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The Influence of Small Amounts of Aluminium on the Spheroidization of Cast Iron with Cerium Mischmetal

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Abstract

The influence of aluminium (added in quantity from about 0.6% to about 2.8%) on both the alloy matrix and the shape of graphite precipitates in cast iron treated with a fixed amounts of cerium mischmetal (0.11%) and ferrosilicon (1.29%) is discussed in the paper. The metallographic examinations were carried out for specimens cut out of the separately cast rods of 20 mm diameter. It was found that the addition of aluminium in the amounts from about 0.6% to about 1.1% to the cast iron containing about 3% of carbon, about 3.7% of silicon (after graphitizing modification), and 0.1% of manganese leads to the occurrence of the ferrite-pearlite matrix containing cementite precipitates in the case of the treatment of the alloy with cerium mischmetal . The increase in the quantity of aluminium up to about 1.9% or up to about 2.8% results either in purely ferrite matrix in this first case or in ferrite matrix containing small amounts of pearlite in the latter one. Nodular graphite precipitates occurred only in cast iron containing 1.9% or 2.8% of aluminium, and the greater aluminium content resulted in the higher degree of graphite spheroidization. The noticeable amount of vermicular graphite precipitates accompanied the nodular graphite.

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

1. Introduction

The presence of aluminium significantly influences the cast iron graphitizing power. If cast iron is subjected to the spheroidization treatment, this presence influences very distinctly the shape of graphite precipitates. It is a common opinion [1-9] that aluminium counteracts the crystallization of nodular graphite precipitates.

The results of author's investigation [10] confirm the cited opinion and specified that the influence of aluminium which impede the spheroidization treatment is related to its effect on the growth of the maximum eutectic temperature. The work cited states that it is not possible to produce the hypereutectic low-aluminium-chromium cast iron containing about 3% of Al and exhibiting ferritic matrix with solely nodular graphite precipitates in the as-cast state. The metal was treated with cerium mischmetal and ferrosilicon. The treatment with cerium-containing mixture and the following graphitizing modification with ferrosilicon also failed to bring about the full spheroidization of graphite in the case of either cast iron containing about 3% of Al and about 1% of chromium [11], or the hypoeutectic low-aluminium cast iron ($S_C \approx 0.9$) [12], or the cast iron of lowered silicon content with the addition of about 3% of aluminium [13].

Continuing the investigation in the field of achieving the nodular (or vermicular) graphite precipitates in cast iron with aluminium addition, it was assumed that carrying out the investigation concerning the influence of aluminium (added in the amount less than 3%) on the structure of cast iron treated with cerium mischmetal is reasonable.

2. Author's investigation

The work was aimed to determine the influence of aluminium in the amount from about 0.6% to about 2.8% on the structure of cast iron treated with cerium mischmetal and subjected to graphitizing modification with 75% ferrosilicon. Four experimental melts were held during the investigation. The charge was composed of the specially prepared grey iron, containing the basic elements within the presumed limits. While determining the desirable quantity of carbon in the charge cast iron, two contradicting conditions were taken into account, i.e. that the purpose is to achieve the nodular cast iron (which means that the relatively large carbon amount would be demanded) and that introducing aluminium to the melt results in the decreased solubility of carbon in cast steel. Taking this into account, it was stated that the quantity of carbon in the charge cast iron should be maintained within the range of 3.2÷3.4%. It has been assumed that the silicon content in the charge material should fall within 0.7÷1.0%, as it was during the former investigations. Manganese content was restricted to 0.1% maximally in order to achieve the desired structure with ferrite fraction as high as possible. It has been also assumed that the content of both sulphur and phosphor should be at the possible lowest level.

Table 1 shows the content of basic elements in the charge cast iron. Chemical compositions of the cerium mischmetal and ferrosilicon used in experiments are given in Tables 2 and 3, respectively.

