ARCHIVES of FOUNDRY ENGINEERING

Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences

ISSN (1897-3310)
Volume 12
Special Issue
2/2012

95 – 99

19/2

A Comparison of Selected Methods of Graphitizing Inoculation Applied after the Spheroidizing Treatment

P. Gunia[a], M. S. Soiński[b]*

[a] "TERIEL" Iron Foundry, ul. Lipowa 2a, 63-800 Gostyń, Poland

[b] Department of Foundry, Technical University of Częstochowa, Armii Krajowej 19, 42-200 Częstochowa, Poland

* Corresponding author. E-mail address: soinski.ms@wip.pcz.pl

Received 13.07.2012; accepted in revised form 05.09.2012

Abstract

The work compares the effectiveness of selected methods of graphitizing inoculation applied after the spheroidization in the slender tundish ladle of 1 Mg capacity. The inoculation was carried out according to the three various options. The first one was performed simply by means of the block of inoculant inserted in the gating system of the mould, the second one started with initial inoculation by the in-stream method during the transfer of metal from the slender ladle to the pouring ladle and was completed with the secondary modification by means of the inoculant insert placed in the mould, the third one consisted in similar initial inoculation by the in-stream method during the transfer of metal from the slender ladle to the pouring ladle followed by the secondary inoculation, again by the in-stream method, applied during the pouring operation. Examination of cast iron structure allowed to find that the best results of inoculation are achieved in the case of inoculation carried out according to the Option III, though in all cases it was possible to produce cast iron of EN-GJS-400-15 grade meeting the demands of the Standard [8].

Keywords: Metallography, Cast Iron Structure, Spheroidization, Nodular Graphite, Graphitizing Inoculation

1. Introduction

The nodular cast iron production process consists in three main stages:

- production of initial cast iron with strictly determined basic chemical composition; it cannot contain elements suppressing the precipitation of nodular graphite [1];
- introduction of magnesium or magnesium alloys (the most common method) or cerium and/or other rare earth metals (mainly lanthanum, neodymium and praseodymium);
- graphitizing inoculation (e.g. using ferrosilicon, often along with an addition of other elements like aluminium, calcium, boron, strontium, or zirconium).

The most difficult part of the process is introducing magnesium addition into the molten metal. This is caused by the large difference between the density of cast iron (about 7 Mg/m^3) and magnesium (about 1.7 Mg/m^3), and by the low boiling point of the latter element (1102°C).

But the critical point of nodular graphite cast iron production process is graphitizing inoculation [2]. It is decisive for the microstructure and properties of the resulting material. A properly performed inoculation enables the solidification of cast iron according to the stable equilibrium system (i.e. counteracts the precipitation of carbides), promotes precipitation of rounded forms of graphite and an increase in density of graphite nodules. As a result, cast iron properties are stabilized at the uniform level; this often occurs in the casting walls of various thickness.

The effect of modification fades away with time. This process starts immediately after introduction of inoculant into the molten cast iron and proceeds at the greatest rate during the first minutes after the performed treatment [2]. It is therefore obvious that the modified cast iron should be poured into moulds as soon as possible.

C. Podrzucki [3] notices that there are some differences between inoculation processes taking place during production of gray and nodular cast iron. In the case of gray cast iron the pure ferrosilicon is ineffective as an inoculant, while in the case of the latter alloy it reveals the modifying properties. The cited author emphasizes simultaneously that addition of calcium and aluminium to the inoculant (FeSi75) influences favourably the effectiveness of modification. The maximum effect is achieved at the content of 0.4÷1.0% Ca and 1.8% Al – the structure of cast iron exhibits then the greatest quantity of graphite nodules, and this corresponds to the maximum ferrite percentage in the matrix of the alloy and maximum elongation value [3].

Basic methods of cast iron inoculation can be described as follows:

- ladle inoculation by the in-stream method during the transfer of metal from the ladle used for cast iron spheroidization to the pouring ladle;
- in the case of multiple metal transfer between ladles, the inoculation by the in-stream method during last such transfer or during the mould pouring operation;
- modification of the alloy in the mould.

