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Characteristics of Graphite Precipitates in Aluminium Cast Iron Treated with Cerium Mixture

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Abstract

The work determined the influence of aluminium in the amount from about 1% to about 7% on the graphite precipitates in cast iron with relatively high silicon content (3.4% to 3.90%) and low manganese content (about 0.1%). The cast iron was spheroidized with cerium mixture and graphitized with ferrosilicon. The performed treatment resulted in occurring of compact graphite precipitates, mainly nodular and vermicular, of various size. The following parameters were determined: the area percentage occupied by graphite, perimeters of graphite precipitates per unit area, and the number of graphite precipitates per unit area. The examinations were performed by means of computer image analyser, taking into account four classes of shape factor. It was found that as the aluminium content in cast iron increases from about 1.1% to about 3.4%, the number of graphite precipitates rises from about 700 to about 1000 per square mm. For higher Al content (4.2% to 6.8%) this number falls within the range of 1300 – 1500 precipitates/mm^2. The degree of cast iron spheroidization increases with an increase in aluminium content within the examined range, though when Al content exceeds about 2.8%, the area occupied by graphite decreases. The average size of graphite precipitates is equal to 11-15 µm in cast iron containing aluminium in the quantity from about 1.1% to about 3.4%, and for higher Al content it decreases to about 6 µm.

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

1. Introduction

An addition of aluminium to the cast iron results, first of all, in the significant increase in the fire resistance of the alloy [1-4]. Aluminium can also replace silicon in cast iron [5-10]. In this way the advantage can be taken of its high graphitizing ability, practically the highest one among all elements [2]. This results in the elimination of hard spots in thin-walled cast iron products and enables die casting of the material.

An increase in aluminium content in cast iron results, on the one hand, in the increased allowable working temperature for obtained castings, and on the other hand – in the reduced carbon solubility in the alloy and the lowered carbon content in eutectics [4, 11-14]. The amount of aluminium in cast iron influence significantly both the form which can be taken by graphite in the alloy, and the microstructure of metal matrix, though various authors are of different opinions as to the intensity of graphitizing influence of aluminium [3, 12, 14-17].

The Ref. [14] presents an attempt of determining the influence of aluminium in the amount from about 0.6% to about 8% on graphitization of cast iron with relatively high silicon content (3.4%-3.9%) and low manganese content (about 0.1%). The cast iron was spheroidized with cerium mixture and graphitized with ferrosilicon. Achieving of strictly nodular graphite precipitates in cast iron treated with magnesium or cerium mixture is, however, very difficult or even impossible, because the discussed element hinders the process of cast iron spheroidization [3, 11, 18].

Ref. [14] made also the assessment of graphite precipitates according to the pertinent Standard [19] and the assessment of pearlite and ferrite fractions in the cast iron microstructure. There was also determined the total area occupied by graphite precipitates. The proportion of this area to the examined area of microsection was assumed to be a measure of graphitization ability of cast iron.

A continuation of investigations realised in Ref. [14] was recognized as reasonable with respect to the detailed quantitative characteristics of graphite precipitates, taking into account the shape, the number, and the size of these precipitates.

2. Authors' investigations

The purpose of the investigation was to find the characteristics of graphite precipitates in cast iron containing aluminium in the amount from about 1% to about 7%, spheroidized with cerium mixture added in the amount of 0.11% with respect to the total mass of the melt and graphitized with 75% ferrosilicon added in quantity of 1.29%. The quantities of both cerium mixture and ferrosilicon used for treatment of aluminium cast iron were found as optimum ones in the case of spheroidization process performed for the low-aluminium cast iron containing about 3% Al addition [20], i.e. for the alloy with aluminium content falling more or less in the middle of the range of Al content here considered. Cast iron coming from nine melts carried out during examinations presented in the Ref. [14] was investigated. Chemical composition of the discussed cast iron is given in Table 1.