Table 1.
Chemical composition of charge cast iron

Content of elements, %				
C	Si	Mn	P	S
3.29	0.84	0.092	0.040	0.026

Table 2.
Chemical composition of cerium mischmetal

Content of elements, %							
Si	Al	Mg	Ce	Nd	Pr	La	Fe
0.20	0.05	0.20	49.2	17.5	5.4	23.7	0.05

Table 3.
Chemical composition of ferrosilicon

Content of elements, %						
Si	C	Mn	P	S	Al	Ca
67.1	0.27	0.42	0.038	0.004	2.05	2.40

The experimental melting was carried out by means of a laboratory induction furnace; the inductor was supplied with the AC of 10kHz frequency from the thyristor converter of the Leybold-Heraeus IS1/III-type induction vacuum furnace. The melting process was carried out in a crucible of about 8 kg capacity, made of heat-resistant concrete (neutral material).

Molten charge cast iron, after being overheated up to 1400°C, was treated with aluminium introduced beneath the metal mirror. The melt was heated again up to 1360-1380°C, then cerium mischmetal was added, and the roasted ferrosilicon was introduced five minutes later. The quantities of cerium mischmetal and ferrosilicon were equal to 0.11% and 1.29% of the achieved cast iron mass. Such quantities had been found optimal in the case of spheroidization process of low-aluminium cast iron containing about 3% Al [14]. Five minutes after the graphitizing modification with ferrosilicon, sand moulds were poured with molten metal directly from the crucible. The specimens were cast in the shape of truncated cones, their average diameter (measured halfway along their test parts) being equal to 20 mm.

Table 4 presents chemical composition of the produced cast iron.

Table 4.
Chemical compositions of the examined cast iron

No. of melt	Content of elements, %					
	Al	C	Si	Mn	S	P
1	0.63	3.08	3.68	0.11	0.018	0.060
2	1.11	3.10	3.60	0.10	0.018	0.060
3	1.89	3.08	3.79	0.10	0.017	0.050
4	2.79	2.89	3.68	0.11	0.022	0.055

Specimens for metallographic examination of about 20 mm diameter at the microsection surface were cut out of the cast material. Optical microscope examination allowed to determine the features of graphite precipitates according to the Standard [15] and the fractions of pearlite and ferrite according to the Standard [16]. The presence of cementite was also found in the material from melt No. 1 and No. 2.

Computer image analysis was used for the quantity assessment of the shape of graphite precipitates and the degree of spheroidization. Similarly to the Ref. [10], it was assumed that the degree of graphite spreroidization is described by the formula:

$$\eta_{sph} = \frac{\sum P_{(F \geq k)}}{\sum P} \cdot 100\% , \qquad (1)$$

where η_{sph} – the degree of graphite spheroidization, %;
P – the area of a graphite precipitate, mm^2;
F – the shape factor of a graphite precipitate;
k – the critical value of shape factor.

The shape factor F was determined for each individual graphite precipitate according to the formula:

$$F = \frac{P}{C^2}, \qquad (2)$$

where P – as in the previous formula;
C – the perimeter of a graphite precipitate, mm.

The shape factor values calculated according to the above formula are 0.0796 for a circle, 0.0625 for a square, 0.048 for an equilateral triangle.

The results of metallographic examination carried out by means of an optical microscope are presented in Table 5.

Table 5.
Results of metallographic examination of cast iron

No. of melt	Microsection area occupied by pearlite (P), ferrite (Fe), cementite (C)*, %	Features of graphite precipitates**
1	P30 / Fe45 / C25	II B 6
2	P30 / Fe45 / C25	II B 6
3	P0 / Fe	80% III A 4 + + 20% VI A 5
4	P6 / Fe94	70% III A 4 + + 30% VI A 4

* according to the Standard [16]
** according to the Standard [15]

Figures 1-8 show in sequence graphite precipitates and microstructure of cast iron in each of the experimental melts.