Particular attention should be paid to the last of the mentioned methods. The inoculation treatment is here carried out at the last possible moment – directly before complete filling of the mould and final solidification of cast iron.

It should be noticed that the criteria for the assessment of the effectiveness of inoculation concerning grey cast iron [4-7] differ from those which refer to the spheroidized cast iron [2, 3].

2. Author's investigation

The work was intended as a study of the effectiveness of graphitizing inoculation of cast iron performed after its spheroidization and carried out according to the three various options (see data in Table 1).

Experiments were carried out under the industrial conditions in one of Polish foundries, during the production of castings made of nodular cast iron, grade EN-GJS-400-15, according to the Standard [8].

Cast iron was melted in the medium frequency induction crucible furnace and then transferred to the channel induction furnace. An adjustment of chemical composition of cast iron was carried out in this latter furnace along with overheating the metal up to the presumed temperature. Spheroidization process was held in a slender ladle of 1 Mg capacity with VL63M master alloy; seven such courses of treatment were carried out in total.

Table 1.
Option of graphitizing inoculation of spheroidized cast iron

Option of graphitizing inoculation	Range of the performed cast iron treatment
I	Cast iron subjected only to graphitizing inoculation by means of the Germalloy K60 inoculant block insert placed in the gating system of the mould
II	Cast iron initially inoculated by the in-stream method during the transfer of metal from a slender ladle to the pouring ladle (0.4% of FeSi75 inoculant; grain size 2 to 10 mm) and then secondary inoculated by means of the Germalloy K60 modifier block insert (as in Option I)
III	Cast iron initially inoculated by the in-stream method during the transfer of metal from a slender ladle to the pouring ladle (as in Option II) and then inoculated again by the in-stream method during the mould pouring operation by means of a special dispenser. Inolate 60 inoculant was applied in the amount of 0.30%, grain size 0.2 to 0.7 mm.

Chemical compositions of inoculants applied during the experiment are given in Table 2.

Table 2.
Chemical compositions of graphitizing modifiers

No.	Inoculant	Content of elements, %								
		Si	Al	Ca	C	P	S	Ti	Zr	Fe
1	Germalloy K60	71.9	3.91	1.02	0.0	0.0	0.0	0.0	0.0	rest
2	FeSi75	74.0	1.90	0.0	0.16	0.029	0.006	0.0	0.0	rest
3	Inolate 60	72.0	1.22	1.98	0.0	0.0	0.0	0.14	1.41	rest

The effectiveness of the performed treatment was assessed on the basis of material analysis carried out for specimens cut out of the produced castings. The mechanical properties of cast iron were determined from the tests performed for specimens cut out of the Y-blocks cast in the sand moulds. The wall thickness of their test part was 25 mm.

The tested cast elements were flanges. The mass of a single casting was 6 kg and 6 flanges were cast simultaneously in one mould. The mass of gating system was equal to 18 kg. Basing on the appropriate directives [9], the Germalloy inoculant block inserts of 60 g mass each, designation K60, were selected for use.

Fig 1 shows a scheme of gating system with inserted both an inoculant block and a foam filter. Fig. 2 presents the lower part of the mould.

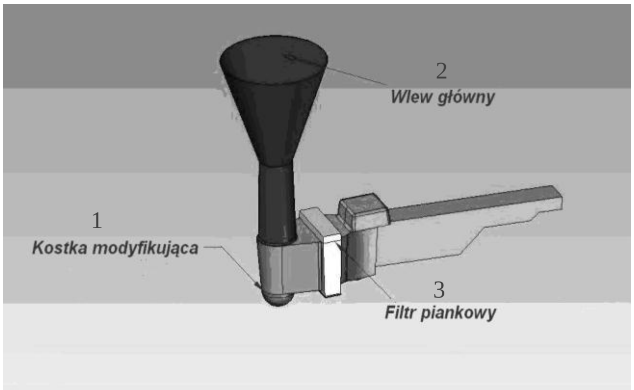

Fig. 1. A scheme of the gating system in the mould;
1 – block of inoculant, 2 – downsprue, 3 – foam filter

