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IN-MOULD GRAPHITIZING, SPHEROIDIZING, AND CARBIDE STABILIZING INOCULATION OF CAST IRON MELT

The results of investigations on optimization of granulometric composition of additives for in-mould graphitizing, carbide stabilizing, and spheroidizing inoculation of cast-iron melt are reviewed and analysed. As revealed, the maximum absorption of graphitizing ferrosilicon inoculant FeSi75 and spheroidizing inoculant FeSiMg7 during treatment of melts in the reaction chamber of a mould is achieved by means of grain size of 5.0 ± 2.5 mm. The most effective inoculative additive for in-mould carbide-stabilizing treatment of cast iron is an alloy of nickel with magnesium of the NiMg15 grade. Independently on the grain size in the range from 1 to 10 mm, the alloy of nickel and magnesium is sufficiently soluble by the flow of molten iron during the mould filling. New technological ways for intensification of in-mould treatment of cast-iron melt using the fine dispersed (including powdery) additives are proposed and studied.

Keywords: casting, inoculant, grey iron, white iron, ductile iron, graphitizing inoculation, carbide-stabilizing inoculation, spheroidization inoculation, granulometric composition, reaction chamber.

1. Introduction

One of the most common construction materials for a wide range of cast products is cast iron. In industry, cast iron is used for production of various cast products, *e.g.*, parts of metalworking machines, casings, lids, cylinders, bushings, pulleys, gears, flywheels, hydraulic cylinders, cylinder blocks, piston heads and rings, brake drums, levers, weights,

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heating radiators, sewer pipes, household and art destination products, *etc*. [1].

According to the census of the world production of casting conducted annually by 'Modern Casting' journal, in the general structure of the output of cast products, the share of cast iron is 70%, and this value remains approximately at the same level in recent years [2, 3].

Wide application of this construction material is caused by its most favourable combination of foundry, technological, mechanical, and operational properties. Besides, cast iron is an affordable, readily available, and relatively cheap material melted easily in various types of smelters, possesses good workability and its application for production of castings makes it possible to reduce machining allowances and to increase technological yield of suitable castings [4, 5].

However, in recent years, there has been a constant tightening of the requirements for reliability and performance characteristics of machines and equipment, which makes it necessary to produce castings, including those of cast iron, with improved structural, mechanical, and operational properties.

In modern technological processes for producing ingots of cast iron with high mechanical and operational properties, one of the most important technological operations is inoculative melt treatment. This is the most versatile, relatively cheap, technologically flexible and highly efficient method for controlling the structure of crystallizing alloy, and, consequently, the properties of products, since most properties of technical alloys are structurally sensitive [4–6].

During the production of grey iron ingots, an inoculation of basic melt is aimed at elimination or substantial reduction of chill, structure refinement, increase of homogeneity of the structure and properties of metal in casting walls of different thickness. Another aim is the formation of a predetermined, commonly pearlitic or ferrite–pearlite metal matrix with graphite inclusions of favourable shape and required dimensions uniformly distributed throughout the bulk of ingot.

Inoculative treatment of white iron is carried out mainly for stabilization of the cementite phase, formation of the required metal matrix and uniform distribution of carbides throughout the bulk of metal in order to improve performance characteristics of cast iron products, mainly concerning hardness and wear resistance.

The obtainment of high-quality castings from ductile iron with spheroidal and vermicular graphite under real casting conditions without spheroidizing or complex spheroidizing and graphitizing inoculative treatment of the base melt of cast iron is practically not possible at all.

Taking into consideration the above-mentioned, actually, there have been developed and found practical application a lot of inoculative additives and methods of their introduction into cast iron melt: in a melting fur-

nace, in a cupola runner, in sealed or open ladles, in an autoclave, into the jet of a metal being cast, *etc*. [7–12].

Current development of cast iron inoculation processes is characterized by the trend of transition from furnace or ladle methods to more efficient, environmentally friendly and economical ways of late in-mould inoculation [12–14].

Among the known methods of recent inoculation, the method of molten cast iron treatment with inoculants or master alloys directly in mould deserves attention, widely known in literature and in practice as the 'in-mould process' [12, 15–17]. During the in-mould process, the melt treatment is carried out by inoculative granular additives placed into a special reservoir or into a special cavity of a mould, *i.e.*, an intermediate flow reaction chamber of the gating on the path of the melt travel to the casting. During the filling of the mould, the inoculant in the reaction chamber interacts with the melt, dissolves in the flow of the liquid metal, and is subsequently finally absorbed by the cast metal. Suchlike inoculation, without significant altering of the chemical composition of the alloy, affects the crystallization process and leads to a significant change in the structure and properties of iron castings, compared to the parent metal cast into the mould.

In-mould inoculation of cast-iron melt, bringing extremely together in space and time the stage of melt treatment with the processes of filling, the mould and solidification of metal in its cavity provides optimal structure formation of castings, eliminates the problem of deinoculation characteristic for ladle methods, and is a safe and relatively ecologically clean process. In addition, when switching from furnace or ladle methods of inoculation to the in-mould process, the melt treatment technology becomes simplified; no additional equipment is needed or special complicated devices or facilities used. Furthermore, the consumption of relatively expensive inoculative additives is significantly reduced, which is important in terms of reducing the cost of casting, and, consequently, increases competitiveness of foundry products [15–20].