Table 1.
Chemical content of cast iron

No.	No. in Ref. [14]	Content of elements, %						S_c
		Al	C	Si	Mn	S	P	
1	2	1.11	3.10	3.60	0.10	0.018	0.060	1.07
2	3	1.89	3.08	3.79	0.10	0.017	0.050	1.15
3	4	2.79	2.89	3.68	0.11	0.022	0.055	1.15
4	5	3.44	2.77	3.66	0.11	0.022	0.055	1.17
5	7	4.24	2.70	3.50	0.10	0.014	0.042	1.20
6	8	4.67	2.57	3.87	0.10	0.010	0.041	1.26
7	9	5.34	2.71	3.40	0.10	0.018	0.046	1.33
8	12	6.38	2.53	3.42	0.10	0.020	0.033	1.40
9	13	6.79	2.63	3.72	0.11	0.012	0.033	1.62

In the above table S_c stands for the eutectic saturation degree determined from the formula:

$$S_c = \frac{C_c}{4{,}25 - 0{,}3Si - 0{,}33P + 0{,}027Mn - 0{,}40S + 0{,}063Cr - 0{,}22Al} \quad (1)$$

where: C_C – total carbon content in cast iron, %;
Si, P, Mn, etc. – total content of the respective element in cast iron, %.

The presented data indicate that the investigated cast iron was the hypereutectic one, and the value of eutectic saturation degree increased from 1.07 to 1.62 with the increase in aluminium content in cast iron from about 1.11% to about 6.8%.

The assessment of graphite precipitates reported in Ref. [14], carried out accordingly to the Standard [19], revealed that flake graphite was not found for either of the examined specimens. Graphite denoted as IV occurred in cast iron containing about 1.11% Al; cast iron from all other melts exhibited graphite precipitates of shapes denoted as III and VI accordingly to the Standard [19]. Cast iron containing about 3.4% Al revealed also a small amount of graphite denoted as V. Figs. 1 to 6 show exemplary graphite precipitates and the microstructure of cast iron containing 1.11%Al, 3.44%Al, and 6.79%Al, respectively.

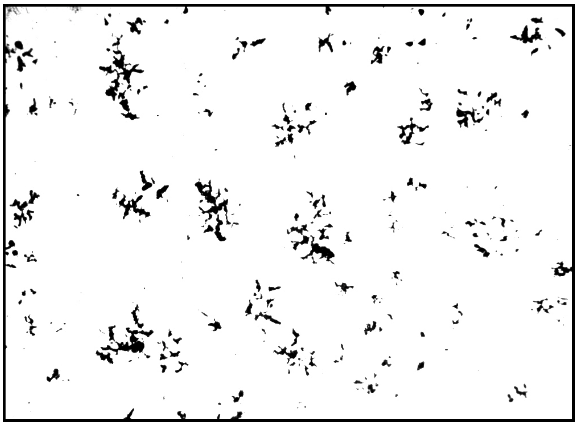

Fig. 1. Graphite in cast iron containing 1.11% Al; non-etched microsection, magn. 100×

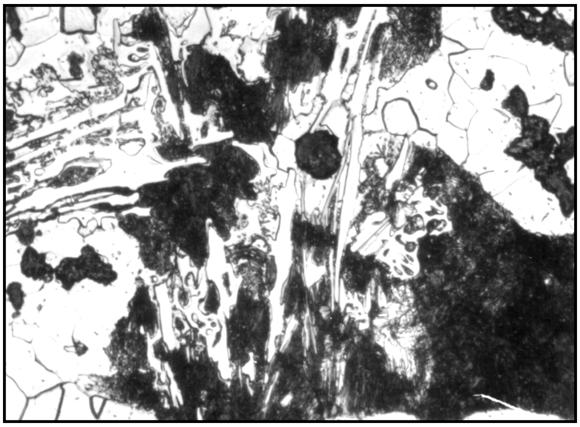

Fig. 2. Microstructure of cast iron containing 1.11% Al; etched with Nital, magn. 300×

