The study of influence of chemical composition of steel 35HGSL on the characteristics of shrinkage, casting defects and microstructure

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Abstract. Today, steel castings have become an integral part of modern foundry production. In the process of obtaining castings, any defects inevitably appear. In this paper, we consider the production reasons for the formation of defects in the manufacture of castings made of 35XGSL steel when casting on investment models. The features of heat removal from the casting during primary and secondary crystallization are also considered. The classification of casting zones by the orientation of crystals in castings is given. The regularity of the influence of the cooling intensity on the shrinkage character is revealed.

1. Introduction
Today, there are many industrial enterprises that are engaged in the manufacture of parts from metal materials. In order to produce high-quality products, the main operation is to identify certain defects that can later cause the parts to fail [1-3].

In the manufacture of castings when casting on investment models there are the following reasons for the formation of defects:

- insufficient surface cleanliness of molds;
- poor wetting of the surface with a special solution;
- insufficient surface strength of the shell;
- breaking of the first facing layer of the suspension with sand when sprinkling blocks;
- formation of cracks in the layers of the mold shell due to its insufficient heat resistance;
- formation of air bubbles on the surface of the models and between the layers of the shell due to poor wetting of the surface of the models with a solution;
- formation of cracks in the shell under the pressure of the support filler;
- chemical activity to the shell material of oxides dissolved in the alloy;
- overheating of the metal when pouring into molds;
- strong heating of individual sections of the mold cavity;
- defects in the Gating system;
- painting parts of the mold shell during the filling process;
- ingress of molding sand into the shell cavity when forming the support filler;
- shedding of furnace lining material and ladle;
• increased tendency to oxidation when melting individual elements that make up the alloy (Ti, Al);
• the Gating system has an incorrect design and dimensions;
• errors related to the location of castings in the block;
• increased gas saturation of metal with gases and oxides;
• ingress of molten slag into the mold during pouring;
• insufficient gas permeability of the mold;
• non-technological design of castings and casting block;
• high melt temperature during pouring, which leads to an increase in internal stresses;
• increased content of harmful impurities in the metal;
• non-technological design of castings and casting block;
• stresses from external influences on the casting;
• metal spraying when pouring into the mold, cooling and oxidation of the droplet surface;
• poor quality of metal cleaning;
• reduced casting properties of the metal due to its low temperature during casting;
• formation of air bags in the mold when filling due to the low gas permeability of the mold shell;
• insufficient amount of metal in the bucket.

2. Defects in cast steel
The process of crystallization of cast steels is accompanied by the formation and growth of crystals, hydrodynamic phenomena (movement of the melt in the crystallizing casting), heat transfer, compression, gas release, etc.: All this is the cause of various defects.

The formation of crystals during the transition of steel from a liquid state to a solid state is called primary crystallization. Changing the shape of crystals during polymorphic transformations occurring in the solid state is called secondary crystallization [4-6].

The primary crystallization of steel in the mold depends on many factors: the heating temperature of the liquid metal in the melting furnace, the duration of steel exposure at temperatures higher than the melting temperature, the temperature of the steel when filling the mold, the heat sink conditions in the mold during crystallization, and others.

In real conditions of obtaining shaped steel castings, the factors that determine the heat sink from the crystallizing casting - the heat storage capacity of the casting mold and the thermal properties of the metal-have the greatest influence.

In real conditions, there are three zones in the macrostructure of steel castings: the outer zone with small undirected crystals, the middle zone with crystals oriented in the direction of the heat sink, and the Central zone with relatively large and randomly oriented crystals.

The outer zone is formed when the melt is significantly supercooled and a large number of crystallization centers appear. The middle zone is also formed in the presence of a large number of crystallization centers, but with less supercooling and the possibility of free growth of crystals in the direction of the casting center. The Central zone is characterized by an equalization of temperatures in the center of the casting and a more uniform structure [7, 8].

Shrinkage during cooling is an important property of steel, which determines the production of high-quality castings.

The shrinkage of steel castings is to reduce their sizes in the process of cooling and crystallization. It can be linear or volumetric. The volume shrinkage coefficient of steel castings is approximately 3 times greater than the linear shrinkage coefficient.

3. Ways to solve the problem
When pouring liquid steel into a mold and then cooling it, it is necessary to distinguish three types of volumetric shrinkage: in the period from the fill temperature to the liquidus temperature; in the
crystallization interval and in the solid state. The total volume shrinkage is the sum of these three types of shrinkage [9, 10].

