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The Influence of Small Amounts of Aluminium on the Effectiveness of Cast Iron Spheroidization with Magnesium

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Abstract

The influence of aluminium added in amounts of about 1.6%, 2.1%, or 2.8% on the effectiveness of cast iron spheroidization with magnesium was determined. The cast iron was melted and treated with FeSiMg7 master alloy under industrial conditions. The metallographic examinations were performed for the separately cast rods of 20 mm diameter. They included the assessment of the shape of graphite precipitates and of the matrix structure. The results allowed to state that the despheroidizing influence of aluminium (introduced in the above mentioned quantities) is the stronger, the higher is the aluminium content in the alloy. The results of examinations carried out by means of a computer image analyser enabled the quantitative assessment of the considered aluminium addition influence. It was found that the despheroidizing influence of aluminium (up to about 2.8%) yields the crystallization of either the deformed nodular graphite precipitates or vermicular graphite precipitates. None of the examined specimens, however, contained the flake graphite precipitates. The results of examinations confirmed the already known opinion that aluminium widens the range of ferrite crystallization.

Keywords: Metallography, Aluminium, Cast iron, Spheroidization, Graphite precipitates

1. Introduction

The fire resistance of cast iron depends greatly on the shape of graphite precipitates. In the case of grey cast iron they create a kind of skeleton which facilitates the access of oxygen to the interior of a casting thus considerably limiting the temperature range within which castings made of this material can work. The spheroidization treatment yields the change in the shape of graphite; the nodular precipitates arise. These precipitates, as well as the accompanying (or separately arisen) vermicular graphite precipitates, are independent and not connected one to another. The 'replacement' of flake graphite precipitates with nodular and/or vermicular ones results in a distinct increase in the high-temperature oxidation resistance of the alloy.

The fire resistance of cast iron can be significantly increased by introducing a proper alloying element. One of the most important additions introduced in order to increase the fire resistance of the alloy, and comparatively inexpensive, is aluminium [1-3]. However the allowable working temperature for castings made of aluminium cast iron increases with the increase of aluminium content in the cast iron, already relatively small content of aluminium in the alloy (2-3%) influences advantageously its fire resistance. It results from the fact that aluminium increases the temperature of generation of the most harmful layer in the scale, i.e. wüstite [1]. As the content of the discussed element in cast iron increases, the temperature of the eutectoid transformation rises [4-5], contributing largely to the fire resistance of cast iron.

Aluminium is commonly regarded as the addition counteracting the crystallization of the nodular graphite precipitates [1-3, 6]. This opinion was confirmed by results of a series of experiments during which the low-aluminium cast iron

was subjected to the treatment with cerium mixture and the graphitising inoculation with ferrosilicon [3, 7-9].

2. Author's investigations

The purpose of the work was the determination of the influence of aluminium added in quantities from about 1.6% to about 2.8% on the effectiveness of the spheroidizing treatment done with magnesium. The idea was to verify the suggestions found in professional literature (e.g. Ref. [10]) that it is possible to obtain the nodular graphite in low-aluminium cast iron as a result of applying magnesium as a spheroidizing agent.

The experiment was realised using the cast iron produced by one of domestic foundries. The following method was applied: cast iron after being spheroidized in a ladle by pouring the liquid metal over the FeSiMg7 master alloy and 75% ferrosilicon was transferred into the two shank ladles carefully heated before the experiment. The suitable portion of molten aluminium was added to one of these ladles just before its filling with the cast iron and then the specimens were cast, both of the basic cast iron and of the one with aluminium addition. The rod-like samples were of the truncated cone shape with the average diameter (i.e. the diameter halfway the test part length) equal to 20 mm. Three experiments were performed altogether, the aluminium content being changed each time and equal to about 1.6%, 2.1%, or 2.8%, respectively for the subsequent experiments. The diameter of specimens cut out of the rods for metallographic inspection was 20 mm (at the microsection surface).