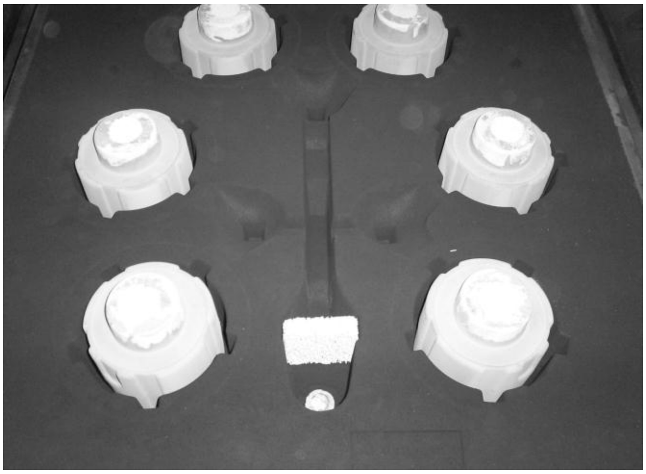

Fig. 2. Lower part of the mould. Six cores, a foam filter and the Germalloy K60 inoculant block (bottom of the figure, in the middle) can be seen

After spheroidization held in the slender tundish ladle, the metal was transferred to the pouring ladle, also of 1 Mg capacity. During this transfer a weighed amount of FeSi75 inoculant was introduced into the metal stream (initial inoculation). This treatment was omitted only in the case of cast iron inoculated according to the Option I (see Table 1). After the completion of metal transfer, the slag coagulant was put on the metal surface, and then the slag was removed. After measuring the molten metal temperature, moulds were poured. Pouring time for an individual mould ranged from 12 to 15 seconds.

The content of basic elements in the examined cast iron determined by means of spectroscopic analysis is given in Table 3.

Table 3.
The content of basic elements in the examined cast iron

Content of elements, %					
C	Si	Mn	P	S	Mg
3.53÷3.71	2.42÷2.79	0.26÷0.29	0.027÷0.043	0.014÷0.028	0.039÷0.065

It should be mentioned that during the inoculation carried out according to either Option II or III (see Table 1) the secondary inoculation was done either immediately after the initial inoculation or after about 10 minutes' time (±1 minute) from that treatment. Mechanical properties of the examined nodular cast iron, determined for specimens cut out of Y-blocks poured in the final period of pouring operation, are gathered in Table 4.

Table 4.
Mechanical properties of the examined nodular cast iron

Option of graphitizing inoculation	Number of the Y-block	Mechanical properties of cast iron			
		R_m [MPa]	$R_{0.2}$ [MPa]	A_5 [%]	HB
I	Y1	440	285	17	163
II	Y2	425	285	18	163
	Y3	425	285	22	170
	Y4	430	300	22	156
	Y5	435	300	17	170
III	Y6	435	285	20	163
	Y7	425	285	18	163

The results of examination concerning the shape and the size of graphite precipitates in the cast iron under consideration carried out for specimens cut out of the produced castings are presented in Table 5. Graphite precipitates were classified according to the Standard [10]. The letter A denotes castings produced of cast iron poured immediately after the initial modification, while the letter B indicate castings poured after 10 minutes' time from that initial treatment.

Table 5.
The assessment of shape and size of graphite precipitates occurring in the examined casting according to the Standard [10]

Option of graphitizing inoculation	Number of specimen	Number of casting	Assessment of graphite precipitates
I	1	M.1.1	95% VI 6/7 + 5% V 6/7
	2	M.1.2	95% VI 6/7 + 5% V 6/7
	3	M.1.3	98% VI 6/7 + 2% V 6/7
	4	M.1.4	95% VI 6/7 + 5% V 6/7
	5	M.1.5	97% VI 6/7 + 3% V 6/7
II	6	M.2.1A	97% VI 6/7 + 3% V 6/7
	7	M.2.1B	97% VI 6/7 + 3% V 6/7
	8	M.2.2A	98% VI 6/7 + 2% V 6
	9	M.2.2B	98% VI 6/7 + 2% V 6/7
	10	M.2.3A	98% VI 6/7 + 2% V 6
	11	M.2.3B	97% VI 6/7 + 3% V 6/7
III	12	M.3.1A	95% VI 6/7 + 5% V 6/7
	13	M.3.1B	95% VI 7/8 + 5% V 6/7
	14	M.3.2A	98% VI 7/8 + 2% V 6/7
	15	M.3.2B	95% VI 6/7 + 5% V 6