When basic cast iron melt is treated internally in the reaction chamber of the gating, the degree of assimilation of the basic alloying (inoculative) component depends on the type and chemical composition of applicable inoculant, its dispersity (granularity), type of reaction chamber, temperature conditions of treatment, and some other factors [18–35]. This degree of the basic alloying component determines its residual content in cast iron after inoculative treatment and, ultimately, the character of the forming structure and properties of the casting [18–35]. Besides, the technology is very sensitive to the chemical composition of the initial melt and, first of all, to the content of sulphur and other active impurities in the cast iron. All these factors necessitate the individual testing of technological process at operating with cast

iron of different chemical composition and transiting from castings of one type to another.

Considering mentioned above, it becomes a necessity to choose the type and to optimize chemical composition and particle size of inoculative additive for in-mould graphitizing, carbide stabilizing, and spheroidizing treatment of cast iron melt of specific chemical composition, which is the scope of this paper.

2. Experimental Procedures

As an object of the experimental study, we chose the casting 'three-section sample' in Fig. 1 with weight of 5 kg and wall thicknesses of 8 mm, 32 mm, and 64 mm.

To obtain the experimental castings, a single casting mould made of foundry sand was filled with handheld cone ladle by initial basic molten cast iron, melted in an frequency induction crucible furnace having the 60-kg capacity on charge materials consisting of cast iron PL2 (GOST 805-95), foundry pig iron L2 (DSTU 3132-95-GOST 4832-95) and steel scrap 30.

Inoculative additives applied during the experiments according to their ratio to the mass of the experimental casting, their brands and chemical composition are presented in Table 1.

To optimize granulometric composition, lump inoculants and ferroalloys were crushed, after which they were sieved for grains (fractions) of less than 0.63 mm (including pulverized fraction): 0.63–1.6 mm; 1.6–2.5 mm; 2.5–5.0 mm; 5.0–10.0 mm.

During graphitizing inoculation, the moulds were filled by pre-eutectic cast iron with carbon equivalent CE = 3.0–3.2% prone to crystallization with chill, and during carbide stabilizing and spheroidizing inoculation, by eutectic cast iron melted in an induction furnace

Table 1. **Chemical composition of the investigated inoculants, ferroalloys and additives [36]**

Grade	GOST, TU	Quantity of additive, %	Mass fraction of element, %							
			Mg	REM	Si	Ni	Cr	Mn	CaF_2	Fe and/or impurities
FeSi75	GOST 1415-70	2.0			77.5					residual
NiMg15	TU 5013-72	1.5	14.7	0.3	–	residual	–	–	–	–
FeSiMg7	TU 14-5-136-86	2.0	7.2	–	51.7	–	–	–	–	residual
FeCr200	GOST 4757-91	1.5–2.0	–	–	–	–	64.2	–	–	residual
FeMn78	GOST 4757-80	1.5–2.0	–	–	–	–	–	76.4	–	residual
MPF1	GOST 6001-51	0.1–0.7	99.8	–	–	–	–	–	–	residual
FFS95	GOST 4421-73	1.0–2.0	–	–	–	–	–	–	95.0	residual

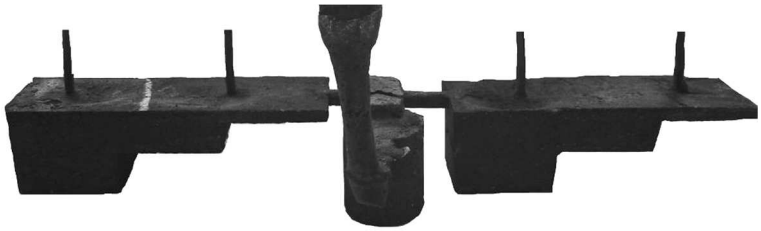


Fig. 1. General view of experimental casting 'three-section sample' with pouring gate inoculative system

with carbon equivalent CE = 4.2–4.4% at temperature 1440 ± 20 °C for 12 ± 1 s.

The output parameters for optimization of in-mould inoculation process were the increase in content and corresponding calculated ratio of assimilation of the basic chemical elements of the inoculant by the cast metal as well as the character and colour of the fracture macrostructure, microstructure, and hardness of cast iron in the controlled sections of the sample.

The contents of carbon and sulphur were determined *via* the gas-volumetric method; the contents of silicon, manganese, magnesium, nickel, and chromium were determined *via* the spectral analysis through the method of three standards; the content of phosphorus was determined using the photocolorimetric method. Carbon equivalent of cast iron was determined using the thermographic method. The temperature of the melt of the cast iron was controlled by tungsten–rhenium thermocouples of the WRe5/20-type with an accuracy of ±10 °C.

Identification of structural constituents in cast iron was carried out in accordance with GOST 3443-87. Hardness of cast iron in different sections of the experimental Brinell casting was measured in accordance with GOST 9012-59 (DSTU ISO 6506-1: 2007) on the TSH-2M device (hardness tester).

The macro- and microstructure of the cast irons was examined with MIM-10 optical microscope and was photographed using a Tucsen digital video camera with subsequent PC recording. Statistical processing and construction of regression equations were performed using Microsoft Excel.

