Features of Forming of the Cast Preparations Received at External Influence and Suspension Filling of Medium-alloy Steel

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Abstract. In this paper, the influence of different impacts on cast steel allow are considered. We studied the effect of an external force applied during casting of high-strength steel alloy into a thin-wall metal sheath mold with external cooling and suspension molding as well. We studied macro- and micro-structure of obtained samples, mechanical properties at normal (+20°C) and increased (+350°C) temperature as well. As a reference metal, we used conventionally casted samples. We showed that the main advantage of proposed technology is a better uniformity of mechanical properties along the cross-section and height of the samples, especially elasticity and impact toughness. It was also shown, that different external impac
ts applied during casting allow to control the metal structure and mechanical properties at different operating temperature

1. Introduction
The development of casting technologies for the production of castings is associated with solving a number of engineering challenges related to the operation peculiarities of finished products [1 - 5]. Therefore, high-strength alloyed steels are widely used in various branches of technology [3, 4, 6 - 9]. Such steels are almost impossible to produce using conventional metallurgical methods – just due to alloying [3, 7, 10 - 12]. Currently, both in the world and in the domestic practice, high metallurgical quality isensuredbysecondary metallurgy of the molten metal melted using any steelmaking vessel. The use of secondary metallurgy in terms of sharp reduction of harmful impurities, gases, non-metallic inclusions, changes in the morphology of the latter, and protection of molten metal from secondary oxidation during casting and melt modification [11 - 15] allow to produce steel products with high-level mechanical and service properties.

Due to active control of solidification and crystallization, since it is when crystals start to form and grow, a primary structure is formed, the amount, shape and location of non-metallic inclusions, and hence the density and mechanical properties of the cast metal, are determined. Experience has show
t that the larger the casting is, the more developed its structural and physicochemical inhomogeneities and the accompanying defects are. Productionof large steel castings or ingots uniform in structure, density and properties is complicated by the fact that their homogeneity influenced by the formation conditions and other factors. It is also known that microcrystalline steels and alloys have a number of advantages in comparison with macrocrystalline steels and alloys [2, 9, 12 - 18].

In papers [12 - 15], numerous investigations of the change in mechanical properties along the cross-section of carbon and alloyed steel castings and ingots are presented. As the distance from the surface of the casting grows, the relative contraction decreases markedly with a decrease in the solidification rate. In the central zones, this value is reduced by 50-70% or more, with ultimate tensile strength reduced by 30%. The properties of Cr-Ni-Mo steel are degraded greater than those of carbon
Steel ingots and castings, due to the greater susceptibility of alloyed steels to segregation and the development of structural heterogeneity, which in turn are related to the solidification rate.

Despite the great success in foundry production, the problem of improving the quality of cast sections dense and homogeneous throughout their volume is not completely solved and remains relevant for modern domestic engineering. This is especially important due to the development of special branches of engineering, where castings of such steels are increasingly used.

To obtain high-quality castings, the secondary action of external cooling on a crystallizing casting is increasingly used [18, 19]. In papers [17 - 22], a positive effect of inoculators on the mechanical and service properties of castings was shown.

2. Methods of research
During the formation, the test castings were subjected to an external (variant 1) and complex action (variant 2) on crystallization and solidification. The external action was that the castings were produced in thin-walled metal-shell molds (TMSM) with external forced water-air cooling of the surface and a height-differentiated refractory layer. In the complex action, the casting was produced under the same conditions, while simultaneously injecting 2% of dispersed solid particles into the molten metal jet, i.e. the suspension pouring was performed (TMSM SP). For comparison, the same castings were produced conventionally using bulk liquid-glass molds, i.e. without any action on the forming cast (variant 3 – the reference).

Preliminary laboratory tests showed the following: intense cooling of the molten metal of a casting in a metal shell mold promotes progressive crystallization, increases the density and improves mechanical properties of the metal. However, the action of external cooling during solidification especially of thick-walled castings is limited, since with an increase in the thickness of the solidifying crust its thermal resistance starts limiting heat transfer from the crystallizing molten metal.

Another way of controlling the structure and properties of the cast metal is the suspension pouring, which, as an internal action, allows to influence the crystallizing metal throughout its entire volume, reducing macro- and microheterogeneity, shrinkage porosity, hot cracking and formation of other casting defects that affect the mechanical and service properties of castings [10].

It is noted that castings produced for these variants have high mechanical properties, in particular ductility and toughness. However, the issues of the effect of the technologies of interest on the quality of large alloyed steel castings have not been virtually investigated.

