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Inoculation of grey cast iron with master alloys containing strontium and zirconium

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Abstract

The effectiveness of cast iron inoculation performed by means of three various inoculants: FeSiSr – SYSTR 75 AV, FeSiZr – SYZR 25 AV and Zircinoc was determined. The inoculants were introduced to the cast iron during the pouring of production moulds. Examination of cast iron structure and mechanical properties were carried out for specimens cut out of the collars of the cast valve bodies. It was found that the quantity of eutectic cells increased to the greatest degree if FeSiZr – SYZR 25 AV inoculant was applied in quantities of 0.20% or 0.25%. This inoculant in the mentioned quantities also increases the tensile strength to the greatest degree, rising it to the level of 250-265 MPa.

Keywords: Solidification process, Cast iron, Inoculation, Structure, Mechanical properties

1. Introduction

The grey cast iron is inoculated mainly to improve its mechanical properties or to assure its solidification according to the stable system both in thin and thick walls of a casting. The treatment under consideration consists in introducing a small amount of particular master alloy into the ‘initial’ (i.e. intended for treatment) cast iron. Although there is no significant changes in the chemical composition of the cast iron, its physical and chemical state is distinctly altered due to such inoculation, and the solidification process is also influenced.

The effect of inoculation depends on a series of factors [1-3]. First of all, there should be mentioned chemical composition of the ‘initial’ cast iron, as well as the temperature of the alloy overheating, its holding time at this temperature, the type and the quantity of the applied inoculant, and conditions under which it is introduced into the molten metal (i.e. metal temperature during the treatment and the way of introducing the inoculant). The inoculation effect depends also on the cast iron solidification and cooling conditions.

A very important feature of an inoculation process is a significant decrease of the effectiveness of the treatment as the period of time elapsing from the moment of adding the inoculant to the pouring operation grows.

According to C. Podrzucki [1], the strongest effect of inoculation is observed when solidification of casting is started within 1-5 minutes after the introduction of inoculant into cast iron, and the effectiveness of the applied inoculants is the stronger, the greater is the supercooling tendency of the initial cast iron.

The effectiveness of cast iron inoculation can be assessed according to the various criteria [2, 4]. Quite frequently the following points are taken into account:

- an increase in the number of eutectic grains;
- changes in characteristics of graphite precipitates
- a decrease in the cast iron chilling tendency;
- changes in mechanical properties of the alloy.

2. Own studies

The purpose of the work was an assessment of the effectiveness of both an inoculant containing strontium, along with Fe, Si, Al, Ca commonly occurring in master alloy, and two inoculants containing zirconium besides the mentioned basic elements. Chemical compositions of the individual inoculants (of grain size 0.2 ÷ 0.7 mm) are given in Table 1.

Table 1.
Chemical compositions of inoculants

No.	Inoculant	Content of elements, %				
		Si	Al	Ca	Sr	Zr
1	FeSiSr-SYSTR 75 AV	70-75	max 0.5	max 0.1	0.6-1.0	–
2	FeSiZr- SYZR 25 AN	70-75	1.0-1.5	1.5-2.5	–	1.0-2.0
3	ZIRCINOC	73-78	1.0-1.5	2.0-2.5	–	1.3-1.8

The investigations were performed under industrial conditions in one of Polish foundries. Cast iron was melted in a hot-blast cupola, then poured into a medium-frequency induction crucible furnace, where its chemical composition was adjusted and the overheating to the presumed temperature was carried out. Subsequently the metal was poured into the induction channel furnace used for pouring moulds at the DISAMATIC automatic moulding line.

The inoculation was performed during the operation of pouring moulds by introducing the measured portion of master alloy into the metal stream by means of the compressed air stream (see Fig. 1). During the experiments each type of inoculant has been added in the quantities equal to 0.20%, 0.25%, or 0.30% with respect to the cast iron mass.