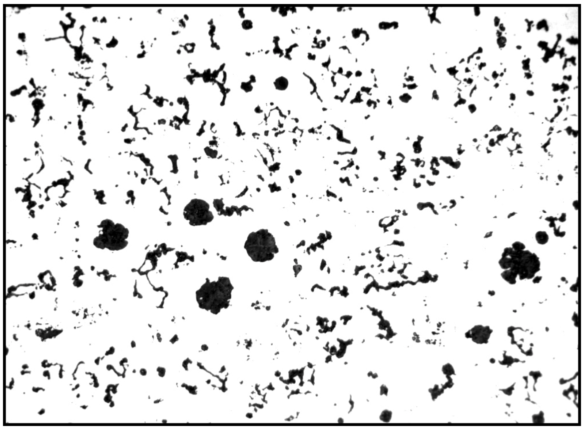

Fig. 3. Graphite in cast iron containing 3.44% Al; non-etched microsection, magn. 100×

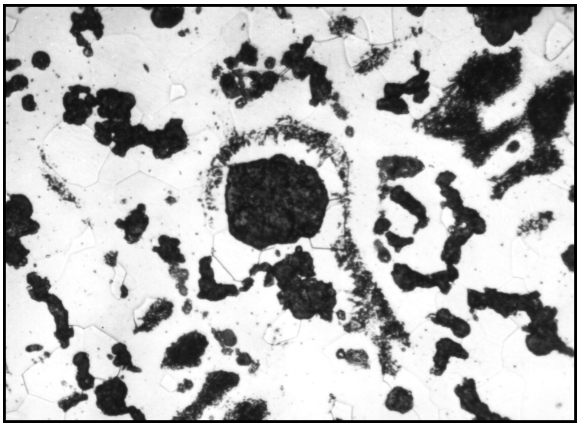

Fig. 4. Microstructure of cast iron containing 3.44% Al; etched with Nital, magn. 300×

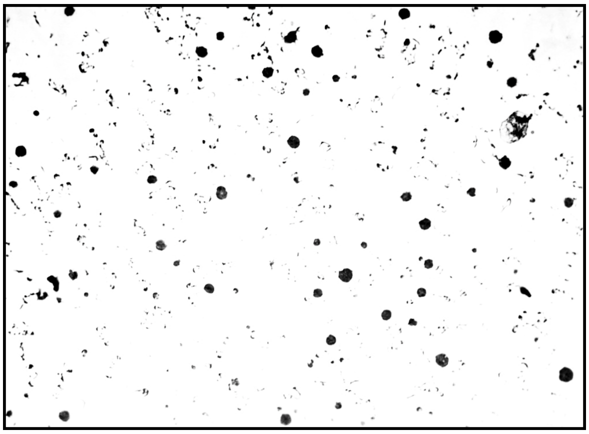

Fig. 5. Graphite in cast iron containing 6.79% Al; non-etched microsection, magn. 100×

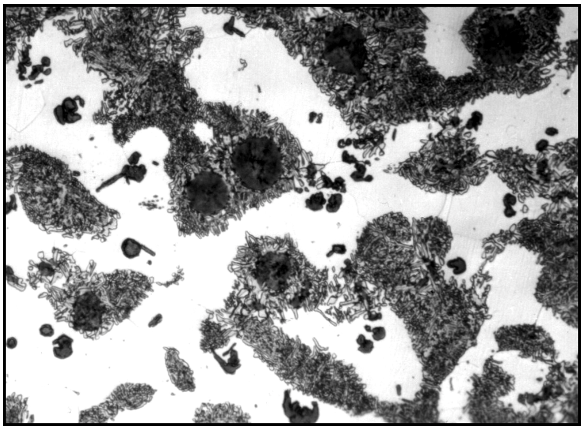

Fig. 6. Microstructure of cast iron containing 6.79% Al; etched with Nital, magn. 300×

Metallographic examinations performed by means of computer image analyser for metallurgical microsections prepared from specimens taken during the former stage of investigations [14], included the determination of:

– the area percentage occupied by graphite (graphite fraction) G_w, %;
– the total perimeter of graphite precipitates per unit area P, mm/mm^2;
– number of graphite precipitates per unit area N, 1/mm^2.