Figure 1 shows the total shrinkage curve of 35HGS1 steel in the liquid state (segment AB), in the crystallization interval (segment BC), and in the solid state (segment CD).

Each of the three types of shrinkage can cause defects in the casting. Thus, the shrinkage of steel in the liquid state and in the crystallization interval significantly affects the formation and size of shrinkage shells in steel castings. Shrinkage in the solid state can cause cracks, internal stresses, and deformations of castings.

Shrinkage is associated with the main technological difficulties in the production of shaped steel castings from alloy steels. When liquid steel is cooled in the casting mold, a surface crystallizing layer is formed (during sequential solidification) and a crystal frame is formed (during volumetric solidification). As the surface layer of the crystal frame cools, the temperature decreases and the linear dimensions of the casting change accordingly [11, 12].

The intensity of cooling significantly affects the nature of shrinkage. At low intensity, the shrinkage is determined by the coefficient of linear expansion of the alloy. At high intensity at the end of solidification, the temperatures of the various parts of the casting differ significantly from each other, since they are cooled at different speeds. As a result, internal stresses are formed, leading in many cases to the curvature of steel castings. The greatest difference in the degree of shrinkage development in different cooling modes is observed during the initial cooling period, i.e. immediately after casting the mold with metal [13, 14].

Figure 1. Steel shrinkage Curve with 35HGS1 AB - in the liquid state; BC - in the crystallization interval; CD - in the solid state.

The crystallization temperature range, alloy ductility, and other parameters significantly affect linear shrinkage. It is established that the shrinkage of alloys begins in the crystallization interval when about 75...95% of the solid phase falls out (the liquid will be 25...5%, respectively).

Casting shrinkage depends on the configuration of the steel casting, the design of the mold, and other factors. The final dimensions of the casting are particularly affected by its configuration. Shrinkage is more difficult the greater the difference between the cross-section sizes of the individual parts of the casting. There are free and difficult shrinkage.

The volume shrinkage of the steel casting during solidification is 2.7...3.0% of its volume at normal temperature.

The shrinkage of steel castings also depends on the chemical composition of the steel, the rate of cooling, the rate of filling, the release of gases, the nature of volume changes during phase transformations, and so on [15, 16].

Figure 2 shows the effect of the chemical composition of steel on the total linear shrinkage of the solid metal.
Figure 2. Effect of the chemical composition of steel on total linear shrinkage.

Shrinkage in castings can be determined by static and dynamic methods. In the first case, the length of the mold to be filled is equal to the final length of the cooled casting; in the second case, a continuous change in the casting length is recorded.

Figure 3 shows the schemes of free and difficult shrinkage during casting crystallization [4, 7].

Casting shrinkage depends on the thickness of the casting walls: as the thickness increases, the thermal effect on the walls of the mold and rods increases. At the metal-form interface, the surface layers of the molding mixture are heated to high temperatures and as a result resist less shrinkage of the casting. Therefore, the actual shrinkage of castings increases with the thickness of their walls.

The degree of deformation during shrinkage is affected by the size of the grain and the cooling rate of the alloy (figure 4). Shrinkage also depends on the configuration of the castings. In order to obtain better castings, it is necessary to strive for the presence of maximum pliability of the form and the rod. This can be achieved by adding sawdust to the molding and core mixtures, etc., as well as creating cavities in the form that reduce its resistance during casting shrinkage [17, 18].

Figure 3. Diagram of free (a) and difficult (b) shrinkage in experimental castings.

Figure 4. Influence of temperature and size of the alloy grain on the degree of deformation during shrinkage.
If the mold does not have the necessary flexibility during shrinkage, internal stresses and cracks may occur in places where the mold strength is greater than the casting strength during crystallization [19, 20]. It is essential for practice to know that the smaller the difference between actual (difficult) shrinkage and free shrinkage, the higher the quality of steel castings.

4. Conclusion
Analyzing the data obtained and additional microstructural studies, it can be noted that in the presence of low-temperature sulfides in the steel structure, shrinkage cracks and fractures can be formed due to overheating of the metal during crystallization. To reduce the probability of occurrence of such defects of the rock-like fracture, the presence of refractory manganese sulfides, titanium, and rare earth metals is necessary. With increasing purity of steel for sulfur and nitrogen, the tendency to form casting defects and shrinkage shells increases. It also reveals one of the main features of the formation of cracks and fractures – the presence of phases that are concentrated on the borders of former austenitic grains.

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