3. Experimental Results and Discussion

As the results of the experimental studies show, during in-mould graphitizing inoculation of pre-eutectic cast iron, prone to crystallization with chill, by ferrosilicon FeSi75, peak absorption of silicon (Fig. 2, *a*), complete elimination of eutectic iron carbides through intermediate structures in controlled sections (white iron WI → mottled iron MI → grey

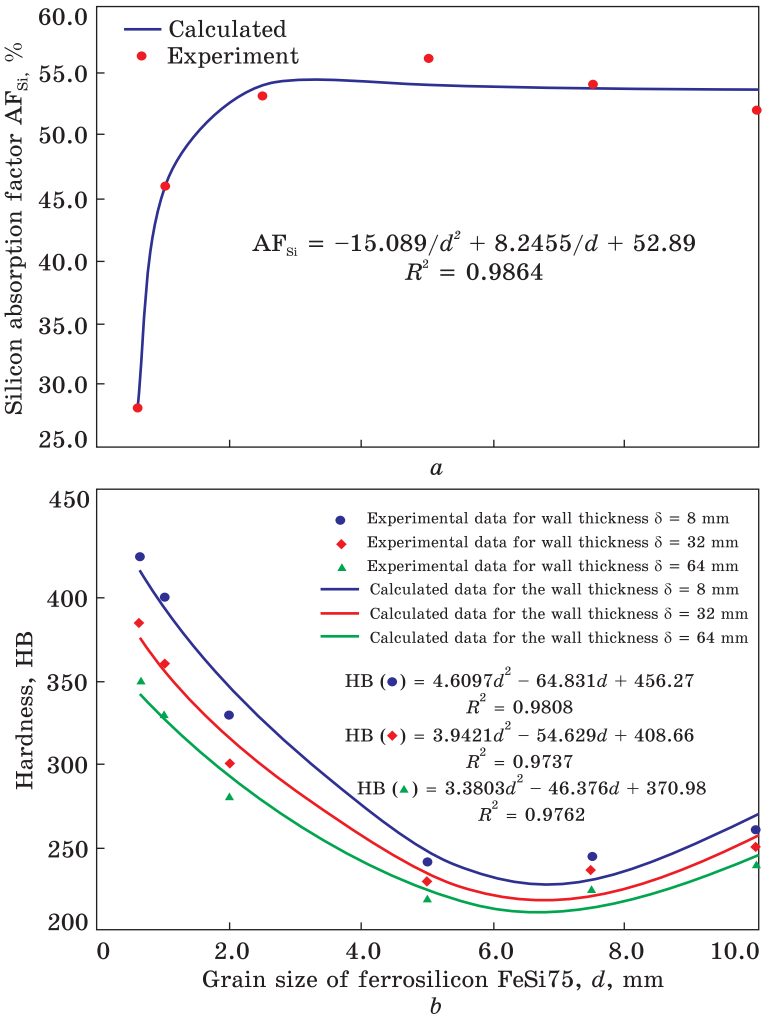


Fig. 2. Influence of grain size of ferrosilicon FeSi75 on the ratio of absorption of silicon (*a*) and hardness of cast iron (*b*) in casting after in-mould inoculation (see also Ref. [36])

iron GI) provides additive with particle size 5.0 ± 2.5 mm. At the same time, in all the sections of the studied technological sample, a typical grey iron structure is formed with inclusions of graphite of lamellar shape (Fig. 3), which, as expected, grows larger when transiting from thickness of 8 mm to thicker (more massive) sections of the casting (32 mm and 64 mm).

Such an additive reduces hardness of cast iron from 410–450 to 225–240 HB. Characteristically, the influence of wall thickness of the casting (cooling rate) on hardness of modified cast iron is largely levelled, compared to the parent metal (Fig. 2, *b*).

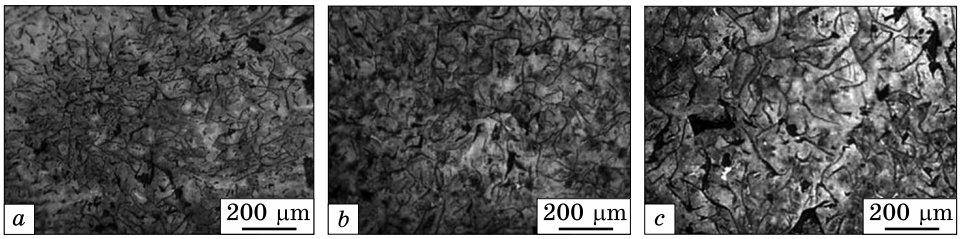


Fig. 3. Microstructure of cast iron after inoculation by ferrosilicon FeSi75 with grain size 5.0 ± 2.5 mm in casting with different wall thicknesses: 8 mm (*a*), 32 mm (*b*), and 64 mm (*c*)

To explain the nature of the obtained curves (see Fig. 2), in our opinion, we can proceed as follows. When applying an additive with particle size 5.0 ± 2.5 mm, bulk-surface mechanism of interaction of solid particles with melt is observed. Granules measuring 5.0 ± 2.5 mm without fine and pulverized particles allow liquid metal to be filtered between the gaps of the inoculant grains to a certain depth, which is confirmed by our previous experimental studies on transparent physical model [37, 38]. Intensive heat transfer between the solid and liquid phases, sufficient total area of reaction surface and synchronization of mould filling speed with the rate of advance in the chamber of the two-phase solid–liquid reaction layer from top to bottom, provide, in combination, a relatively uniform layer wise dissolution of ferrosilicon grains in the stream of cast iron.

In this case, the low maximum value of silicon assimilation factor (54–56%) under experimental conditions is due to intentionally excessive amount of FeSi75 additive. This additive is not able to dissolve in the melt during short filling period, so that a significant part of ferrosilicon of the lower layer is sintered with the remainder liquid metal and remains in the reaction chamber.

Addition of ferrosilicon with particle size of more than 7.5 mm allows intergranular filtration of metal throughout the chamber as well as throughout the mould filling process from the very beginning of the introduction of the melt into the reaction chamber [37]. While interaction of additives of this size, they partially dissolve in cast iron stream, resulting in elimination of chill in separate sections of the sample. However, for the most part, relatively large ferrosilicon particles do not have time to react with molten iron and dissolve in it, and after filling, they are sintered with the remnants of liquid metal in the reaction chamber. Results of such in-mould inoculation are not stable.