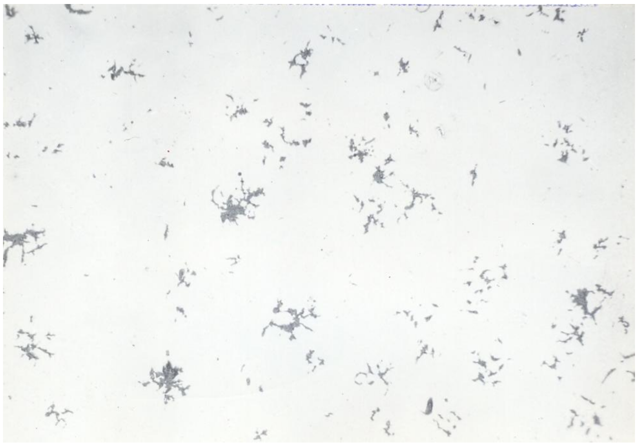

Fig. 1. Graphite precipitates in cast iron from the melt No. 1, the non-etched microsection, magn. 100×

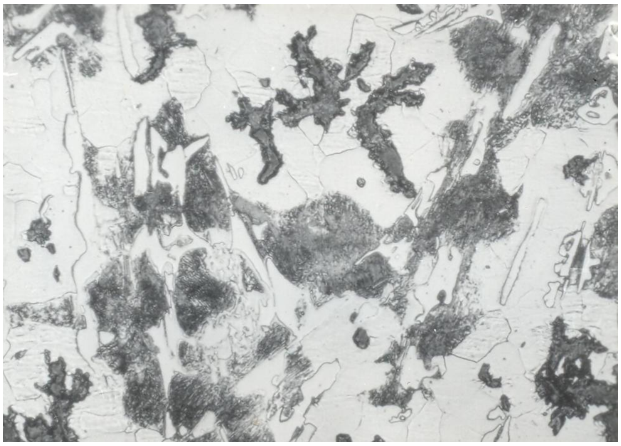

Fig. 2. The microstructure of cast iron from the melt No. 1, etched with Nital, magn. 300×

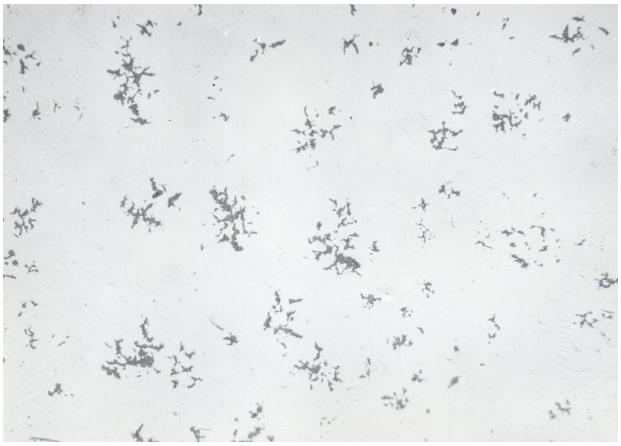

Fig. 3. Graphite precipitates in cast iron from the melt No. 2, the non-etched microsection, magn. 100×

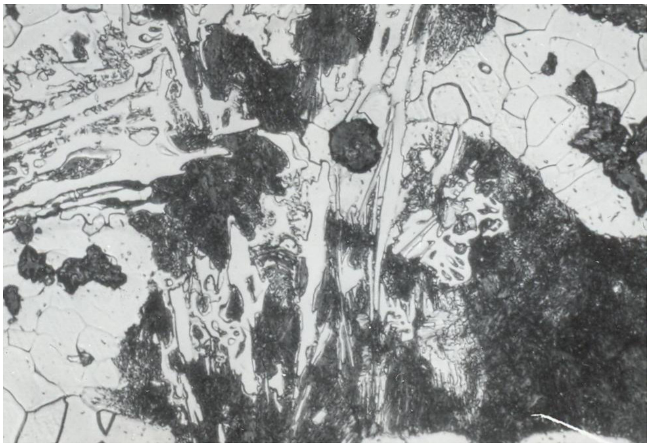

Fig. 4. The microstructure of cast iron from the melt No. 2, etched with Nital, magn. 300×

