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The Initial Assessment of Effectiveness of the Impulse Method of Introducing an Inoculant into Cast Iron

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Abstract

An initial assessment of the effectiveness of cast iron inoculation, performed by the method of impulse introducing the master alloy into cast iron, is presented. The experiment was concerned with the hypoeutectic gray cast iron inoculated with either the Alinoc or the Barinoc master alloy by means of an experimental device for pneumatic transportation. Examinations involved pneumatic injection of the powdered inoculant carried in a stream of gaseous medium (argon) into the metal bath held in the crucible of an induction furnace. It was found that the examined process is characterised by both high effectiveness and stability.

Keywords: Metallurgy, Inoculation, Hypoeutectic cast iron, Pneumatic transport

1. Introduction

Cast iron is the most popular foundry alloy over the world. Its cheapest type – the grey cast iron – as a rule demands for improving its quality, and the most effective and relatively not expensive way of achieving it is inoculation. It is performed in order to increase the mechanical properties of the alloy and to obtain uniformity of structure across the wall of a casting. The possibility of hard spots elimination, especially in thin walls, is here of particular significance. The inoculation process consists in introducing certain additions called 'inoculants' into the molten alloy, so that the primary structure of a casting is changed, but the chemical composition of the alloy generally is not altered. This additions increase the number of active nuclei of graphite crystallization, thus increasing the nucleation ability of the alloy [1]. Popular methods of adding the inoculants, applied in foundry practice, are: inoculation performed in a ladle; the on-stream inoculation in the course of metal pouring; the in-mould inoculation, consisting in placing the fine-grain inoculant in the pouring basin or in the reaction chamber down the gating system; dosing the inoculant to the ladle in the form of cored wire [1-7]. One of a variety of such methods, which is particularly worth attention, is the pneumatic dosage of inoculant to the molten metal by the inoculant/carrier gas two-phase stream [1, 2, 8].

The fine-grained components injected into a metal bath by means of a carrier gas intensify metallurgical processes due to the large contact area between the liquid metal and the blown powder. Quick mass exchange takes place, increased additionally by the movement of liquid metal forced with the carrier gas. The movement causes intensive removing of substrates from the reaction zone, increasing the rate of a given metallurgical process [9].

The pneumatic transport reveals a series of advantages and is more and more popular in foundries, finding applications which include [9-16]:

– carburization of liquid metal;
– desulphurization;
– foaming the slag in steel making processes;

– recycling of steelworks dust;
– pneumatic reclamation of moulding sands;
– pneumatic injection of the alloying additions;
– utilization of dust generated by metallurgical furnaces and its injection into cupolas and arc furnaces;
– moving green sand from storage silo to the sand conditioning plant;
– conveying of the used sand to the reclaiming systems;
– dynamic compacting of moulding sands;
– impulse measurement of moulding sand humidity.

The application of pneumatic transport for performing injection of an inoculant into cast iron is not commonly used thus far, and there is little references dealing with this problem. The injection process itself can be further improved by adding the master alloy in a carrier gas jet by the impulse method. This method leads to the increase in dynamics of the process due to the multiplied contact area between master alloy and molten metal, which is a cause of increased rate of inoculant dissolution and of its larger yield.

It seems reasonable to study the application of impulse method for injection of inoculants into cast iron in detail, taking into account particularly the fact that the method makes possible a quick introduction of quite large amount of inoculant into the liquid alloy. Moreover, the way of inoculation discussed here results in a significant improvement of working conditions and enables the automation of the process.

2. Authors' investigations

The purpose of the examination was to determine if and with how much effectiveness the process of grey cast iron inoculation proceeds when carried out by the impulse method of injecting the master alloy.

Certain initial presumptions were made before examination. It was assumed that the injection of the inoculating master alloy into the metal bath would take place five times during each of the planned two melting operations. It was decided that the injection of the inoculant in carrier gas jet would be performed by means of a lance placed above the molten metal surface due to the specific construction of induction furnaces. The distance of the lance from the metal surface should be chosen in such a way that the individual grains of inoculant would achieve the energy sufficient for overcoming the resistance of liquid cast iron. This distance was selected on the basis of technical literature data [9]. It was assumed that the initial assessment of the effectiveness of the developed method of treatment would be done by evaluating the chemical composition of samples taken before the first inoculation and then after each of the five subsequent blowing operations.

The material selected for experiments was cast iron taken from two melts previously held in one of domestic foundries in the MFT-Ge 4000 Junker medium-frequency induction furnace of 4 tons capacity. Chemical compositions of both cast irons (denoted as A and B) are shown in Table 1. Cast iron cylinders 30 mm long and 30 mm in diameter produced under the industrial conditions were presently used as a charge for the experimental melts.