Ferrosilicon with particle size of less than 0.63 mm, including pulverized fraction, practically does not react to liquid metal. According to its physical properties, such a finely dispersed inoculant in reaction chamber is similar to a non-compacted briquette, which eliminates the

possibility of filtering cast iron between the inoculant grains [38]. The phase of warm-up to the melting temperature of a similar powder briquette appears to be comparable to or exceeds the filling time of the mould itself. Therefore, when the melt enters the reaction chamber, this powder briquette partly performs the role of a refrigerator that facilitates formation of solid or solid–liquid layer of cast iron on its surface. As a result, a bulk of finely dispersed inoculant, after cooling the castings and extracting them from the mould, remains in the reaction chamber in original non-sintered state.

In the second phase of the experiment, optimization of granulometric composition of inoculative additives placed in reaction chambers is carried out to stabilize eutectic iron carbides in cast iron structure close to eutectic composition, prone to crystallization according to stable system without chill even in thin sections of the walls of the castings.

As known, chromium is a traditional element to stabilize carbides in iron-carbon alloys. However, after conducting a series of experiments with ferrochromium FeCr200, it was found that it is not advisable to use it as a carbide-stabilizing additive for in-mould treatment of basic melt. During inoculation of cast iron flow by ferrochromium, regardless of the size of its particles in the range from pulverized fraction to 10 mm or more, increment in chromium content in cast metal does not exceed chemical analysis error. Addition of ferrochrome together with fluorspar or powdered magnesium to the reaction chamber to intensify its dissolution also does not provide an increase in chromium assimilation ratio by cast iron. We attribute the negative results of carbide-stabilizing inoculation of cast iron by ferrochromium to the increased melting point (2265 °C) and the presence of scale-resistant protective oxide film of Cr_2O_3 on the surface of its grains.

Another effective stabilizer of iron carbides in cast iron is magnesium. As known, the cast iron, inoculated by metallic magnesium in an autoclave or in a sealed ladle without additional graphitizing inoculation by ferrosilicon, as a rule, crystallizes according to metastable system even in thick sections of the walls of castings. However, high oxygen activity and low boiling point do not allow the use of powdered or granular metallic magnesium as carbide stabilizing in-mould inoculants for the in-mould process. All attempts of such inoculation are accompanied by backfilling of liquid metal from the riser and the sprue cup under the pressure of magnesium vapour in the mould, which is dangerous for the fillers and does not provide required assimilation of magnesium by cast iron.

To reduce interaction intensity of magnesium with iron, magnesium powder MPF1 was mechanically mixed with the filler, for what finely dispersed ferromanganese FeMn78 with grain size of 0.63–1.5 mm was used. Magnesium content in mechanical mixture with ferromanganese varied from 5% to 35%. However, it was found that filling of moulds

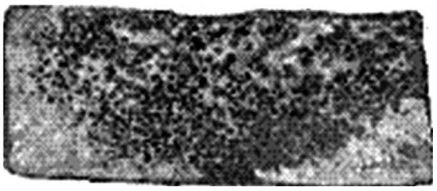


Fig. 4. Macrostructure of cast iron fracture in 32 mm cross section of stepped sample after in-mould inoculation of initial melt of cast iron of eutectic composition by mechanical mixture of powdered magnesium, ferromanganese, and 1–2% of ФФС95 flux

by additive of 20–35% magnesium concentration is accompanied by almost the same dangerous splashes of liquid metal from the riser and the sprue funnel, as when filling of moulds by powdered magnesium without any filler. In this case, iron in casting crystallizes with grey fracture. Once the concentration of powdered magnesium in mixture with ferromanganese is lower, mould-filling process becomes relatively quiet. However, the results of in-mould carbide stabilizing inoculation of cast iron with such additives, including those with additive of 1–2% ФФС95 flux, are not stable. In thick cross-sections of casting fracture, the colour of cast iron remains grey, but in the middle and thin sections cast iron is mottled with relatively large rounded inclusions of grey on white fracture (Fig. 4).

As experimentally revealed, the most effective additive for in-mould carbide stabilizing inoculation of cast iron of eutectic composition is nickel–magnesium master alloy NiMg15. Regardless of the grain size in the range from 1 mm to 10 mm, the alloy of nickel with magnesium is quite soluble in the flow of cast iron during the filling stage. Low inclination of nickel to the formation of oxide films on the surface of the master alloy particles, relatively low melting point of the master alloy (1140 °C), and 'barbotage' of the flow of iron in the reaction chamber with bubbles of moderately evaporating magnesium favour the process of dissolution of the additive. The metal of the casting consumes about 40% of magnesium and 57–58% of nickel, introduced with finely dispersed master alloy and up to 30% of magnesium and 40% of nickel, introduced with grain and lump master alloy (Figs. 5, *a*, *b*). High residual magnesium content (0.06–0.09% $Mg_{residual}$) stimulates supercooling crystallization of cast iron according to metastable system (Fig. 6). Under experimental conditions, treatment by nickel–magnesium master alloy provides an increase in hardness of cast iron after inoculation compared with initial cast iron from 150–180 HB to 360–440 HB (Fig. 7).

At the third stage of the experimental studies, the additive was optimized for in-mould spheroidization inoculation of cast iron of eutectic composition. It should be noted that a significant number of publications on the in-mould process have been devoted to the solution of this problem [8–24].

As a basic component for spheroidization inoculation of cast iron, the ferrosilicon alloy with magnesium FeSiMg7 was selected.

