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RESEARCH PAPER

Use of inoculators to improve the quality of castings in the lost foam casting process

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ABSTRACT

The growth dynamics of global steel production indicate market saturation. The slowdown in steel production growth is offset by improvements in steel quality and reduced product consumption. Further improvement in steel quality is not about correcting the composition, but about increasing purity and improving the structure. An increase in operational properties is possible provided that harmful impurities (oxygen, hydrogen, sulfur, phosphorus, non-ferrous metals, etc.) are effectively removed from the metal, and the remaining emissions are controlled to reduce their negative impact on the quality of metal products. And this is impossible without the development and industrial implementation of innovative materials and high technologies aimed at improving the quality and competitiveness of steel and alloys for foundry production, achieving the highest productivity values, reducing production costs, implementing energy- and resource-saving and environmentally friendly technologies, and significantly exceeding the efficiency of existing traditional materials with significantly lower consumption. Modern foreign studies and publications highlight several advanced methods for producing alloy castings in foundries. Special attention is paid to gasified model casting (LGM), which enables the production of high-strength products with precise geometry and improved surface finish. For example, in Fisher et al. (2024), modern non-destructive testing methods are discussed and effectively used to assess the quality of castings produced by these methods.

Keywords: alloyed castings, suspension casting, gasified casting method, structure, inoculators, ferroalloys, foundry-grade polystyrene.

INTRODUCTION

The main challenges in producing castings using the Lost Foam Casting (LFC) process are [1–2]:
– carburization of the surface layer of steel castings due to the burnout of the polystyrene pattern;
– the high cost of foundry-grade polystyrene used as the pattern material. This significantly increases the final casting cost, limiting the widespread adoption of the LFC process in production.

In global practice, construction-grade polystyrene beads are not typically used for model production in LFC. However, earlier studies have demonstrated the possibility of using them as a component of the pattern material [3–4]

At the same time, controlling the structure—and, consequently, the properties—of the resulting castings presents certain difficulties [5–6]. The ability to obtain castings with a fine-grained structure (high strength) and a homogeneous composition throughout the volume of the casting blanks is made possible by regulating the thermal regime of casting [7], for example, by combining suspension casting with the lost foam casting method. Inoculants are introduced directly into the melt via the polystyrene model.

MATERIAL AND METHODS

Taking into account the materials currently used at foundry enterprises in the Karaganda region, the research utilized foundry-grade polystyrene of PSV-L1 and PSV-L2 grades. As an additive to the composite model material, construction-grade expanded polystyrene (EPS) of PPS-10 and PPS-20 grades was selected, as it is the most common and readily available in the region.

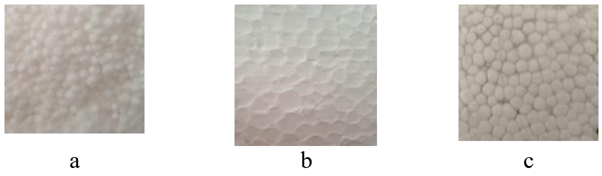
Experimental studies were carried out at LLP “KMZ named after Parkhomenko” (Karaganda city). The models were made from a mixture of foundry polystyrene granules with particle sizes of 0.7–1.0 mm (as supplied) and construction-grade EPS granules with sizes up to 3.0 mm (typical for this type), in proportions ranging from 10% to 50%. According to the factory’s standard technology, the polystyrene was pre-expanded using steam, dried, and then injected into a mold. The mold was held in an autoclave until the polystyrene beads fused together [8–9].

The “cover” casting made of 35L steel was also considered in this research. Inoculants used included crushed scrap metal, metallic inclusions extracted from slag, and similar materials. To reduce production costs, a combination of construction-grade (Fig. 1a) and foundry-grade polystyrene (Fig. 1b) is proposed as the model material [10-11]. Accordingly, the composite model (**Fig. 1c**) will comprise both coarse and fine grains, thereby increasing its density. As is well known, increased density reduces carburization in the casting's surface layer during burnout. The compositions of polystyrene models used in the research are shown in **Table 1**.

Table 1 Composition of polystyrene models used in the experiments

Sample No.	Foundry Polystyrene PSV-1L, %	Construction Polystyrene PPS-20, %
1	–	100
2	100	–
3	50	50
4	60	40
5	70	30
6	80	20
7	90	10

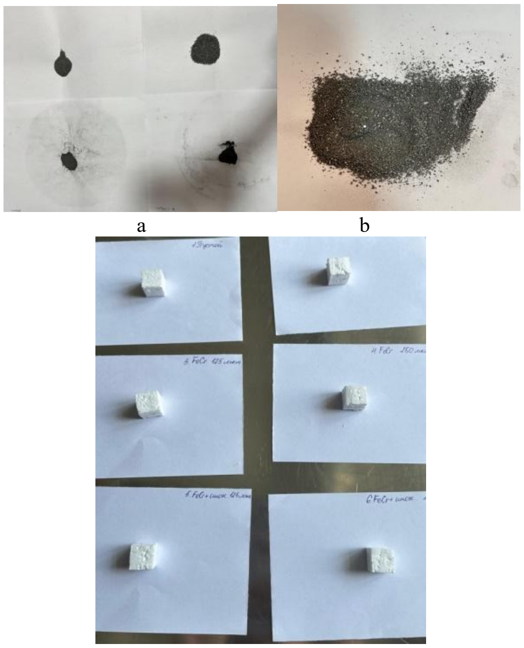
Quartz sands of grades 1K02 and 1K016 were used in the research.