Fig. 1. Modification of the alloy during the mould pouring

Sample wall pieces were cut out of the collars of cast valve bodies 15 mm thick (see Fig. 2), and then the specimens for mechanical test were prepared (see Fig. 3). The gauge diameter has been equal to 6 mm.

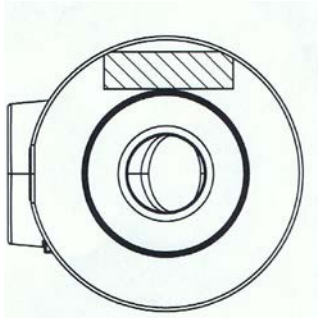

Fig. 2. A scheme of a casting with the marked place from which the material for tensile specimens was taken

Fig. 3. A specimen for mechanical testing made of material cut out of a collar of a casting

Besides strength determination, also cast iron hardness at the middle of walls of valve collars was measured by Brinell method. The 10 mm diameter ball was used, and the force of 29430 N (3000 kG) was applied.

The material cut out of the tensile specimen tabs was used for preparing metallographic specimens. Metallographic examination was carried out by means of the Nikon Epiphot microscope. The features of graphite precipitates were assessed on the non-etched specimens at 100× magnification, according to the Standard [5]. The cast iron microstructures were examined on microsections etched with Nital, according to the Standard [6]. Moreover, the ferrite and pearlite fractions were determined for Nital-etched microsections by means of automatic measurement methods and the NIS-Elements AR 3.10 program. Further, the quantity of eutectic grains was found. The grain boundaries were revealed with Stead's reagent, as in Ref. 4.

Chemical composition of 'initial' cast iron was as follows: C - 3.42%, Si - 1.87%, Mn - 0.48%, P - 0.147%, S - 0.126%, Ni - 0.51%, Cr - 0.092%, Mo - 0.009%, Cu - 0.123%, Al - 0.002%, and its saturation degree S_C was equal to 0.962. These percentage values are the average ones, determined on the basis of several spectrometric analyses performed for the samples taken during the experiment.

Table 2.
The results of metallographic examinations

The alloy type*	Graphite features determined according to the Standard [5]	Microsection areas occupied by pearlite and ferrite determined according to the Standard [6]	Microsection areas occupied by pearlite and ferrite determined by means of NIS-Elements AR 3.10 program	Quantity of eutectic grains $1\cdot cm^{-2}$
1	*2*	*3*	*4*	*5*
10	IA3/4	P/Fe0	F 3.65%, P 96.35%	106
11	IA4	P92/Fe8	F 14.08%, P 85.92%	199
12	IA4	P92/Fe8	F 7.47%, P 92.53%	202
13	IA5	P85/Fe15	F 12.42% P 87.58%	208
20	90%IA3+10%IE5	P96/Fe4	F 9.60%, P 90.40%	126
21	IA4	P96/Fe4	F 15.41%, P 84.59%	255
22	IA4	P92/Fe8	F 13.1%, P 86.84%	259
23	IA4/5	P92/Fe8	F 15.26%, P 84.74%	215
30	30%ID8+70%IE6	P92/Fe8	F 15.10%, P 84.90%	135
31	IA4/5	P96/Fe4	F 8.88%, P 91.12%	242
32	IA6	P92/Fe8	F 16.32%, P 83.68%	252
33	IA5	P92/Fe8	F 13.90%, P 86.10%	218

* - the first digit denotes a type of inoculant:
1 – the FeSiSr – SYSTR 75 AV inoculant;
2 – the FeSiZr – SYZR 25 AV inoculant;
3 – the Zircinoc inoculant;
- the second digit denotes the quantity of the applied inoculant:
0 – without inoculant (the ‘initial’ cast iron) ;
1 – inoculant quantity of 0.20%;
2 – inoculant quantity of 0.25%;
3 – inoculant quantity of 0.30%.

Table 2 compares the results of metallographic examination of the considered cast iron, and Table 3 gives the results of mechanical tests.