First the inoculation of cast iron coming from the melt No. 1 (A) was performed by means of Alinoc master alloy (grain size 0.2÷0.7 mm). Then, after a slight modification of a laboratory stand, the cast iron coming from the melt No. 2 (B) was treated with Barinoc (grain size 0.4÷0.8 mm). Chemical compositions of both inoculants are presented in Table 2. Figure 1a shows the basic element of the laboratory stand – a feeder – used during the first experimental melting, while Figure 1b illustrates the modified version of the element used during the second melting.

Table 1.
Chemical composition of cast iron used for the purpose of experimental melting

Melt des.	Content of elements [%]								S_C [1)] [1]	C_E [2)] [%]
	C	Si	Mn	P	S	Cu	Cr	Al		
A	3.26	1.65	0.65	0.033	0.021	0.057	0.022	0.003	0.87	3.76
B	2.91	2.37	0.48	0.049	0.032	0.383	0.027	0.004	0.82	3.53

1) the saturation degree was found using the formula:

$$S_C = \frac{C_C}{4.26 - 0.31Si - 0.33P - 0.4S - 0.22Al + 0.027Mn}$$

2) eutectic carbon equivalent was found using the formula:

$$C_E = C_C + 0.31Si + 0.33P - 0.027Mn + 0.40\,S$$

where: C_C – total content of carbon in cast iron,
Si, P, S, Mn – the quantities of silicon, phosphor, sulphur and manganese, respectively, occurring in cast iron

Table 2.
Chemical compositions of inoculants

Inoculant name	Content of elements* [%]			
	Si	Al	Ca	Ba
Alinoc	70÷75	3.5÷4.5	0.5÷1.5	-
Barinoc	75.1	1.15	1.56	2.41

* according to attestations

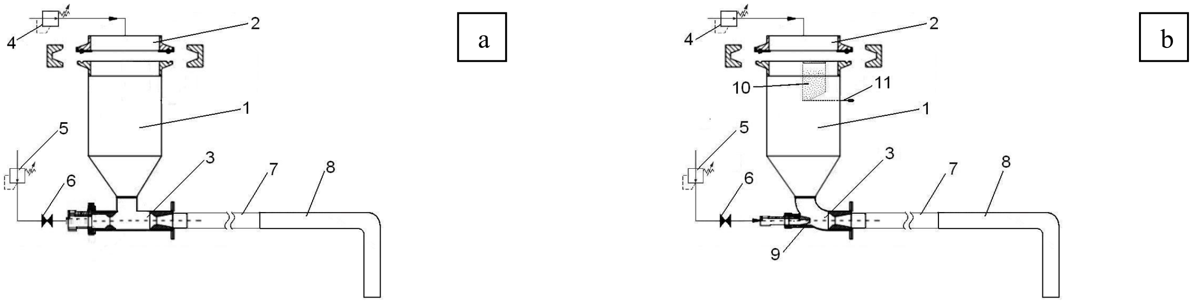

Fig. 1. The scheme of a feeder for the injection of inoculant: a) the initial stand, b) the stand after modification; 1 – pressure vessel; 2 – pressure clamp; 3 – dosing chamber; 4 – pressure regulator; 5 – carrier gas pressure regulator; 6 – electrovalve; 7 – conveying pipe; 8 – the lance injecting master alloy into metal bath; 9 – regulation nozzle; 10 – inoculant storage bin; 11 – shutter

Basing on the technical literature review [9, 15-16] as well as on the previous initial examinations, the following parameters were selected: the pressure p_1 inside the vessel equal to 0.7 MPa (for the first melt, again denoted as A) or 1 MPa (for the second melt, denoted as B); the carrier gas supply pressure equal to 3 or 4 MPa, respectively, for the first or the second melt. The distance of 40 mm between the lance (8 mm in diameter) and the surface of the melt was adopted, as well as the assumption of a constant time of a single impulse duration equal to 100 ms was made.

The melting operations were carried out at the Department of Foundry of Częstochowa University of Technology, by means of a crucible induction furnace of 10 kg capacity. The furnace inductor was supplied with 10 kHz AC. After the complete melting of the charge, the slag was removed and the temperature of melt was measured with the PtRh10-Pt immersion thermocouple equipped with digital indicator. When the temperature of melt reached 1440°C (melt A) or 1480°C (melt B), a sample for the analysis of chemical composition was taken. During the first melting operation (melt A) the weighted portions of previously heated and cooled inoculant were poured directly into the pressure tank of the pneumatic conveyor feeder. After each loading, the inoculant was injected by the carrier gas jet into the liquid cast iron of the temperature equal to 1350 +/-30°C hold in the furnace crucible. During the second melting operation (melt B) the weighted portions of the heated and then cooled inoculant were poured into the inoculant storage bin (Fig. 1b, no. 10). This time the temperature of inoculated melt was equal to 1420 +/- 5°C.