a – foundry-grade polystyrene (grain size 0.3–0.6 mm); b – construction-grade polystyrene (3–4 mm); c – composite polystyrene (1–1.5 mm)

Fig.1 Structure of polystyrene foams of various grades

To make the samples (**Fig. 2**), models made of expanded polystyrene filled with inoculants of various fractions were used: an empty sample (reference model for comparison), a model containing 125 microns inoculators (sample 2), and a model containing ferrochrome and 125 microns inoculators (sample 3). The model samples were cut out with dimensions of 20×20 mm.


a b

c

Fig. 2 Prepared models for the further stage of the study
a – inoculators ground in different fractions; b – ground FeCr; c – experienced models made of polystyrene foam

For the production of Lid casting models, 60% of foundry polystyrene, with small fractions of 0.3-0.9 mm, and 40% of recycled polystyrene foam, 0.6 mm fraction, were used, both recycled from construction polystyrene waste. Polystyrene together with ferro-alloys with a fraction of 0.5-1.5 mm in a volume of 3-5% (in addition). It was previously suspended in a steam bath and dried for 2 hours at a temperature of 45 ° C. Suspended polystyrene was blown into the molds, after which the molds were placed in an autoclave and held until the polystyrene granules were sintered. The models were then cooled [12-13].

RESULTS AND DISCUSSION

Work was carried out to produce test samples to study their properties. The samples were cut out, and the sanding and polishing work was performed on the Saphir560 machine (**Fig. 3**)


a b c

Fig.3 Prepared models for the further stage of the study
a – an empty sample (reference model for comparison); b – a model containing 125 microns inoculators (sample 2); c – a model containing ferrochrome and 125 microns inoculators (sample 3)

The actual density of expanded polystyrene for the PPS-10 brand is 15 kg/m^3, for the PPS-20 brand it is 25 kg/m^3, etc. Obviously, the higher the density of expanded polystyrene, the lower its porosity, and the worse its ability to gorenje.
In this regard, the porous structures of the brands PPS-10, PPS-20, and PPS-30, which are the most common and used in LGM, were studied. Table 2 shows the main properties of the studied polystyrene grades (Table 2).

Table 2 Main properties of the studied polystyrene grades

Stamp	Density, kg/m^3	Ultimate strength, MPa	Combustion time at a temperature of 1200 °C, sec
PPS-10	15	0,05	3,7
PPS-20	25	0,1	4,0
PPS-30	35	0,16	5,2

Based on the obtained characteristics, polystyrene grades PPS-10 and PPS-20 can be equally recommended for the manufacture of models, since their porous structures and, consequently, the burnout process are almost identical [14].
The latter assumption has been confirmed experimentally. Identical-sized pieces of polystyrene grades PPS-10 and PPS-20 were subjected to tests for combustion time. The gorenje process was carried out in an atmospheric, confined space that closely approximates real conditions. Ignition occurred due to contact with the melt (at 1620 °C). The times to complete combustion were 4.5 and 5.8 seconds, respectively.
Table 3 shows the results of a study of the mechanical properties of castings obtained using experimental polystyrene models [15-16].

Table 3 Mechanical properties of the prototypes

Sample number	Hardness, HB	Tensile strength, MPa
1	248	546
2	277	559
3	266	573

As shown above, the use of inoculators in polystyrene models increases the strength and hardness of the castings. The addition of ferrochrome further enhances the effect.

Investigation of the influence of technological parameters of casting on the properties of castings

The process of filling the "Lid" part with 35L steel by casting according to gasified models using the proposed technology was considered. The chemical composition of the alloy is shown in **Table 4**.

Table 4 Chemical composition 35L

C	Si	Mn	Ni	S	P	Cr	Cu	Fe
0,32-0,4	,52	0,4-0,9	up to 0,3	up to 0,045	up to 0,04	up to 0,3	up to 0,3	~97

The weight of the "Lid" casting is 25 kg. Taking into account the gate system, the mass of the melt per mold is 27.5 kg. The main technological modes of casting molds are the alloy temperature and the casting speed.
In LGM, the casting has a dense, solid structure throughout its volume. Two components of the casting production process were considered: filling the casting mould and its solidification. As a result of the simulation, refrigerators were added to the Running Wheel part and the gate system was changed, which created directional crystallization and, as a result, defects in the casting were eliminated [17].
In addition, slag on the metal surface from the furnace significantly reduces the cooling rate. Direct measurements have shown that the temperature distributions in large and small buckets are uniform immediately after release. This alignment results from jet-induced convection during filling. However, after a while, convection slows sharply, and vertical temperature differences develop in the metal, reaching their maximum with sufficiently large steel masses [18].
The influence of casting speed and temperature on roughness and fit was evaluated, as these indicators (along with the absence of internal defects) are the primary indicators of casting quality (**Tables 5 and 6**).

