – properties» type [1, 2], which are constructed using regression analysis and experimental optimization methods [3, 4], computer modeling is used to identify the influence of the first factor. For example, in the study [5], a method for segmenting casting defect areas was developed based on a dual-channel encoding-fusion-decoding (DCE-FD) network, which accurately segments potential fuzzy areas of multi-scale defects. This is important for accurately determining the localization of defects and cast parts. The paper [6] presents the results of developing intelligent control for detecting surface discontinuities in castings. A comparison of models based on several algorithms showed that the most accurate method for detecting discontinuities in castings is the use of the support vector machine (SVM). In [7], it is shown that computer modeling taking into account physical and chemical laws – the Arrhenius equation, the law of conservation of mass, Darcy's law – allows predicting gas defects in the processes of manufacturing gray cast iron castings. As follows from [5–7], the main direction of research is the detection of locations of internal defects caused by the processes of casting solidification. This circumstance is also noted in [8], where pattern recognition methods were used to identify locations of defects.

Moreover, detection methods play an important role. However, it should be noted that the casting design itself plays a particularly important role, therefore, although the choice of a particular defect detection method is important, as noted in [5–8], taking into account the design features of the casting should be mandatory. In support of this, we can mention [9–12]. Thus, in [9], the results of studies of plate casting defects are presented, obtained on the basis of modeling in Auto-castX1, which made it possible to make decisions that ensured a decrease in the percentage of defects from 8.5 to 3.5 %. In [10], the porosity defects and secondary distance between dendrite axes (SDAS) in a cast cylinder head were investigated. For this purpose, computer simulation and an experiment were performed, which showed that porosity defects mainly exist in thick walls, as well as in the joints of thick and thin walls. Based on the obtained results, an assumption was made that an increase in the cooling rate can partially reduce porosity defects and a conclusion was made that a decrease in the cooling rate can reduce the SDAS of the casting, which leads to a dense microstructure. Therefore, it was proposed to give preference to regular shapes and thin walls in the casting design in order to reduce porosity defects and obtain homogeneous microstructures. In [11], it was found that the destruction of the cylinder head is facilitated by multiple cracks arising due to the presence of porosity in the casting, regardless of the loading mode. In addition, the formation of porosity defects in the casting in the cylinder head is caused by poor local cooling conditions during the casting process. This is confirmed by the results of computer tomography, metallurgical observations and modeling using the finite element method. The role of melt solidification in the mold cavity on the formation of volume shrinkage and porosity on the quality of casting is studied in [12]. A wheel casting was used for the study. The results of computer modeling for the location of shrinkage defects, cracks and porosity in the body of the casting and their comparison with the results of experimental tests showed good results. This made it possible, as noted by the authors of this work, to optimize the design of feeders.

Therefore, computer modeling of casting formation is a tool that allows identifying the locations of internal defects in castings. This, along with the construction of mathematical models of «composition – properties» and identifying the influence of geometric characteristics of casting equipment on the formation of defects [13], can be decisive in matters of casting quality management. It is important to note that it is also necessary to take into account the properties of the alloy, since, for example, the technology of producing high-quality steel castings is more complex than castings made of cast iron due to significantly worse casting properties of steel. Therefore, computer modeling in steel casting technologies requires special attention.

All this allows to talk about the feasibility of research developing the topic of the influence of design and technological factors on the quality indicators of steel castings.

The object of research is the technology of manufacturing shaped steel castings in disposable sand molds.

The aim of research is to identify patterns of shrinkage cavity formation for different risers, riser options and their sizes. This will allow to formulate rational design and technological solutions for installing risers.

2. Materials and Methods

For the experiment, the «Body» part (Fig. 1) was selected from medium-carbon steel, the casting of which is produced by casting in disposable sand molds.

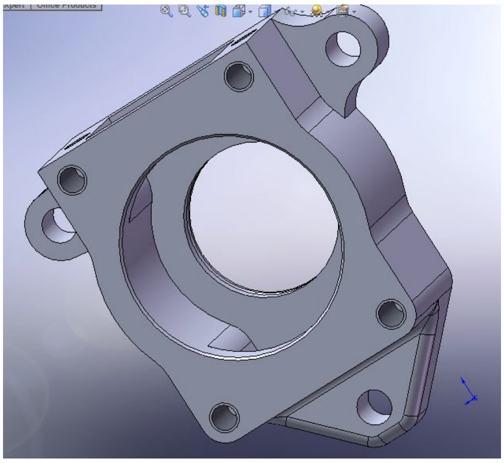

Fig. 1. «Body» part

During the production of this casting, a number of defects may occur, associated, in particular, with the penetration of a shrinkage cavity into the body of the casting.

