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**RESEARCH PAPER**

# INVESTIGATION OF THE EFFECT OF INOCULATORS ON THE STRUCTURE OF CAST STEEL BLANKS

*Vitaliy Kulikov[1], Akzhan Kordasheva[1], Kvon Svetlana[1], Aristotel Issagulov[1], Pavel Kovalev[2]*

[1]Karaganda Technical University named after Abilkas Saginov, Department of Nanotechnology and Metallurgy, Nursultan Nazarbayev Avenue No. 56, 100003, Karaganda, Kazakhstan

[2]NRU Peter the Great St. Petersburg Polytechnic University, Institute of Mechanical Engineering, Materials and Transport, Polytechnic street No. 29B, 1940216 Saint Petersburg, Russia

*Corresponding author: akzhankordashs@gmail.com , tel.: +77000909012, Department Department of Nanotechnology and Metallurgy, Karaganda Technical University named after Abilkas Saginov, Nursultan Nazarbayev Avenue No. 56, 100003, Karaganda, Kazakhstan

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**ABSTRACT**

Despite the active development of modern production methods, producing parts by casting remains one of the most common and economically profitable. At the same time, modern production places high demands on the quality of cast parts. It is possible to ensure high-quality castings by forming a homogeneous dense ingot structure (casting). In turn, these indicators can be achieved by regulating the rate of solidification of the casting and the distribution of alloying elements inside it throughout the volume. One of the promising ways to control the casting structure is casting according to gasified models using inoculators (suspension casting). Using ferroalloy particles in styrofoam models simultaneously with inoculators (refrigerators) can adjust the number of crystallization centres and the distribution of alloying elements. One of the important indicators in the production of castings by suspension casting is the absence of defects, chemical heterogeneity, porosity and mechanical properties. These indicators can be obtained using inoculators used in suspension casting. In suspension casting, from the point of view of creating waste-free technologies, using various metal wastes during casting is promising chips, slag components, trimmings, die-cuts, etc. This project will introduce inoculators and use foundry waste, providing the required service and technological properties.

**Keywords:** alloyed castings, suspension casting, gasified casting method, structure, inoculators, ferroalloys.

## INTRODUCTION

One of the most common ways to obtain high-quality castings is to manufacture them by casting them into gasified molds. This method will be successfully applied at several machine-building plants in the Karaganda region. This allows us to produce castings with various products for various industries – mining, construction, energy, etc. The resulting castings have high dimensional accuracy, low roughness, and a low percentage of defects. At the same time, the management of the structure and, consequently, the properties of the castings obtained has certain difficulties [1-2]. The ability to produce castings with a fine-grained structure (high strength) and a homogeneous composition over the entire volume of cast blanks allows the control of the temperature regime of castings [3], for example, when combining suspension casting and casting according to gasified models. A polystyrene model is used directly to insert inoculators into the melt. Previously, a complex composition of the model [4-5] was proposed, combining foundry and construction polystyrene. It was determined that along with the reduction in the cost of such a model, the depth of carburization of the surface of the castings decreases. This article presents the results of studies conducted on the effect of inoculators on the properties and structure of castings.

Modern production places high demands on the quality of cast parts. The quality of castings can be ensured by forming a homogeneous dense structure. In turn, these indicators can be obtained by adjusting the hardening rate of the ingot and the distribution of alloying elements inside it. One promising method for controlling the casting structure is casting gasified models using inoculators. With the simultaneous use of ferroalloys, the number of crystallization centers and the distribution of alloying elements can be adjusted.

From the point of view of creating waste-free technologies in slurry casting, using various metal waste in casting is promising slag-forming sawdust, cutting, etc. In other words, a metal suspension is introduced, not a liquid overheated metal, as in regular casting. In this case, the dispersion medium is a liquid metal, and the dispersion phase is solid crystals suspended in a liquid melt or specially introduced small particles [6-7].

## MATERIAL AND METHODS

The research was conducted at LLP "KMP named after Parkhomenko" (Karaganda). The castings "Flange", made of 35L steel, were considered. Crushed scrap, metal inclusions from slag, etc. were used as inoculators (**Fig.1.**)

**Fig.1** Metal droplets extracted from slag used for inoculators

Metal splashes were crushed in an Emax mill and then dispersed into fractions on a Retch analytical sieving machine (**Fig. 2**).