Table 1 gives the chemical composition of each of the produced cast iron types.

Table 1.
Chemical composition of the examined cast iron

Cast iron designation*	Content of element [%]						
	Al	C	Si	Mn	S	P	Mg
1A	1.62	3.16	3.04	0.25	0.018	0.14	ND
1B	-	3.60	2.93	0.24	0.020	0.14	0.12
2A	2.06	3.10	3.33	0.22	0.019	0.13	ND
2B	-	3.27	3.31	0.22	0.019	0.12	0.06
3A	2.81	3.15	3.02	0.19	0.020	0.12	ND
3B	-	3.36	3.20	0.19	0.018	0.12	0.07

* Figures 1-3 designate the number of melt; letters stand for:
A – cast iron with the aluminium addition;
B – cast iron without the aluminium addition

A comparison of cast irons of similar basic composition, and what more coming from the same melt and spheroidized in the same way with magnesium master alloy, the one containing aluminium and the other without this addition, allow to assess the influence of the alloying addition under consideration on formation of nodular graphite in cast iron.

Metallographic examinations performed by means of an optical microscope enabled the assessment of features of graphite

precipitates according to the Standard [11] and of pearlite and ferrite fractions according to the Standard [12] (Table 2).

Table 2.
The results of metallographic examination of cast iron

Cast iron designation*	Microsection area occupied by pearlite and ferrite determined according to the Standard [12]	Features of graphite precipitates determined according to the Standard [11]
1A	P45 Fe55	V 6/7
1B	P45 Fe55	VI 6/7
2A	P20 Fe80	60% VI 6 + 40% III 7/8
2B	P45 Fe55	VI 6/7
3A	P20 Fe80	50% V 6 + 50% III 6
3B	P45 Fe55	VI 6/7

* see the footnote in Table 1

Figures 1-3 present the graphite and the microstructures of cast iron coming from the examined melts.
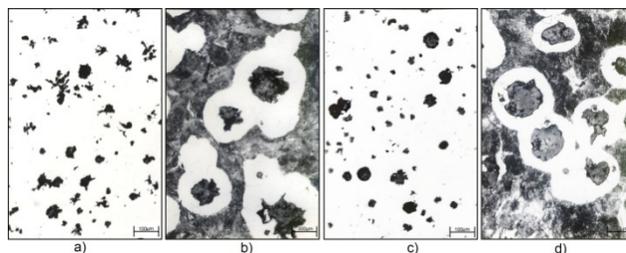

Fig. 1. Cast iron from the melt No. 1; a) and c) – graphite precipitates in cast iron with about 1.6% of Al addition and without the addition, respectively, non-etched microsections; b) and d) – microstructure of cast iron with about 1.6% of Al addition and without the addition, respectively, etched with Nital
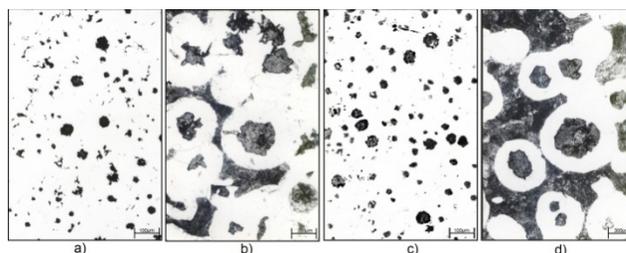

Fig. 2. Cast iron from the melt No. 2; a) and c) – graphite precipitates in cast iron with about 2.1% of Al addition and without the addition, respectively, non-etched microsections; b) and d) – microstructure of cast iron with about 2.1% of Al addition and without the addition, respectively, etched with Nital
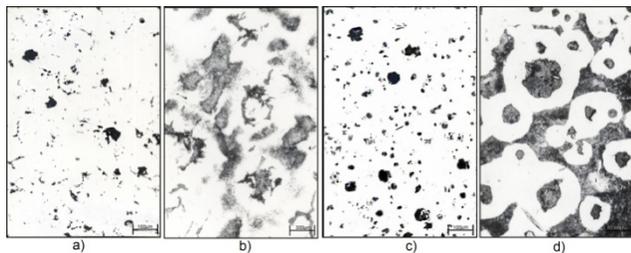
Fig. 3. Cast iron from the melt No. 3; a) and c) – graphite precipitates in cast iron with about 2.8% of Al addition and without the addition, respectively, non-etched microsections; b) and d) – microstructure of cast iron with about 2.8% of Al addition and without the addition, respectively, etched with Nital