For design and technological reasons, 3 risers were installed feeding the most massive, thermal units of the casting – a large cylindrical riser of rectangular cross-section with fillets and two small risers on the side of the metal supply to the mold cavity, with one of them installed above the feeder entry point.

The 3D model of the casting is shown in Fig. 2.

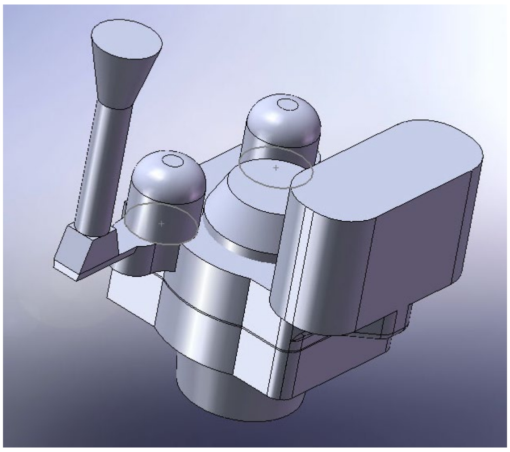

Fig. 2. 3D model of the «Body» casting

Thus, the following concepts are adopted:

- a riser of circular cross-section, located closer to the feeder, – riser No. 1_1;
- a riser of circular cross-section, located further from the feeder, – riser No. 1_2;
- rectangular cross-section riser with fillets – riser No. 2.

The riser sizes are presented in Table 1.

It should be noted that for risers No. 1_1 and No. 1_2 the variable variables are the height and diameter in experiments 1–3, while experiments 1 and 2 are conducted with a constant value of these variables, which can allow to assess the homogeneity of the experiments. For riser No. 2 the variable is the height of the riser. The input data presented in Table 1 indicate that the experiments involve not only identifying the influence of the variable variables, but also the option of setting the riser.

Table 1

Riser sizes

Experiment No.	Riser size, mm				
	Riser No. 1_1		Riser No. 1_2		Riser No. 2
	d	*H*	*d*	*H*	*H*
1	42	42	42	42	74
2	42	42	42	42	55
3	42	70	42	70	50
4	55	42	55	42	48
5	60	75	60	75	48

3. Results and Discussion

The results of computer modeling of the formation of a shrinkage cavity for different risers, riser options and their sizes are presented in Fig. 3–7.

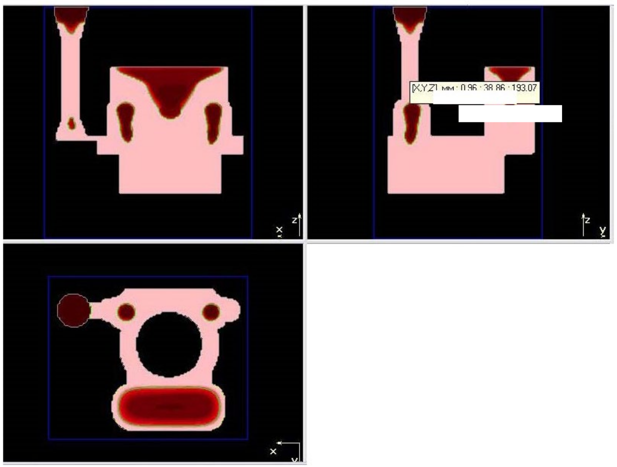

Fig. 3. Results of modeling shrinkage formation in 2D projections (experiment No. 1)

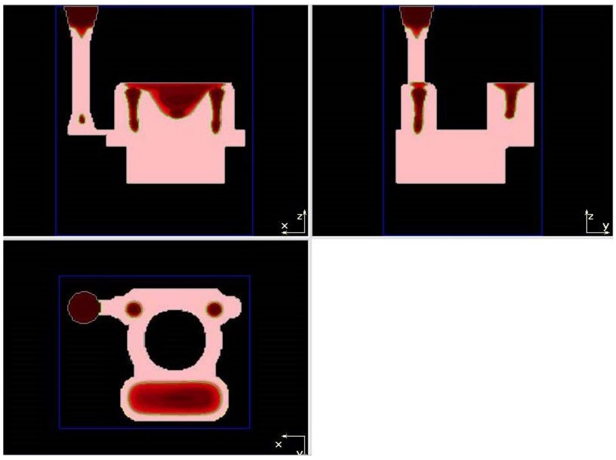

Fig. 4. Results of modeling shrinkage formation in 2D projections (experiment No. 2)