The quantities of nodular graphite precipitates occurring in the examined cast iron are shown in Figure 3. They were determined basing on the model presented in Ref. [2]. Figure 4 shows the percentage of ferrite in the examined cast iron matrix. Figures 5-10 present alternately graphite precipitates occurring in the examined cast iron ant the microstructures of the alloy.

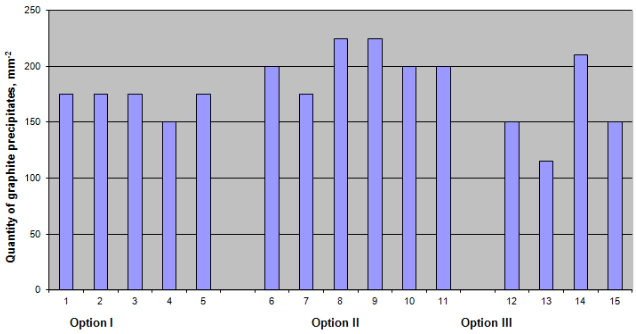

Fig. 3. Quantities of nodular graphite precipitates occurring in the examined cast iron. Options of inoculation treatment are characterised in Table 1. Numbers 1÷15 correspond to the numbers of specimens used in Table 5

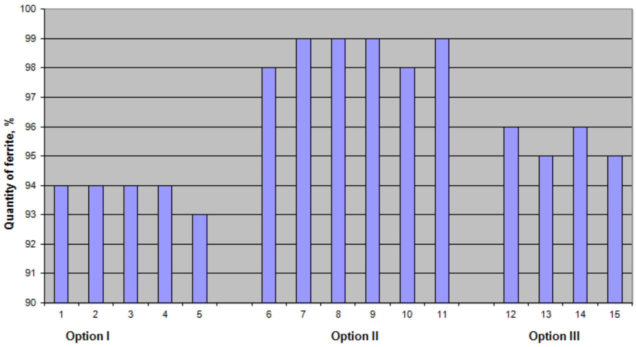

Fig. 4. Percentage of ferrite in the examined cast iron matrix. Options of inoculation are characterised in Table 1. Numbers 1÷15 correspond to the numbers of specimens used in Table 5

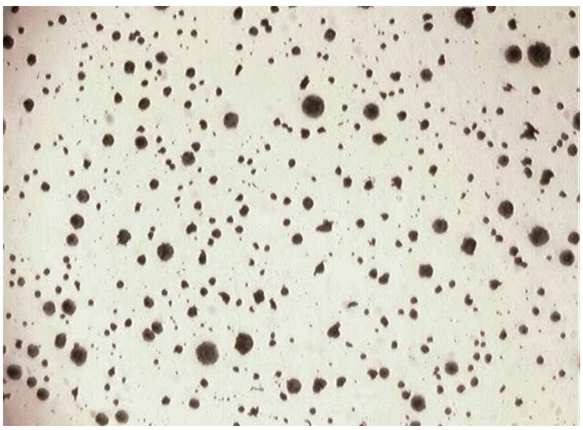

Fig. 5. The shape, the size and the arrangement of graphite precipitates in cast iron inoculated according to the Option I. Specimen No. 3, the non-etched microsection, magn. 100×