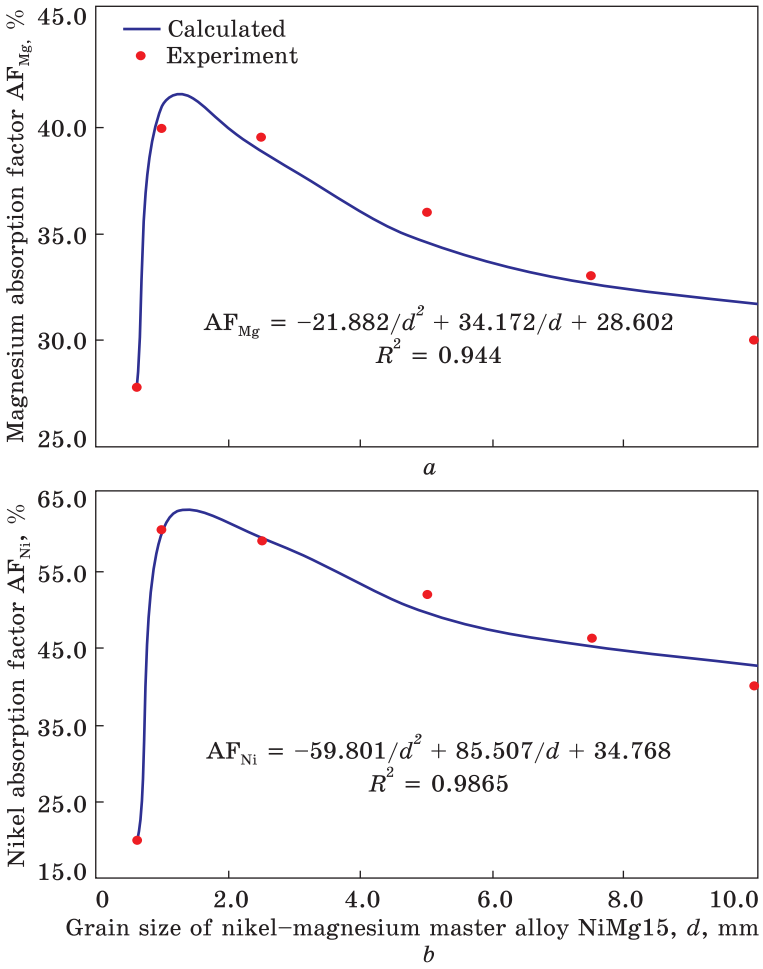


Fig. 5. Effect of grain size of nickel–magnesium NiMg15 master alloy on assimilation ratio of Mg (*a*) and Ni (*b*) by cast iron after in-mould inoculation [36]

We found that at the rate of consumption of 2.0% of the weight of the ferrosilicon casting, magnesium inoculant FeSiMg7 of pulverized fraction with particle size less than 0.63 mm, like ferrosilicon FeSi75 of similar fraction, practically does not dissolve in the flow of liquid metal. Only 8–12% of silicon and 5–8% of magnesium is absorbed from inoculant with grain size 0.63–1.6 mm (Fig. 8). With such a low absorption ratio, the residual magnesium content is insufficient for spheroidization of graphite in the cast metal. Macrostructure colour of the modified cast iron fracture remains grey, although separate inclusions of vermicular and globular graphite appear in its structure.

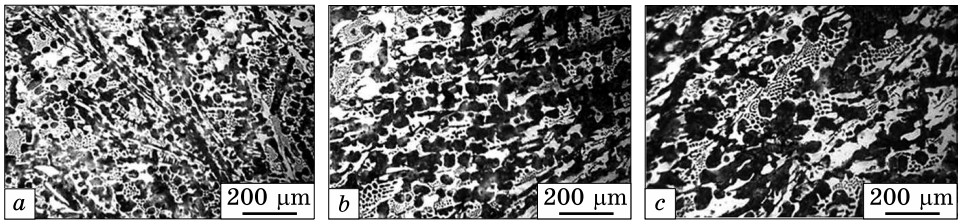


Fig. 6. Cast iron microstructure after inoculation by NiMg15 master alloy with grain size of 5.0 ± 2.5 mm in a casting with wall thickness of 8 mm (*a*), 32 mm (*b*), and 64 mm (*c*)

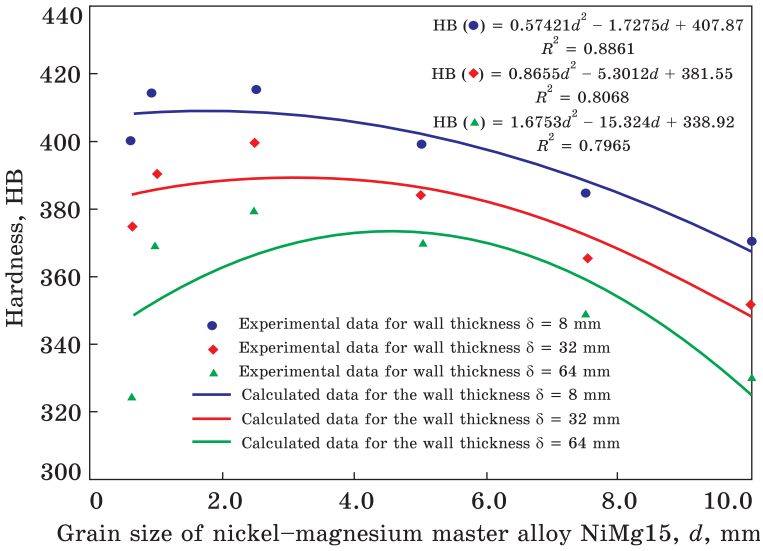


Fig. 7. Influence of grain size of NiMg15 master alloy on hardness of cast iron in casting after in-mould inoculation [36]

Under experimental conditions, the maximum ratio of assimilation of magnesium (20–25%) and silicon (45–50%) is achieved by FeSiMg7 inoculant with grain size 5.0 ± 2.5 mm (Fig. 8). Grains of the inoculant of this size are dissolved relatively uniformly and layer by layer in the flow of liquid metal passing through the reaction chamber. Yet residual magnesium content in cast metal exceeds the critical value (0.03–0.04% $Mg_{residual}$), which ensures complete spheroidization of graphite in the structure of cast iron (Fig. 9). Increased ratio of assimilation of graphitizing silicon (45–48%) from inoculant with grain size 5.0 ± 2.5 mm stimulates primary crystallization of alloy according to stable system without eutectic iron carbides. At the same time, conditions are created for ferritization of metallic matrix along with eutectoid transformation of austenite, which leads to hardness decrease (Fig. 10) and, as expected, to increase in impact resistance of iron in the cast state.