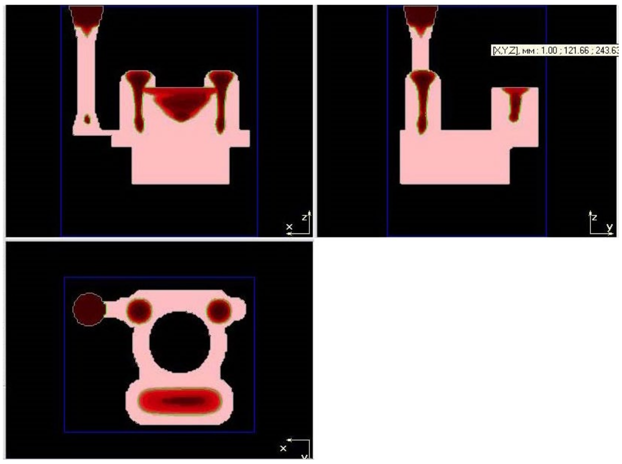

Fig. 5. Results of modeling shrinkage formation in 2D projections (experiment No. 3)

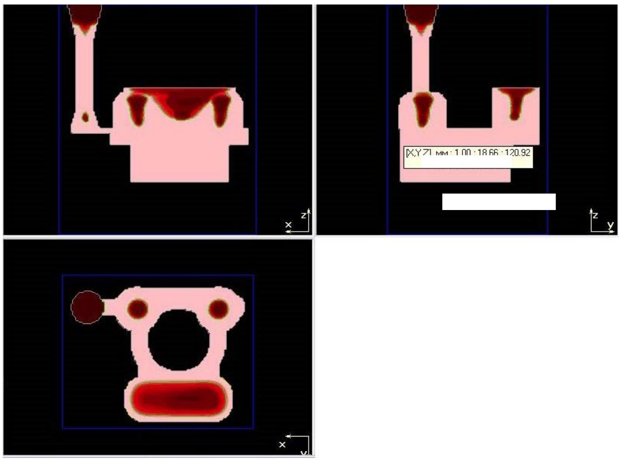

Fig. 6. Results of modeling shrinkage formation in 2D projections (experiment No. 4)

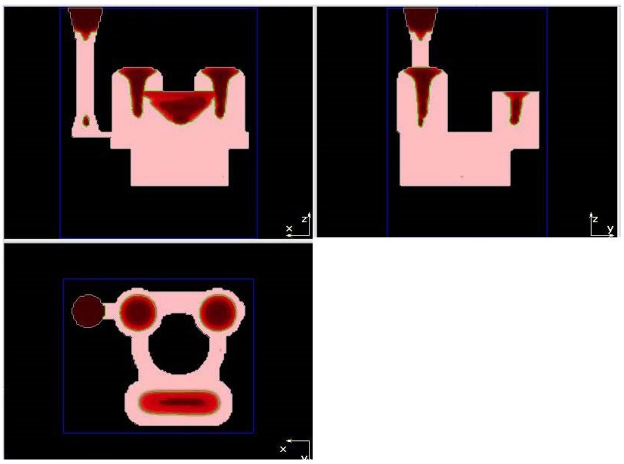

Fig. 7. Results of modeling shrinkage formation in 2D projections (experiment No. 5)

The results of calculating the position of the lower point of the shrinkage cavity based on the computer simulation show that changing the riser installation method affects the size and configuration of the shrinkage cavity. In experiment No. 1, the greatest depth of the shrinkage cavity and its probable penetration into the casting body was observed for riser No. 1_1 and riser No. 1_2. In experiments No. 2 and No. 3, the shrinkage cavity passed through these risers, but the penetration depth probably does not exceed the size of the allowance for mechanical processing. In experiments No. 4 and No. 5, the shrinkage cavity remained completely in risers No. 1_1 and No. 1_2. As for riser No. 2, in all experiments the shrinkage cavity remained in the riser body. Of practical interest is the answer to the question of whether the ratio of the riser sizes (*d*/*H*) and the riser volume (*V*) affect the depth of the shrinkage cavity (*Z*). It should be noted that it is not the absolute value of this quantity that is of particular interest, but the relative value – the increase in the shrinkage cavity depth relative to its minimum value, at which the cavity does not penetrate into the casting body. This quantity can be expressed by the increase coefficient (K_z) and taken as the output variable. This coefficient can be calculated using the formula:

$$Kz = \frac{Z_0}{Z_i}, \tag{1}$$

where Z_0 – the coordinate of the lower point of the shrinkage cavity, at which it does not penetrate into the casting body; Z_i – the coordinate of the lower point of the shrinkage cavity in the *i*-th variant of the riser design.

The origin of the coordinates, in this case, is located at the point of pouring the metal into the sprue funnel.