Table 5 Influence of the casting temperature on the roughness and fit of the casting at a casting speed of 0.5 kg/sec

Filling temperature, °C	**Roughness, microns**	**Temperature range, g/cm^2**
1520	84	0,18
1540	79	0,19
1560	77	0,22
1580	83	0,26
1600	91	0,27

An elevated pouring temperature promotes deeper melt penetration into the pores between sand particles, resulting in increased surface roughness. Additionally, a higher temperature leads to greater heat transfer to the mold material.

Table 6 The effect of casting time on the roughness and fit of the casting at a temperature of 1550 ° C.

Filling time, seconds	**Roughness, microns**	**Temperature range, g/cm^2**
20	97	0,19
30	74	0,18
40	86	0,17
50	94	0,15

Obviously, the most optimal filling speed is about 0.5 kg/sec. The high casting speed results in excessive accumulation of polystyrene combustion products in the casting solidification zone, thereby degrading the casting surface purity. The slow casting speed leads to cooling of the casting and the formation of scale, both of which affect the roughness. The filling speed does not fundamentally affect the burn size [19].

One of the main representatives of the nomenclature of castings manufactured at KMZ LLP. Parkhomenko" is a part of the "Running wheel".

The proposed manufacturing technology for the "Running Wheel" part enabled an increase in metal consumption to 95% by reducing casting weight, saving 20-25% of energy, shortening process time, and significantly reducing product defects to 0.8%.

Optimal technological modes have been experimentally determined for the Lid casting: the filling speed is 0.5 kg/sec, and the filling temperature is 1540-1560 °C. The Lid casting models were made from the compositions listed in the table (**Fig. 4**).

Fig.4. The "Lid" casting model

After casting, samples were cut from the castings with a disk cutter and used to prepare grinders for microstructural evaluation. Quantitative and qualitative assessments of microstructures were conducted using the Thixomet Pro program (Russia).

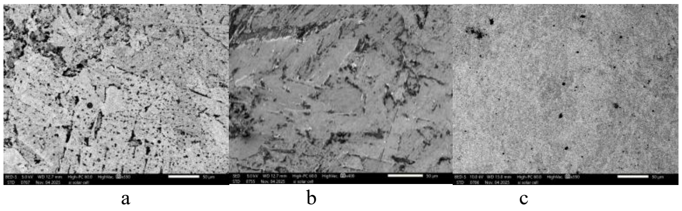

a b c

Fig. 5 Microstructure of samples on a JEOL JCM-7000 microscope
a – an empty sample (reference model for comparison); b – a model containing 125 microns inoculators (sample 2); c – a model containing ferrochrome and 125 microns inoculators (sample 3)

Table 7 Distance between secondary branches of dendrites

	Number of measurements	Total length, µm	Minimum length, µm	Maximum length, µm	Medium length, µm
An empty sampl e(a)	20	865	20,8	39,8	29,4
Sample2 (b)	20	874	16,8	54	30,1
Sample 3 (c)	20	870	22,8	37,8	28,8

Based on the presented data, the addition of inoculants, and especially ferrochrome, slightly alters the average spacing between secondary dendrite arms: 29.4 µm for the reference sample, 30.1 µm for the sample with inoculants, and 28.8 µm for the sample with inoculants and ferrochrome. This indicates a slight densification of the dendritic structure with the addition of ferrochrome, which corresponds to the observed increase in hardness and strength of the castings.

CONCLUSION

The study demonstrated that composite foam patterns produced from mixtures of foundry-grade and construction-grade polystyrene can be effectively used in the Lost Foam Casting process, as PPS-10 and PPS-20 exhibit nearly identical porosity and burnout characteristics while significantly reducing pattern costs. Increased pattern density helps limit carburization of steel castings by ensuring a more controlled burnout. Introducing inoculants directly into the foam pattern proved to be an efficient method of in-mold steel modification, and mechanical testing confirmed notable improvements in material properties. In particular, the addition of ferrochrome, together with fine inoculant fractions, resulted in the greatest enhancement, producing a measurable increase in hardness and tensile strength due to the formation of a finer, more uniform grain structure. Optimal casting parameters—namely, a filling rate of 0.5 kg/s and a pouring temperature of 1540–1560 °C—were established, ensuring stable mold filling, reduced roughness and defect-free castings. The implementation of the developed technology in the production of parts such as the "Lid" and "Running Wheel" significantly improved efficiency, increasing metal yield to 95%, lowering energy consumption by 20–25%, reducing process time and decreasing defect rates to 0.8%. Overall, the integrated approach combining composite foam patterns with in-pattern inoculation enhances mechanical performance—especially hardness—while improving casting quality and reducing production costs.

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