*a* *b*

**Fig.2** Equipment used for the preparation of inoculators:
a – Emax mill; b – Retch analytical screening machine

The resulting inoculators were mixed in different proportions together with granules of construction and foundry polystyrene (Table 1).

**Table 1** Formulations used in research

| № | The content of building polystyrene, % | The content of foundry polystyrene, % | Weight of inoculators, g | Fractional composition, mm |
|---|---|---|---|---|
| 1 | 40 | 60 | 20 | 0,1-0,4 |
| 2 | 40 | 60 | 50 | 0,1-0,4 |
| 3 | 40 | 60 | 80 | 0,1-0,4 |
| 4 | 40 | 60 | 20 | 0,5-0,8 |
| 5 | 40 | 60 | 50 | 0,5-0,8 |
| 6 | 40 | 60 | 80 | 0,5-0,8 |
| 7 | 50 | 50 | 20 | 0,1-0,4 |
| 8 | 50 | 50 | 50 | 0,1-0,4 |
| 9 | 50 | 50 | 80 | 0,1-0,4 |
| 10 | 50 | 50 | 20 | 0,5-0,8 |
| 11 | 50 | 50 | 50 | 0,5-0,8 |
| 12 | 50 | 50 | 80 | 0,5-0,8 |

The supplier was connected to the samples applied with FRDA paint. The models were air-dried at room temperature for three days. The resulting samples were further poured into a rectangular mold with sand (**Fig. 3**), and then smelting was carried out. The mold was vacuumed with a vacuum pump to remove gasification products [8].

**Fig. 3** Ready-made samples for casting

Next, the casting model "Flange" (weight 4.2 kg) was obtained in the mold using the traditional method. **Fig. 4** shows the models in the context of inoculators**.**

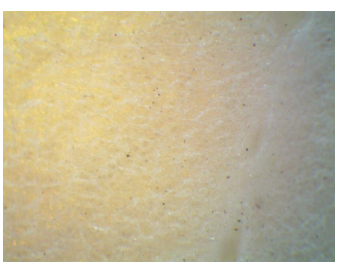

**Fig. 4** Section of the model with inoculators, ×100

The comparative microstructure of the samples is shown in **Fig. 5.**

The maximum effect of suspension casting from the point of view of grain grinding is achieved if two mandatory conditions are met. First, the seed (dispersed particle) must melt. Secondly, the melting should end at a temperature close to the crystallization temperature of the alloy [9].

It is assumed that activated impurity particles are released from their mass during the melting of the seeds (dispersed particles), which can become effective crystallization centers. In this case, if the seed melting ends at the temperature of the surrounding melt significantly above the temperature of the alloy liquidus, then the effect of artificial crystallization and grinding of the structure is not observed since the decontamination of impurity particles occurs.

Since the liquid metal overheating temperature decreases during suspension filling, it is interesting to know the amount of reduced overheating when entering a given number of injected micro-coolers or the metal temperature during suspension filling [10].

Equally important is determining the optimal number of micro-coolers, which depends on the following factors: the thickness of the casting wall and its mass, the temperature of the poured metal, the duration of pouring, the size of the micro-coolers. Since the temperature of overheating of the liquid metal decreases during suspension filling, from the point of view of thermal effect, the optimal number of micro-coolers should be considered, which ensures the removal of overheating to the liquidus temperature or slightly below this temperature [11].

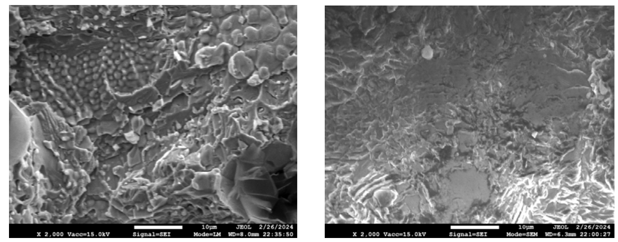

**Fig. 5** Microstructure of 35L steel, ×2000: a – using 20 g inoculators; b – using 50 g inoculators

## RESULTS AND DISCUSSION

The analysis of microstructures determined that using 50 g of inoculators in the proportion of foundry polystyrene to construction 60:40 makes it possible to obtain fine-grained, relatively homogeneous structure castings. Using 20 g reduces the number of crystallization centers and, consequently, increases the grain size. The increased content of inoculators negatively affects the crystallization rate. At the same time, local supercooling occurs, which does not allow the complete release of gases from the metal melt and leads to increased porosity. At the same time, the fractions of inoculators used did not significantly affect the structure of the castings. Therefore, for "Flange" castings, the use of inoculators with fractions from 0.1 to 0.8 mm (the studied range) is satisfactory [12].