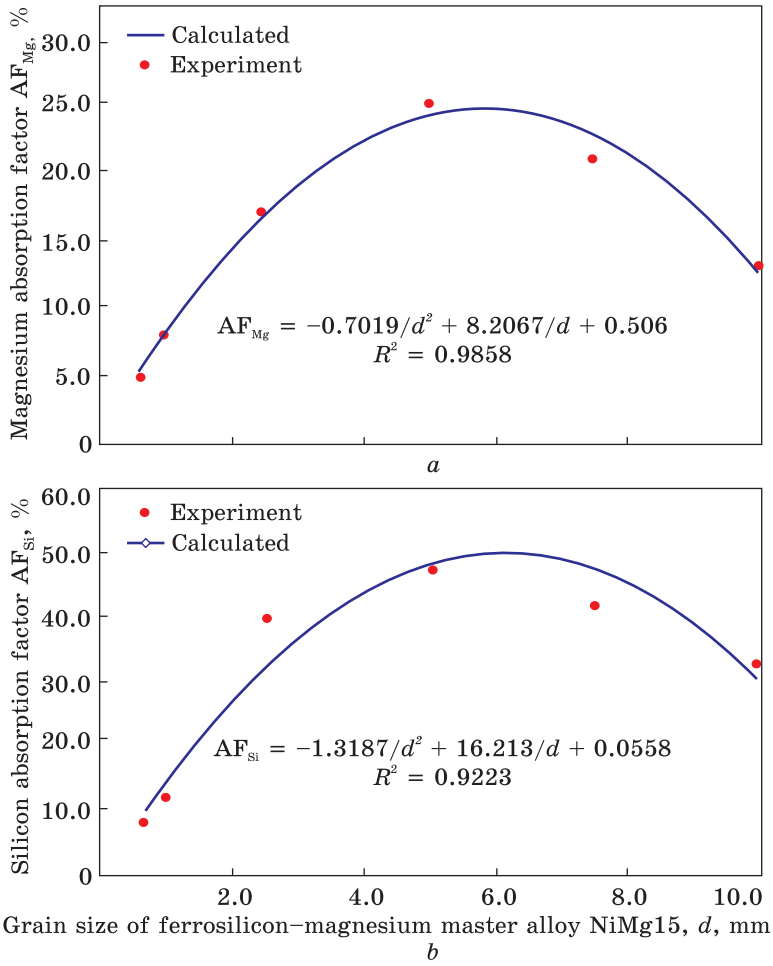


Fig. 8. Influence of grain size of ferrosilicon–magnesium FeSiMg7 master alloy on assimilation ratio of magnesium (*a*) and silicon (*b*) by cast iron after in-mould inoculation (see also Ref. [36])

Thus, in virtue of the performed studies, we established that, in order to ensure acceptable assimilation of inoculative or alloying additives during in-mould inoculation of the melt, they must be of a certain granulometric composition, for which it is necessary to crush them and sift out to required fractions.

Under production conditions, brittle master alloy lumps or additives (*e.g.*, ferrosilicon, ferrosilicon–magnesium alloy, *etc.*) are most often crushed in jaw, roll or hammer crushers. After grinding, particles of various size are formed, including a significant amount of finely dispersed particles and pulverized fraction, which may reach 40–50% of the number of grindable inoculants [39] and which, as studies have

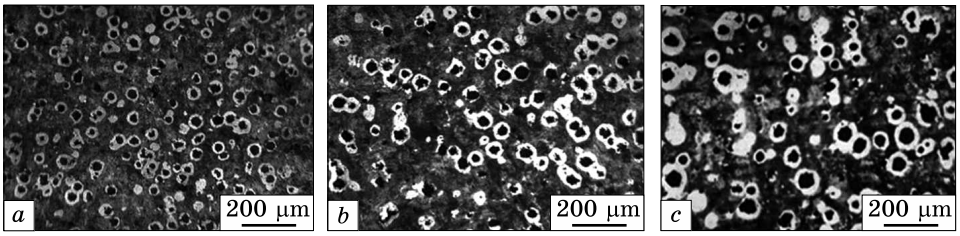


Fig. 9. Cast iron microstructure after inoculation by FeSiMg7 master alloy FeSiMg7 with grain size of 5.0 ± 2.5 mm in casting with wall thickness of 8 mm (*a*), 32 mm (*b*), and 64 mm (*c*)