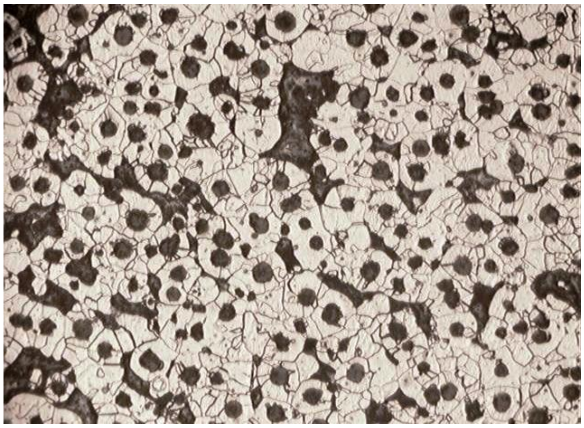

Fig. 6. Microstructure of cast iron inoculated according to the Option I. Specimen No. 3, microsection etched with Nital, magn. 100×

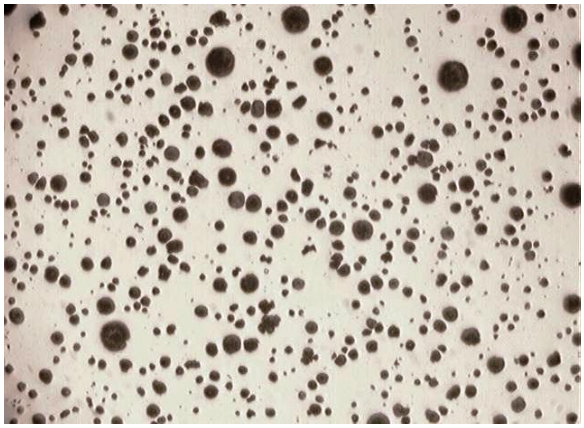

Fig. 7. The shape, the size and the arrangement of graphite precipitates in cast iron inoculated according to the Option II. Specimen No. 8, the non-etched microsection, magn. 100×

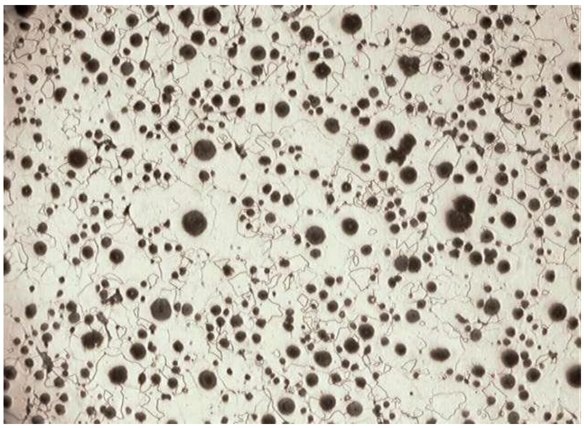

Fig. 8. Microstructure of cast iron inoculated according to the Option II. Specimen No. 8, microsection etched with Nital, magn. 100×

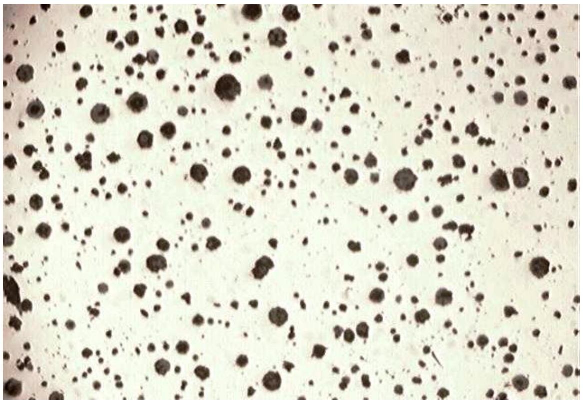

Fig. 9. The shape, the size and the arrangement of graphite precipitates in cast iron inoculated according to the Option III. Specimen No. 12, the non-etched microsection, magn. 100×