The effectiveness of the spheroidizing treatment applied for the cast iron with aluminium addition was assessed by calculating the degree of spheroidization 'F'. For the purpose of comparison the appropriate measurements and calculations were also done for the cast iron without aluminium addition. The 'F' coefficient was determined according to the formula:

$$F = \frac{(L_A)^2}{2 \cdot A_A \cdot P_A} \qquad (1)$$

where: F – the degree of graphite spheroidization,
L_A – the perimeter of graphite precipitates,
A_A – the area occupied by graphite precipitates,
P_A – the number of graphite precipitates.

The examination was carried out each time for 20 measurement fields on the non-etched microsections. The average results of quantitative measurements of the graphite precipitates taken by means of a computer image analyser and the values of the degree of spheroidization 'F' determined on the basis of the measurement data are given in Table 3.

Table 3.
Results of graphite examination by means of a computer image analyser and the determined degrees of graphite spheroidization 'F'

Cast iron designation*	Area occupied by graphite precipitates %	Perimeter of graphite precipitates mm/mm^2	Number of graphite precipitates 1/mm^2	Degree of graphite spheroidization F
1A	7.50	18.40	339.89	6.64
1B	9.03	17.10	365.59	4.43
2A	8.66	25.30	518.40	7.13
2B	8.10	17.32	362.74	5.10
3A	6.79	26.46	661.21	7.80
3B	9.23	19.16	432.71	4.59

* see the footnote in Table 1

3. Conclusion

A comparison of the shape of graphite precipitates and the microstructures of the non-alloyed cast iron and the alloy containing the addition of aluminium in quantities of about 1.6%, 2.1%, and 2.8% (see Figs. 1, 2, and 3), as well as the data presented in Table 2, allows to confirm the opinion that aluminium exerts a despheroidizing influence on cast iron. As the aluminium content in the alloy increases from about 1.6% to about 2.8% (for the more precise data see Table 1), the degree of graphite spheroidization changes as follows:

– F = 6.64 for cast iron containing 1.62% of Al,
– F = 7.13 for cast iron containing 2.06% of Al,
– F = 7.80 for cast iron containing 2.82% of Al.

Simultaneously, the F coefficient took the values from 4.4 to 5.1 for basic cast irons of corresponding compositions. It should be mentioned that the greater value of 'F', the smaller is the graphite spheroidization. The suggestion [10] that it is possible to achieve only the nodular graphite precipitates if magnesium is used for cast iron spheroidization was not confirmed. Instead of purely nodular graphite precipitates occurring in the non-alloyed cast iron, the cast iron containing aluminium revealed also the presence of the following graphite types:

– the type V graphite (according to the Standard [11]) i.e. slightly irregular particles of nodular graphite in cast iron containing about 1.6% of aluminium,
– the type III graphite (vermicular graphite) in the quantity of about 40%, which accompanied the nodular precipitates in cast iron containing about 2.1% of aluminium,
– both the type V (irregular nodular) and the type III (vermicular) graphite in cast iron containing about 2.8% of aluminium.

The results of examinations with regard to the pearlite and ferrite quantities in the analysed cast iron (see data in Table 2) confirmed the reported observations that aluminium widens the ferrite crystallization range.

The fact that introduction of aluminium in the above stated quantities did not lead to the flake graphite precipitation is very important as far as the high fire resistance of material is to be provided.

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