The suspension pouring involves injection of dispersed iron powder PZhV 1.450.26 (GOST 9849-86) in the amount of 1.5% of the casting mass with the addition of 0.1% silicocalcium SK-25 into the molten metal jet using a vortex extension.

After pouring molten steel into a thin-walled mold, the external surface of a metal casing (flask), except for the riser, was cooled with a water-air mixture using a special device.

For products of the investigated steel, the specifications provide for investigation of the microstructure and properties at normal (+20°C, GOST 1497-84) and increased (+350°C, GOST 9651-84) temperatures.

The casting is a part of a hollow cylinder with a branch pipe. The weight of the casting 750 kg, height – 800 mm, wall thickness – 150 - 170 mm.

For a full investigation of the quality of the metal, the longitudinal templates and specimens were cut out from the sub-risers of the casting throughout their height (Fig. 1). The structure (Fig. 2) and the mechanical properties were investigated using the templates.

3. Results of research
Analysis of the macrostructure showed that the reference casting produced in the bulk mold has the coarse-grained structure and shrinkage porosity in the central part of the casting. When the casting solidifies in the TMSM under forced cooling, the macrostructure is significantly different – a dense zone of columnar crystals is observed, which indicates an increase in the temperature gradient across
the section of the casting. In the complex action on the solidifying casting, the zone of columnar crystals and small equiaxed crystals becomes considerably smaller, the structure of the casting is denser and more homogeneous.

The microstructure of investigated steel is sorbitized bainite (Fig. 1). Such a structure is observed in all castings irrespective of the solidification conditions. However, in the test castings, the microstructure is more dispersed, compared with the reference metal. This is particularly noticeable when examining the subgrain structure of the central zones of castings.

**Figure.** 1. Casting macrostructure: - a volume form; – a metalshell form with compulsory cooling; c - complex influence

**Figure.** 2. Microstructure of the studied steel (x100): - a volume form; – a metalshell form with compulsory cooling; c - complex influence

Fig. 2 - 4 shows the substructure of the metal castings produced under different crystallization conditions. The reference metal has the largest subgrains. Increasing the crystallization rate by forced external cooling results in structure refinement. After a complex action on the solidifying molten metal, the smallest and the most homogeneous in the cross-section subgrains are observed, i.e. the size of the subgrains is in direct relationship to the solidification conditions and the specimen cutting location (the periphery – the center).

**Figure.** 3. Casting substructure (volume form):

a – periphery; b – center

**Figure.** 4. Casting substructure (metalshell form with external compulsory cooling):

a – periphery; b – center
Figure 5. Casting substructure (complex influence) 

Table 1 and 2 show the mechanical properties of the metal in the cross-section and throughout the height of the casting at various test temperatures.

| Casting formation conditions | Direction of cutting of samples | Level of cutting of samples | \( \sigma_\tau \), MPa | \( \sigma_n \), MPa | \( \delta \), % | \( \psi \), % | KCU, MJ/m² |
|-----------------------------|---------------------------------|-----------------------------|---------------------|----------------|------------|------------|------------|
| Control casting             | Tangential                      | Top                         | 683                 | 750            | 13.6       | 59.7       | 1.48       |
|                             |                                 |                             | 630                 | 686            | 10.5       | 41.3       | 1.13       |
|                             | Tangential                      | Bottom                      | 695                 | 750            | 14.5       | 62.0       | 1.65       |
|                             |                                 |                             | 673                 | 748            | 14.1       | 58.0       | 1.51       |
|                             | Longitudinal                    | Top                         | 698                 | 756            | 13.9       | 57.7       | 1.55       |
|                             | Longitudinal                    | Bottom                      | 701                 | 776            | 15.3       | 65.0       | 1.70       |
| Metalshell form with        | Tangential                      | Top                         | 767                 | 807            | 17.5       | 67.7       | 1.66       |
| forced cooling              |                                 |                             | 740                 | 775            | 17.5       | 64.3       | 1.48       |
|                             | Tangential                      | Bottom                      | 767                 | 827            | 18.0       | 68.7       | 1.70       |
|                             |                                 |                             | 753                 | 803            | 17.3       | 67.0       | 1.68       |
|                             | Longitudinal                    | Top                         | 763                 | 827            | 17.8       | 68.7       | 1.75       |
|                             | Longitudinal                    | Bottom                      | 777                 | 833            | 18.2       | 68.7       | 1.80       |
| Complex influence           | Tangential                      | Top                         | 720                 | 770            | 16.8       | 69.0       | 1.88       |
|                             |                                 |                             | 713                 | 755            | 18.5       | 66.0       | 1.80       |
|                             | Tangential                      | Bottom                      | 730                 | 780            | 17.8       | 69.7       | 2.03       |
|                             |                                 |                             | 723                 | 767            | 17.5       | 68.0       | 1.88       |
|                             | Longitudinal                    | Top                         | 737                 | 783            | 18.3       | 69.7       | 1.91       |
|                             | Longitudinal                    | Bottom                      | 747                 | 793            | 18.8       | 71.3       | 2.02       |

Note: In numerator mechanical properties of the samples which are cut out from a peripheral zone in a denominator – from the center of casting are specified.