Taking into account the simulation result, which showed that in the case of using riser No. 2, the entire shrinkage cavity is inside the riser, further analysis was carried out in relation to risers No. 1_1 and No. 1_2. In this case, taking into account that these risers are placed symmetrically relative to the axis and have the same dimensions, it can be considered that the results of modeling the formation of a shrinkage cavity are the results of two parallel experiments. Thus, the average value of the cavity depth (Kz_m) can be estimated:

$$Kz_m = \frac{Kz_{m1\_1} + Kz_{m1\_2}}{2}. \tag{2}$$

The riser volume is calculated using the formula:

$$V = \frac{\pi d^2}{4} H, \tag{3}$$

where *d* – the riser diameter; *H* – the riser height.

Taking this into account, the results of calculating K_{Zm} for different values of *d*/*H* and *V* are given in Table 2.

Table 2

Results of calculating Kz_m for different values of *d*/*H* and *V*

Experiment No.	*d*/*H*	Kz_{m1_1}	Kz_{m1_2}	Kz_m	*V*, m^3
1	1	1.308916	1.323953	1.316435	0.058159
2	1	1.168054	1.196608	1.182331	0.058159
3	0.6	1.118387	1.137199	1.127793	0.096932
4	1.309524	1.126711	1.120239	1.123475	0.099734
5	0.8	1	1	1	0.21195

Fig. 8 shows the dependence of Kz_m on the *d*/*H* ratio, and Fig. 9 shows the dependence of Kz_m on *V*.

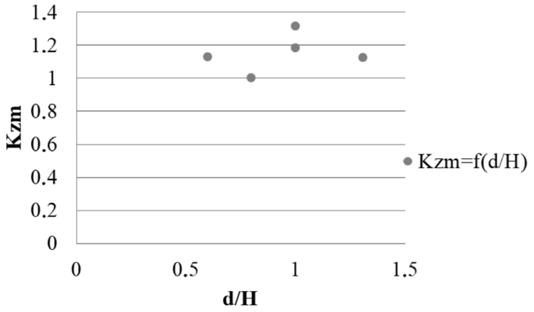

Fig. 8. Dependence of K_{Zm} on the *d*/*H* ratio

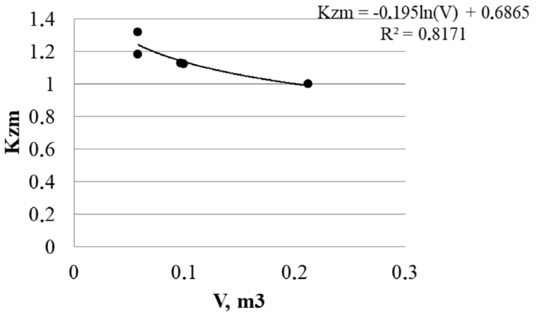

Fig. 9. Dependence of K_{Zm} on *V*

From Fig. 8 it is clear that the *d*/*H* ratio does not affect the value of Kz_m, which does not correspond to the existing recommendations regarding the selection of the ratios of the diameter of the riser and its height for closed risers. However, the volume of riser affects Kz_m, and this dependence can be described functionally:

$$Kz_m = 0.6865 - 0.195 \ln V. \tag{4}$$

From equation (4) it is clear that an increase in the volume of riser reduces the Kz_m value, which tends to 1.

Equation (4) allows to predict the Kz_m value when choosing the volume of riser, as well as to estimate what rational volume of riser can be accepted taking into account that an unjustified increase in the volume of riser from the point of view of reducing the coordinate of the lower point of the shrinkage cavity will lead to an overspending of metal.

The limitation of the study is the selected type and design of the casting, as well as its material. Nevertheless, the obtained results have the potential for scaling, although the fact of checking the absence of the influence of the *d*/*H* ratio on the Kz_m value is obvious. Therefore, a possible direction for further development of the study is 3D modeling for other types and mass-dimensional dimensions of castings with a similar design configuration.

4. Conclusions

Based on the results of computer modeling of shrinkage cavity formation using two types of risers, it was found that with some process options there is a risk of shrinkage cavity penetration into the casting body. The use of a cylindrical riser of rectangular cross-section with fillets ensures complete absorption of the shrinkage cavity at the riser installation location. The use of a round riser at the installation location does not guarantee absorption of the shrinkage cavity. The determining factor influencing the coefficient of shrinkage cavity depth increase is the value of the riser volume. This influence can be described by a logarithmic functional dependence with a sufficiently high determination coefficient $R^2=0.82$. The ratio of the riser diameter to its height does not affect the coefficient of shrinkage cavity depth increase. The resulting functional dependence $Kz_m=f(V)$ allows to establish a rational riser volume that ensures a minimum increase coefficient while simultaneously preventing excess metal consumption.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating this work.

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