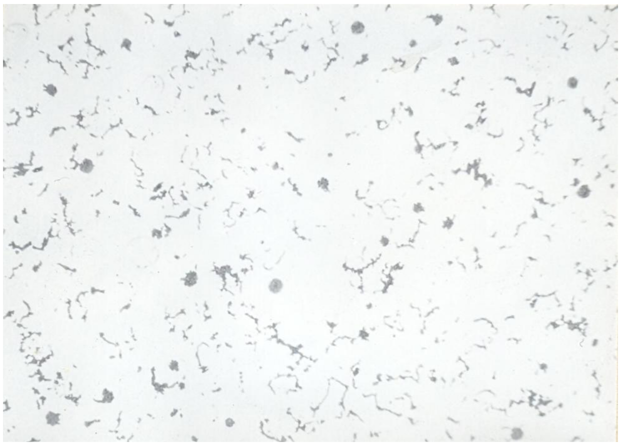

Fig. 5. Graphite precipitates in cast iron from the melt No. 3, the non-etched microsection, magn. 100×

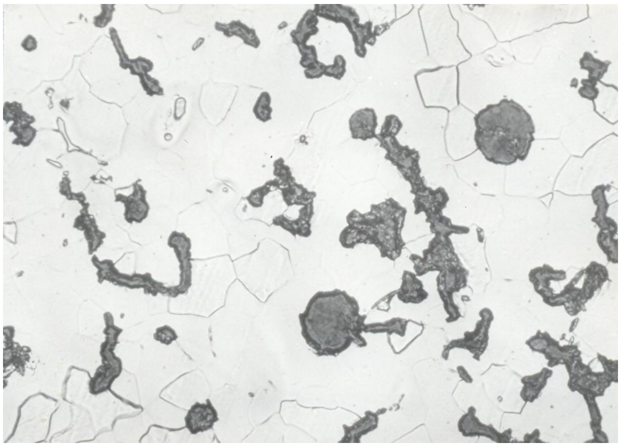

Fig. 6. The microstructure of cast iron from the melt No. 3, etched with Nital, magn. 300×

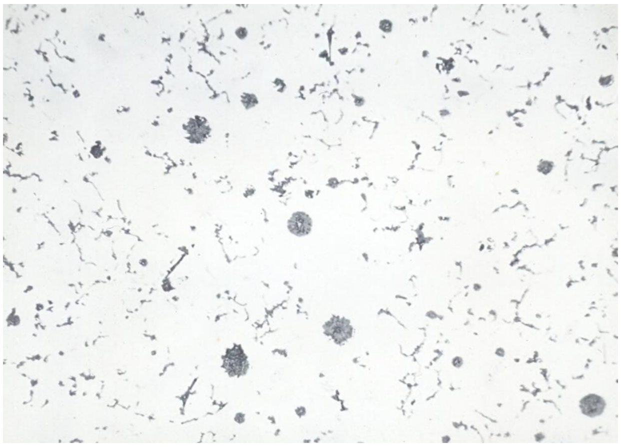

Fig. 7. Graphite precipitates in cast iron from the melt No. 4, the non-etched microsection, magn. 100×

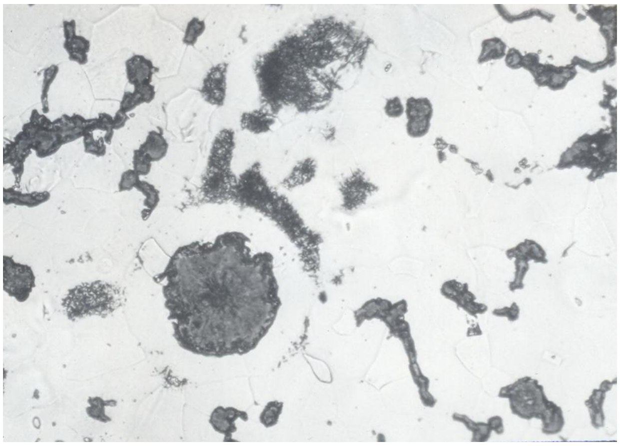

Fig. 8. The microstructure of cast iron from the melt No. 4, etched with Nital, magn. 300×

The results of examination carried out by means of a computer image analyser are shown in Tables 6 and 7.