The data of mechanical properties provided in the table are arithmetic-mean is exemplary.

Analyzing them, we can note the following: in the reference casting, the mechanical properties essentially depend on the place the specimens were cut from, both in height and in cross-section. If the mechanical properties are adequate at the lower level and in the peripheral zones of the casting, then in the central zones, especially at the upper level, it is not possible to obtain values satisfying the specifications, and a quite noticeable anisotropy of the properties is observed. When the casting solidifies in the bulk mold, ductility and toughness change most significantly. Thus, for example, if the strength in the cross-section of the casting vary from 750 MPa at the periphery to 686 MPa in the...
center of the casting, then the relative elongation varies from 13.6% to 10.5%, and the relative constriction – 59.7% to 41.3%, respectively. Toughness also drops from 1.48 to 1.13 MJ/m².

Thus, in the cross-section, the strength of the reference casting drops by about 9%, the elongation and contraction – by 23% and 29%, respectively, and toughness – by 30%. In the central zones, a much greater difference in the mechanical properties is noticeable throughout the height: $\sigma_s$ decreases by 19%, $\delta$ - by 26%, the relative constriction – by 30%, and toughness – by 32%.

**Table 2.** Mechanical properties of the samples which are cut out from pilot and control castings (testing temperature + 350°C) *

| Casting formation conditions | Direction of cutting of samples | Level of cutting of samples | $\sigma_T$, MPa | $\sigma_s$, MPa | $\delta$, % | $\psi$, % | KCU, MDj/m² |
|-----------------------------|---------------------------------|-----------------------------|-----------------|---------------|----------|--------|----------|
| Control casting             | Tangential                      | Top                          | 494             | 555           | 11.7     | 50.5   | 1.30     |
|                            | Tangential                      | Bottom                       | 589             | 617           | 15.0     | 62.3   | 1.65     |
|                            | Longitudinal                    | Top                          | 516             | 542           | 12.0     | 52.5   | 1.40     |
|                            | Longitudinal                    | Bottom                       | 587             | 633           | 15.6     | 67.3   | 1.74     |
| Metalshell form with forced cooling | Tangential                      | Top                          | 640             | 679           | 18.0     | 68.6   | 1.83     |
|                            | Tangential                      | Bottom                       | 641             | 685           | 18.5     | 69.5   | 1.78     |
|                            | Longitudinal                    | Top                          | 645             | 688           | 18.0     | 67.5   | 1.87     |
|                            | Longitudinal                    | Bottom                       | 683             | 698           | 19.2     | 68.4   | 1.85     |
| Complex influence          | Tangential                      | Top                          | 619             | 650           | 17.7     | 72.7   | 2.01     |
|                            | Tangential                      | Bottom                       | 638             | 668           | 18.7     | 70.7   | 2.14     |
|                            | Longitudinal                    | Top                          | 638             | 661           | 18.5     | 71.6   | 2.05     |
|                            | Longitudinal                    | Bottom                       | 641             | 673           | 19.7     | 73.4   | 2.17     |

The casting produced in the metal-shell-mold with forced cooling does not show a noticeable difference in the mechanical properties both throughout the height and in the cross section of the casting. At the same time, strength is an average of 100 MPa higher than that of the reference casting, while maintaining high ductility and toughness.

But the casting produced in the metal-shell mold with a complex action on the solidifying metal by forced cooling and adding inoculators has the best combination of mechanical properties. In this case, highest ductility and toughness are obtained, and the mechanical properties are generally more uniform in the cross section and throughout the height of the casting.

Comparison of the mechanical properties of the reference and test castings produced with the addition of inoculators shows that the most significant difference is observed in the central zones. Thus, ductility in these zones of castings changes by 35-45%, and toughness – by 35-40%.

A similar dependence of a change in the mechanical properties obtained for different variants is also observed in the test at +350°C (Table 2). The mechanical properties in the test castings are much better than in the reference castings. The anisotropy of the properties in the cross-section and throughout the height is much lower and is more uniform throughout the volume of the casting metal.

4. Summary

As a result of the investigations conducted, it was established that the investigated variants of producing the test castings using the external and complex action on the forming casting are very promising and allow to produce castings with better and homogeneous mechanical properties.

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