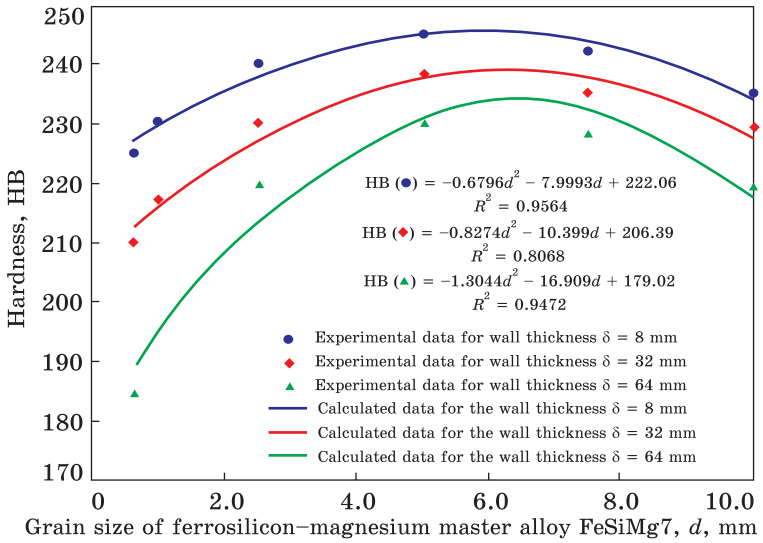


Fig. 10. Influence grain size of FeSiMg7 master alloy on hardness of cast iron in stepped sample after in-mould inoculation [36]

shown, is practically not assimilated by the melt during in-mould inoculation in the reaction chamber. However, it is not economically feasible to relate finely dispersed (pulverized) fraction formed during crushing of inoculants to production waste.

Therefore, the task for further research was the development and investigation of effective methods for intensification of dissolution process of finely dispersed inoculative additives in the flow of molten iron during in-mould inoculation of the melt.

To provide an efficient and economically advantageous process for dissolution of finely dispersed fraction of inoculant (including pulverized one), we propose techniques for stimulation of dissolution using gasified models. At the same time, the following technological options are proposed for in-mould inoculation of the melt (Fig. 11).

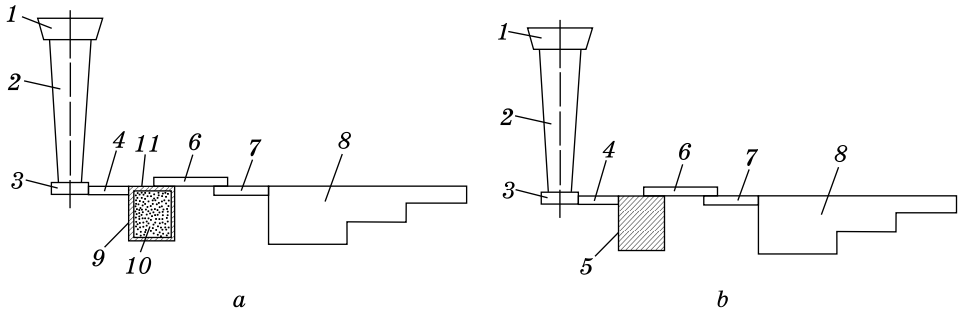


Fig. 11. Sketch of in-mould inoculation of cast iron by finely dispersed inoculant by means of foam polystyrene reaction chamber: *1* — sprue cup, *2* — riser, *3* — connecting duct, *4* — runner, *5* — foam polystyrene cartridge with inoculant, *6* — slag catcher, *7* — ingate, *8* — casting, *9* — foam polystyrene sheath, *10* — inoculant, *11* — foam polystyrene plug

The first option consists in in-mould treatment of initial cast iron by means of reaction chamber, which represents a gasified shell (of foam polystyrene), inside the which, a finely dispersed inoculant is placed in a sand mould during forming and acting as an intermediate flow reaction chamber of the gating (Fig. 11, *a*) [40].

The second option relates to processing of the initial cast iron melt inside the mould through the reaction chamber of the gating, made as a gasification insert (cartridge). Into this cartridge, a predetermined amount of finely dispersed inoculant powder is kneaded during its manufacturing and which is installed in a single sand mould during forming or assembling of the mould (Fig. 11, *b*) [41, 42].

Efficiency of in-mould inoculation according to the proposed technological options was tested by means of example of in-mould spheroidization inoculation.

For in-mould treatment of initial molten cast iron of eutectic composition, finely dispersed powder was used as a spheroidizing inoculant, with particle size less than 0.63 mm (including pulverized fraction) of FeSiMg7 alloy. The amount of the inoculant placed into the reaction chambers of the gating was taken at the rate of 2.0% of the mass of the processed cast iron.

In experimental studies on the 'three-section sample' castings with wall cross-sections of 8 mm, 32 mm, 64 mm and 5 kg mass, we used both a reaction chamber made in the form of a gasifiable foam polystyrene shell (Fig. 11, *a*) and a reaction chamber in the form of a polystyrene cartridge sintered with inoculant (Fig. 11, *b*). For both chambers, in case of in-mould spheroidization inoculation of molten cast iron by finely dispersed particles of size less than 0.63 mm (including pulverized fraction) by the spheroidizing inoculant FeSiMg7, there is complete

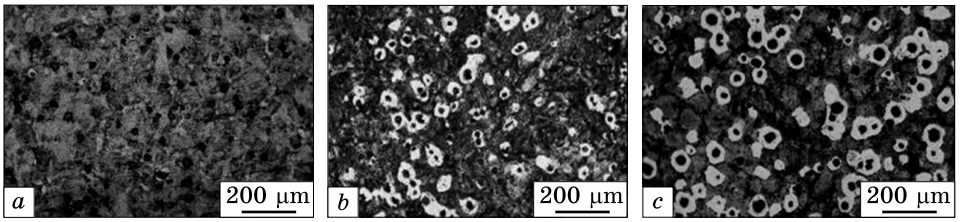


Fig. 12. Microstructure of samples after in-mould inoculation of basic cast iron melt by FeSiMg7 master alloy with particle size less than 0.63 mm in casting with wall thickness of 8 mm (*a*), 32 mm (*b*), and 64 mm (*c*)

assimilation of inoculative additive by liquid metal, which is distributed sufficiently uniformly throughout the casting.