Table 3.
Tensile strength and hardness of cast iron

The alloy type*	Tensile strength, MPa	Hardness, HB
1	*2*	*3*
11	213	175
12	218	173
13	234	183
21	250	181
22	265	191
23	247	178
31	249	193
32	249	189
33	244	189

* - designation according to the footnotes in Table 3

Fig. 4, 5, and 6 show shapes and sizes of graphite precipitates, microstructure of the alloy, and eutectic cells, respectively, in the cast iron inoculated with Zircinoc master alloy added in the quantity of 0.25%.

Fig. 4. Shapes and sizes of graphite precipitates occurring in cast iron inoculated with Zircinoc master alloy;
non-etched microsection, magn. 100×

Fig. 5. Microstructure of cast iron inoculated with Zircinoc master alloy; etched with Nital, magn. 400×

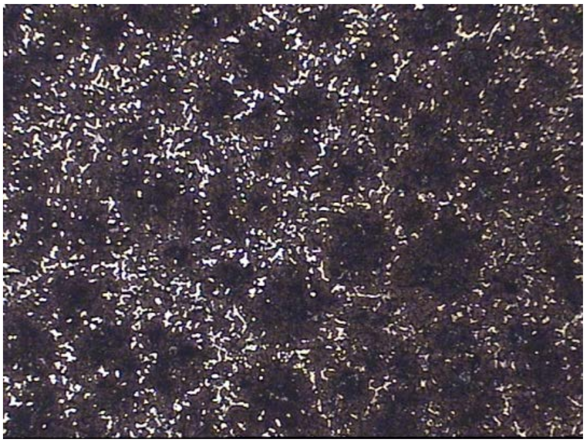

Fig. 6. Eutectic cells in cast iron inoculated with Zircinoc master alloy; etched with Stead's reagent, magn. 25×

3. Conclusion

It should be stressed that the assessment of cast iron inoculation carried out with use of three various master alloys was performed for specimens taken from castings produced under industrial conditions. It results from data cited in Tables 2 and 3 that each of the applied modifiers allowed to obtain cast iron with graphite precipitates of the I shape, being evenly distributed (designation A) and exhibiting the size of 4 – 6 (according to the Standard [5]). It is worth noticing that graphite in the alloy cast directly before inoculation with FeSiZr-SYZR 25 AV or Zircinoc master alloys (denoted as 20 and 30, respectively, in Table 2) occurs partially (for the first of these master alloys) or totally (for the second one) in the interdendritic form (denoted as D or E according to the Standard [5] – see data in column No. 2 in Table 2). The effectiveness of inoculation treatment is confirmed by the photographs presented in Figs 4 to 6.

The inoculation treatment led to the distinct refinement of the alloy structure (see data in column No. 5 in Table 2); the number of eutectic cells increased by about 60% to over 100%. This number was risen to the greatest degree when zirconium-containing master alloy FeSiZr-SYZR 25 AV was introduced in quantities of 0.20% or 0.25%. It should be stressed that for any case the pure pearlitic structure was not obtained after the inoculation (see data in columns No. 3 and 4 in Table 3). The quantity of ferrite ranged from about 4% to about 15%.

An increase in the quantity of the added inoculant resulted, as a rule, in an increase in tensile strength. However, the increase of FeSiZr SYZR 25 AV or Zircinoc form 0.25% to 0.30% resulted in a decrease of the considered parameter value (see data in column No. 2 in Table 3). The highest tensile strength was exhibited by cast iron inoculated with zirconium-containing master alloy FeSiZr SYZR 25 AV (R_m at the level of 250 – 265 MPa). Slightly lower values of this parameter (almost 250 MPa) were obtained in cast iron with Zircinoc addition. Changes in tensile strength were as a rule correlated with changes in cast iron hardness (see data in columns No. 2 and 3 in Table 3).

The results of examinations allow us to be of opinion that the inoculant zirconium-containing is somewhat more efficient than the master alloy containing strontium.

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[6] Polish Standard PN-75/H-04661: Grey cast iron, nodular cast iron and malleable. Metallographic examinations. Determining of microstructure (in Polish).