The uniformity of the distribution of elements in the structure of castings was considered. **Fig. 6** shows a map of the distribution of components of the sample obtained using inoculators (sample 5). **Fig. 7** shows a similar map for sample 1.

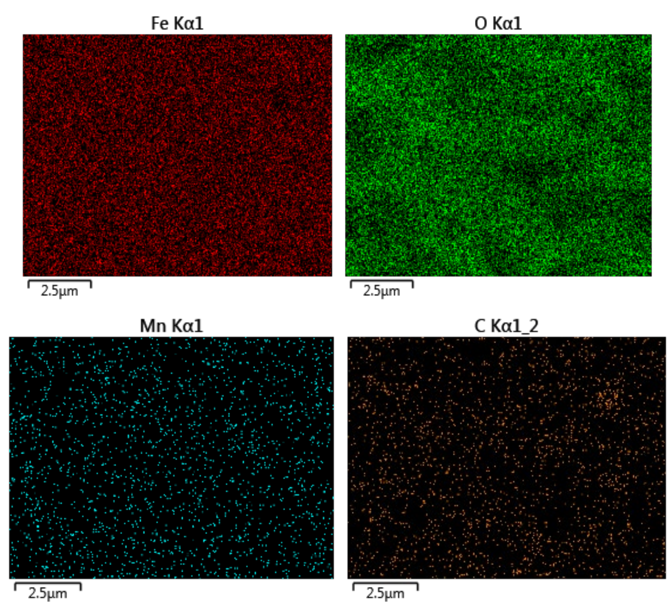


**Fig. 6** Distribution map of sample 5 elements

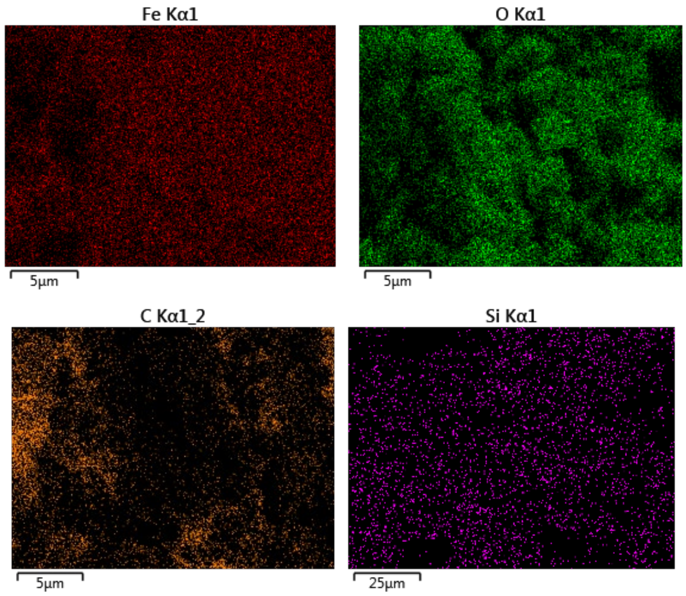


**Fig. 7** Distribution map of sample 5 elements

The melt flow pushes inoculators of a smaller fraction of 100-400 microns out from their locations before melting into the metal, thereby creating liquation sites [13-14].

When using inoculators larger than 500 microns, the melt flow significantly lessens their shape when burning polystyrene, helping to obtain a relatively uniform distribution pattern of the main elements [15-16].

The influence of the fraction and mass of inoculators on the mechanical properties was also revealed. Hardness was measured on a Wilson VH-1150 Macrovickers hardness tester (USA), and compressive strength was evaluated on an Instron 5982 tensile and compressive strength machine (UK). The results of the studies are presented in **Table 2** [17].