Examination results concerning the chemical composition of the inoculated cast iron during the first melting operation (A) revealed a significant diversity of the inoculation effectiveness level calculated for the individual stages of treatment (see Table 3). This contributed to the decision that the shape of dosing chamber, where the mixing of solid and gaseous phases proceeds (see Fig. 1), should be changed. The mass of metal contained in the crucible used in calculations of the inoculation effectiveness, was determined from the charge mass taking into account the 2% melting loss and the reduction for the weight of specimens already cast during the experiment. Also the system supplying gas into the dosing chamber was modified to make possible a change of diameter and position of the regulation nozzle (Fig. 1b, no. 9). Further, an inoculant storage bin was installed inside the pressure vessel (Fig. 1b, no. 10).

Detailed data concerning the performed examinations are presented in Table 3.

Table 3.
Results of examinations

Melt des.	Sample[3]	Content of elements [%]						C_E[2]	S_C[1]	Mass of master alloy m_d	Percentage of master alloy[4]	Mass of metal in the crucible m_m	Expected Si increase[5]	Real Si increase	Effective-ness[6]
		C	Si	Mn	P	S	Al	[%]		[kg]	[%]	[kg]	[%]	[%]	[%]
A	0 A	3.24	1.51	0.61	0.042	0.029	0.000	3.72	0.85	-		7.466	-	-	-
	I A	3.21	1.58	0.61	0.041	0.029	0.001	3.71	0.85	0.007	0.10	7.172	0.074	0.070	94.2
	II A	3.19	1.67	0.61	0.040	0.029	0.002	3.72	0.85	0.010	0.14	6.992	0.104	0.090	86.2
	III A	3.13	1.80	0.62	0.039	0.028	0.004	3.70	0.84	0.010	0.14	5.455	0.134	0.130	97.1
	IV A	3.06	1.92	0.61	0.040	0.028	0.005	3.66	0.83	0.012	0.22	5.270	0.166	0.120	72.2
	V A	3.03	2.09	0.61	0.040	0.029	0.008	3.69	0.84	0.014	0.27	5.094	0.202	0.170	84.2
B	0 B	2.91	2.37	0.48	0.049	0.032	0.004	3.66	0.83	-		8.30	-	-	-
	I B	2.89	2.52	0.49	0.048	0.030	0.007	3.68	0.83	0.0211	0.25	8.085	0.192	0.146	*
	II B	2.79	2.68	0.49	0.046	0.030	0.006	3.63	0.82	0.0211	0.26	7.996	0.194	0.168	86.4
	III B	2.74	2.86	0.49	0.047	0.031	0.004	3.64	0.81	0.0215	0.27	7.905	0.199	0.172	86.5
	IV B	2.73	3.03	0.49	0.047	0.028	0.004	3.68	0.82	0.0211	0.27	7.802	0.197	0.172	87.3
	V B	2.65	3.21	0.50	0.046	0.029	0.004	3.65	0.81	0.0212	0.27	7.680	0.201	0.177	88.2

[1] S_C calculated according to the formula given in Table 1;
[2] C_E calculated according to the formula given in Table 1;
[3] Roman numerals I-V designate the subsequent injecting operations; the '0' digit denotes cast iron before inoculation;
The contents of other elements fell within the following ranges: Cr = 0,027 – 0,04; Ni = 0,017 – 0,020; Cu = 0,060 – 0,384; V = 0,003; Ti = 0,008-0,009
[4] percentage of injected inoculant with respect to the mass of liquid metal;
[5] calculated from the chemical compositions of metal charge and inoculant;
[6] the effectiveness of injecting operation calculated according to the formula [9]:

$$E = \frac{m_m\left(X_K - X_P\right)}{m_d \cdot X_D} \cdot 100\%$$

where: m_m – mass of metal [kg]; m_d – mass of blown inoculant [kg]; X_K – Si content after the number 'i' inoculation [%]; X_P - Si content before the number 'i' inoculation [%]; X_D – Si content in the inoculant;
* skipped in calculations of effectiveness because the inoculant was partially spilt during the storage bin filling.

3. Conclusion

The results of the performed investigations allow to state that the effectiveness of the inoculation process carried out by the method of impulse blowing the master alloy into cast iron, evaluated through the change of Si content, is very high, i.e. of the order of 80-90%. The changes made in the construction of dosing chamber and application of the regulation nozzle made possible stabilization of the process at the high level of effectiveness (of the order of 86-88%). In many cases the stability of a process is of greater significance than the inoculant yield. It makes possible precision planning of the technological process.

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