Table 6.
Area percentage of graphite (related to the total examined area of microsection)

No. of melt	1	2	3	4
Area percentage of graphite, %	4.95	4.81	5.71	6.76

Table 7.
Area percentage of graphite precipitates assigned to the individual shape factor ranges (related to the total examined area of graphite)

Shape factor range	Area percentage of graphite precipitates, %			
	Melt No. 1	Melt No. 2	Melt No. 3	Melt No. 4
1	2	3	4	5
0.00 ÷ 0.01	11.16	9.70	1.86	1.75
0.01 ÷ 0.02	32.89	27.19	20.18	15.96
0.02 ÷ 0.03	18.71	21.49	23.20	19.55
0.03 ÷ 0.04	12.65	15.00	17.20	16.46
0.04 ÷ 0.05	10.11	11.15	12.62	13.92
0.05 ÷ 0.06	8.41	8.89	10.36	12.27
0.06 ÷ 0.07	5.47	5.82	11.25	14.33
over 0.07	0.60	0.76	3.33	5.76

3. Conclusion

The analysis was carried out concerning the data gathered in Tables 4-7 and photographs presenting both the shape, the magnitude, and the distribution of graphite precipitates (Figs 1, 3, 5, 7), as well as those showing the microstucture of cast iron (Figs 2, 4, 6, 8). It allowed for the assessment of the influence of aluminium added in the quantity falling into the concerned range on both the graphitization of cast iron and its susceptibility to spheroidization with cerium mischmetal. The latter addition was used in the quantity of 0.11 wt% of the material subjected to the treatment.

Introduction of aluminium in the quantity of either about 0.6% (the alloy from melt No. 1) or about 1.1% (the alloy from melt No. 2) leads to the arising of the ferrite-pearlite matrix containing the precipitates of free cementite despite the significant silicon content in the cast iron (see data in Table 4 and Figs 2 and 4). The cast iron from these two melts did not contain the regular nodular graphite precipitates. In both cases the shape of graphite precipitates, according to the Standard [15], can be classified as II, its distribution as B, magnitude as 6 (see Figs 1 and 3).

A comparison of data juxtaposed in Tables 6 and 7 allows for statement that as far as the cast iron from the melts No. 1 and No. 2 is concerned, both the areas occupied by graphite and their percentages assigned to the individual shape factor ranges are very similar (compare columns 2 and 3). Also the degrees of spheroidization are similar, i.e. η_{sph1} = 24.6% for the melt No. 1, η_{sph2} = 26.6% for the melt No. 2.

The increase of aluminium content in cast iron up to about 1.9% (material from the melt No. 3) results in crystallization of nodular and vermicular graphite precipitates, the quantity of the latter prevailing (see Fig. 5 and the data in Table 5). The matrix of the alloy turns to pure ferritic one (Fig. 6).

Further increasing of aluminium content in cast iron up to about 2.8% (ally from melt No. 4) causes an increase in the area fraction of nodular graphite and the decrease in fraction of vermicular graphite (comp. Figs 5 and 7); trace quantities of pearlite occur in the alloy matrix (see Fig. 8). The degrees of graphite spheroidization in the case of cast iron from melts No. 3 and No. 4 are η_{sph3} = 37.6% and η_{sph4} = 46.3%, respectively. Total area percentage occupied by graphite precipitates is noticeably greater in cast iron from melts No. 3 and 4 than it is in the material from melts No. 1 and No. 2.

It should be noticed that in the case of cast iron containing from 0.6% to 2.8% of aluminium, about 3% of carbon, and about 3.7% of silicon (after graphitizing modification) the treatment with cerium mischmetal in the quantity of 0.11% allows to achieve the pure ferritic matrix only for the aluminium content of about 1.9%. Only nodular and vermicular graphite precipitates occur in the structure of such alloy. The smaller amounts of aluminium (0.6% to 1.1%) results in the occurrence of cementite precipitates in addition to ferrite and pearlite. In the case of greater aluminium content (about 2.8%), although the degree of graphite spheroidization increases, pearlite starts to occur in the cast iron matrix.

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