This is possible due to the fact that when filling the mould, under the action of liquid metal heat, foam polystyrene of the reaction chamber is gasified, leaving space for the flow of liquid metal between the grains, thereby increasing the contact area of the inoculant particles with the melt. In addition, the evolved gaseous products of gasification inside the reaction chamber promote mixing of liquid metal with inoculant, increasing the ratio of inoculant assimilation. Due to the evolving gaseous products of destruction in the gasification model, reducing atmosphere is created in the reaction chamber cavity and in the runner system, which prevents oxidation of inoculant and increases the efficiency of its inoculative effect while reducing inoculant consumption for melting loss.

After in-mould spheroidization inoculation of cast iron by means of foam polystyrene chambers, in the structure of the test samples cut out from different sections of the casting, there takes place formation of graphite of regular spherical shape (point ShGf5 according to GOST 3443-87) uniformly and uniformly distributed in the plane of microsection at point SGp1 (see Fig. 12). In higher cross sections of the casting, dimensions of globular graphite inclusions increase from point ShGd15 in 8 mm section to point ShGd95 in 64 mm section with simultaneous increase in number from 6% in 8 mm section to 10–12% in 32 mm and 64 mm sections. Microstructure of the samples is a pearlite–ferrite one. Hardness of samples is 240–280 HB.

4. Conclusions

Thus, as a consequence of experimental studies, an optimal granulometric composition of additives for effective in-mould graphitizing, carbide stabilizing, and spheroidizing inoculation of cast iron melt was selected.

As established, the peak absorption of graphitizing ferrosilicon inoculant FeSi75 and spheroidizing inoculant FeSiMg7 during inoculation

of melts in the reaction chamber of the mould is provided for the grain size of 5.0 ± 2.5 mm. The most effective inoculative additive for carbide stabilizing in-mould inoculation of cast iron is the alloy of nickel with magnesium NiMg15. Regardless of the grain size in the range from 1.0 to 10 mm, the alloy of nickel and magnesium is sufficiently soluble by the flow of molten iron during mould filling.

New technological ways of intensification of in-mould inoculation of cast iron melt by means of less efficient finely dispersed inoculative additives is proposed and investigated.

The application of the results of the carried out study into the industrial practice can contribute to the solution of a number of problems and challenges for improving the quality and properties of cast metal of wide range of castings [43–50].

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ГРАФІТИЗУВАЛЬНЕ, СФЕРОЇДИЗУВАЛЬНЕ ТА КАРБІДОСТАБІЛІЗУВАЛЬНЕ МОДИФІКУВАННЯ РОЗТОПУ ЧАВУНУ В ЛИВАРНІЙ ФОРМІ

Оглянуто та проаналізовано результати досліджень щодо оптимізації ґранулометричного складу добавок для графітизувального, карбідоутворювального та сфероїдизувального модифікування розтопу чавуну в ливарній формі. Виявлено, що максимальне засвоєння графітизувального модифікатора феросиліцію марки ФС75 і сфероїдизувального модифікатора марки ФСМг7 під час оброблення розтопів у реакційній камері ливарної форми забезпечується при використанні їх із розміром зерен у 5,0 ± 2,5 мм. Ефективнішою модифікувальною добавкою для карбідоутворювального оброблення чавуну в ливарній формі є стоп ніклю з магнієм марки НМг15. Незалежно від розміру зерна в діяпазоні від 1 до 10 мм стоп ніклю та магнію достатньо повно розчиняється потоком розтопу чавуну під час заливання ливарної форми. Запропоновано та досліджено нові технологічні варіянти інтенсифікації оброблення розтопу чавуну в ливарній формі з використанням дрібнодисперсних (включаючи пилоподібні) модифікувальних добавок.

Ключові слова: виливок, модифікатор, сірий чавун, білий чавун, високоміцний чавун, графітизувальне модифікування, карбідоутворювальне модифікування, сфероїдизувальне модифікування, гранулометричний склад, реакційна камера.

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ГРАФИТИЗИРУЮЩЕЕ, СФЕРОИДИЗИРУЮЩЕЕ И КАРБИДОСТАБИЛИЗИРУЮЩЕЕ МОДИФИЦИРОВАНИЕ РАСПЛАВА ЧУГУНА В ЛИТЕЙНОЙ ФОРМЕ

Обозреваются и анализируются результаты исследований по оптимизации гранулометрического состава добавок для графитизирующего, карбидостабилизирующего и сфероидизирующего модифицирования расплава чугуна в литейной форме. Установлено, что максимальное усвоение графитизирующего модификатора ферросилиция марки ФС75 и сфероидизирующего модификатора марки ФСМг7 во время обработки расплавов в реакционной камере литейной формы обеспечивается при использовании их с размером зёрен 5,0 ± 2,5 мм. Наиболее эффективной модифицирующей добавкой для карбидостабилизирующей обработки чугуна в литейной форме является сплав никеля с магнием марки НМг15. Независимо от размера зерна в диапазоне от 1 до 10 мм сплав никеля и магния достаточно полно растворяется потоком расплава чугуна во время заливки литейной формы. Предложены и исследованы новые технологические варианты интенсификации обработки расплава чугуна в литейной форме с использованием мелкодисперсных (включая пылевидные) модифицирующих добавок.

Ключевые слова: отливка, модификатор, добавка, серый чугун, белый чугун, высокопрочный чугун, графитизирующее модифицирование, карбидостабилизирующее модифицирование, сфероидизирующее модифицирование, гранулометрический состав, реакционная камера.