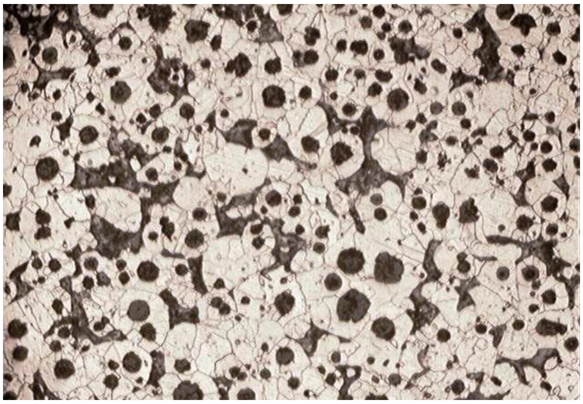

Fig. 10. Microstructure of cast iron inoculated according to the Option III. Specimen No. 12, microsection etched with Nital, magn. 100×

3. Conclusion

The effectiveness of graphitizing inoculation of the spheroidized cast iron, carried out according to the three options (see data in Table 1), was compared in the work. The metallographic analysis indicates (see data in Table 5 and Figs. 3 and 4) that both the maximum quantity of nodular and nearly-nodular graphite precipitates per unit area and the maximum ferrite fraction in the cast iron matrix occurred in the case of inoculation carried out according to the Option II. Therefore the most effective of the considered methods appeared to be the double modification, including the initial in-stream inoculation during the transfer of metal from the slender ladle to the pouring ladle and the secondary inoculation by means of a block of inoculant inserted in the mould. In the case of cast iron treated according to the Option II of inoculation process the quantity of graphite precipitates fell within 175 to 225 objects per mm^2 ($200 \cdot mm^{-2}$ on average), while in the case of cast iron treated according to Options I or III the corresponding value was from 150 to 175 precipitates per mm^2 (about $170 \cdot mm^{-2}$ on average). It should be noticed that however the cast iron inoculated by the inoculation insert alone (Option I) revealed somewhat larger quantity of nodular graphite precipitates than the cast iron double modified by the in-stream method (Option III), it exhibited a little lower ferrite percentage than the other examined cast iron types.

This can be seen in Figs. 5, 7, and 9 presenting shapes, sizes and arrangements of graphite precipitates, as well as in Figs. 6, 8, and 10 showing microstructures of the examined cast iron.

The results of examination of mechanical properties exhibited by the cast iron under consideration (see data in Table 4) allow to state that the alloy inoculated according to any of the applied options meets the demands of the Standard [8] for the nodular cast iron EN-GJS-400-15. However, only the cast iron inoculated according to the Option II revealed the elongation exceeding 20% (two of the four cases).

References

[1] Thielemann T. (1970). Zur Wirkung von Spurenelementen im Gusseisen mit Kugelgraphit. *Giessereitechnik* 16(1), 16-24.

[2] Sorelmetal – Rio Tinto Iron & Titanium Inc. (2006). *The Sorelmetal Book of Ductile Iron.* Warsaw: Metals & Minerals Sp. z o.o.

[3] Podrzucki C. (1991). *Cast iron. Structure, properties, applications*. Cracow: Ed. ZG STOP.

[4] Fraś E., Podrzucki C. (1981). *Modified cast iron. 2nd edition*. Cracow: Ed. AGH.

[5] Soiński M. S., Wawrzyniec A. (2010) Initial assessment of some selected inoculants for grey cast iron. *Archives of Foundry Engineering.* 10(2), 155-158.

[6] Soiński M. S., Wawrzyniec A. (2010) Initial assessment of secondary inoculation of grey cast iron. *Archives of Foundry Engineering.* 10(4), 205-208.

[7] Soiński M. S., Jędrecki P., Grzesiak R. (2011). Inoculation of grey cast iron with master alloys containing strontium and zirconium. *Archives of Foundry Engineering.* 11(3 special), 195-198.

[8] Polish Standard PN-EN 1563:2000. *Founding. Spheroidal graphite cast irons.* Warsaw: PKN.

[9] SKW Giesserei. (2012). Germalloy inoculant for castings of nodular cast iron – information cards. Ed. ASK Chemicals Poland Ltd.

[10] Polish Standard PN-EN ISO 945-1:2009. *Microstructure of cast irons. Part 1: Graphite classification by visual analysis.* Warsaw: PKN.