**Table 2** Results of the study of mechanical properties

| № | Hardness HB, un | Ultimate strength $\sigma_b$, MPa |
|---|---|---|
| 1 | 154 | 437 |
| 2 | 159 | 446 |
| 3 | 162 | 449 |
| 4 | 163 | 454 |
| 5 | 171 | 462 |
| 6 | 172 | 462 |
| 7 | 151 | 433 |
| 8 | 155 | 439 |
| 9 | 158 | 441 |
| 10 | 164 | 452 |
| 11 | 168 | 456 |
| 12 | 167 | 457 |

Determination of the wear resistance of modified surfaces by ball Wear was carried out on the tool "Calotest, CSM Instruments". Wear the treated surface of the prototypes with a rotating carbide ball with a diameter of 25 mm for 5 minutes with a spindle speed of 400 rpm. The test was carried out by contact when there were 0.5–1 micron abrasive diamond particles in the area where the suspension was. Wear resistance was characterised by the diameter of the trace left by the ball during friction. The results of the study of wear resistance are shown on **Fig. 8**.

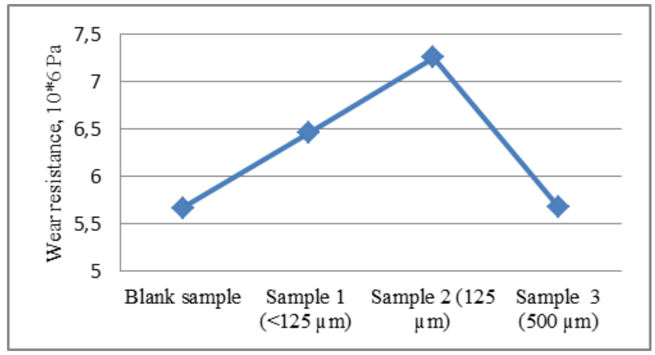


**Fig. 8** Results of the wear resistance study

The study of the effect of the degree of dispersion of ferrochrome on its dissolution in a melt was carried out using an X-ray fluorescent analyzer Niton XL. The results are presented in **Table 3**.

**Table 3** The amount of chromium in the composition of different places in the volume of samples

| Sample | Chromium content, % | | | |
|---|---|---|---|---|
| | On the surface (top) | In the middle | On the side | On the surface (bottom) |
| **Blank sample** | - | - | - | - |
| **Sample 1 (<125 µm)** | 1 | 2 | 1 | 1 |
| **Sample 2 (125 µm)** | 2 | 3 | 2 | 2 |
| **Sample 3 (500 µm)** | 1 | 6 | 1 | 2 |

The reason for the increased wear resistance is the use of grafting tools as a crystallization centre, which leads to the crushing of grain and improved mechanical properties. It should be noted that the fraction <125 microns dissolves immediately without causing local cooling. Some inoculators with a fraction of 500 microns or more do not have time to completely dissolve in the body of the ingot of the size used, which causes internal stresses in the future. Therefore, for small ingots (used in research), 125-500 microns fraction particles are the most optimal.

During suspension casting, spraying and cooling the metal jet with a gas stream before pouring it into the mould makes it possible to obtain ingots of the correct shape, with a defect-free surface, and dense macro- and microstructure, without liquation of elements [18-19].

As can be seen from Table 3, the distribution of ferrochrome in sample 2 is uniform. In a sample containing inoculators of 500 microns, it did not have time to melt at all and spread uniformly. The powder-like inoculators containing up to 125 microns were completely burned [20].

## CONCLUSION

Thus, the studies have confirmed the practicality of using inoculators directly in polystyrene complex models. It was determined that to improve the quality (purity and grain size) of metal for castings of "Flange," it is advisable to use inoculators with a size of 0.5-0.8 mm and a weight of 50 g. Such technological modes of manufacturing the studied castings make it possible to provide a homogeneous defect-free structure for them. The fraction of inoculators less than 500 microns has a slight effect on the structure and properties of the alloy since part of the inoculator floats to the surface of the casting, and part shifts from the dislocation sites, violating the uniformity of the chemical composition. Using the number of inoculators in the volume of 1-1.5% of the casting weight is the most promising for the Flange casting. A smaller amount has a negligible effect, and a larger one may have a slight impact and, in the future, negatively, since in this case, not all inoculators will melt and, therefore, will remain in the casting in the form of inclusions with grain boundaries, which will cause mechanical stresses and reduce the structural characteristics of such a casting.

Mechanical studies have shown that adding inoculators to molds when casting models whose properties are to be gasified can reduce the porosity of the metal, which eliminates anisotropy through the homogeneity of the melt and increases the hardness, wear resistance and other mechanical properties of the steel under study.

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