Taking into account that graphite precipitates in the examined cast iron occurred mainly in the isolated form, their average diameter $\bar{d}$ was found from the relationship [21]:

$$\bar{d} = \frac{P}{\pi \cdot N} \tag{2}$$

where: $\bar{d}$ - average diameter of the isolated precipitates, mm;
P – average total perimeter of the isolated precipitates, mm/mm^2;
N – average number of the isolated precipitates, 1/mm^2.

The results of examination arranged in four classes of graphite precipitate shape factor ξ are juxtaposed in Table 2. The shape factor was calculated as a proportion between the area A_i of the precipitate 'i' and the square of its perimeter P_i.

Figures 7 and 8 present the dependence between the aluminium content in cast iron and – respectively – either the area occupied by graphite precipitates, or their number. The Figures refer also to the distribution of both the area and the number of graphite precipitates between the four classes of shape factor.

Table 2.
Characteristics of graphite precipitates occurring in the examined cast iron

No.	Al content in cast iron, %	Average value in a sample				Classes of the graphite shape factor ξ	Percentage in a shape factor class, %		
		G_w [%]	P [mm/mm^2]	N [1/mm^2]	$\bar{d}$ [µm]		of the area of precipitates	of the perimeter of precipitates	of the number of precipitates
1	1.11	4.81	32.9	680	15.4	(0.00-0.02)	36.89	48.71	6.25
						<0.02-0.04)	36.50	24.30	20.99
						<0.04-0.06)	20.03	18.50	38.16
						<0.06-0.08)	6.57	8.49	34.59
2	1.89	5.66	38.5	1065	11.5	(0.00-0.02)	22.26	30.43	5.78
						<0.02-0.04)	40.81	34.49	25.65
						<0.04-0.06)	23.20	22.93	37.57
						<0.06-0.08)	13.73	12.15	31.00
3	2.79	6.76	37.5	1026	11.7	(0.00-0.02)	17.71	16.36	5.06
						<0.02-0.04)	36.00	35.31	24.57
						<0.04-0.06)	26.19	25.47	37.59
						<0.06-0.08)	20.10	22.86	32.78
4	3.44	6.22	32.5	937	11.1	(0.00-0.02)	22.71	21.98	5.43
						<0.02-0.04)	42.40	38.56	23.96
						<0.04-0.06)	24.52	26.34	38.14
						<0.06-0.08)	10.37	13.12	32.46
5	4.24	5.38	27.9	1331	6.7	(0.00-0.02)	7.73	9.60	2.18
						<0.02-0.04)	26.47	31.52	20.68
						<0.04-0.06)	28.97	32.33	43.69
						<0.06-0.08)	36.83	26.56	33.45
6	4.67	4.67	28.2	1437	6.3	(0.00-0.02)	4.42	4.12	0.92
						<0.02-0.04)	24.54	26.37	13.56
						<0.04-0.06)	34.63	38.44	41.95
						<0.06-0.08)	36.41	31.07	43.57
7	5.34	4.84	30.4	1529	6.3	(0.00-0.02)	7.70	8.88	1.24
						<0.02-0.04)	27.72	29.00	25.36
						<0.04-0.06)	29.62	33.98	35.92
						<0.06-0.08)	34.96	28.14	37.49
8	6.38	4.49	25.9	1311	6.3	(0.00-0.02)	1.31	1.65	0.46
						<0.02-0.04)	18.03	20.86	10.37
						<0.04-0.06)	33.33	38.50	39.55
						<0.06-0.08)	47.32	39.00	49.62
9	6.79	3.84	24.5	1276	6.1	(0.00-0.02)	1.81	1.91	0.49
						<0.02-0.04)	18.49	20.93	11.25
						<0.04-0.06)	33.39	38.10	40.50
						<0.06-0.08)	46.31	39.06	47.76

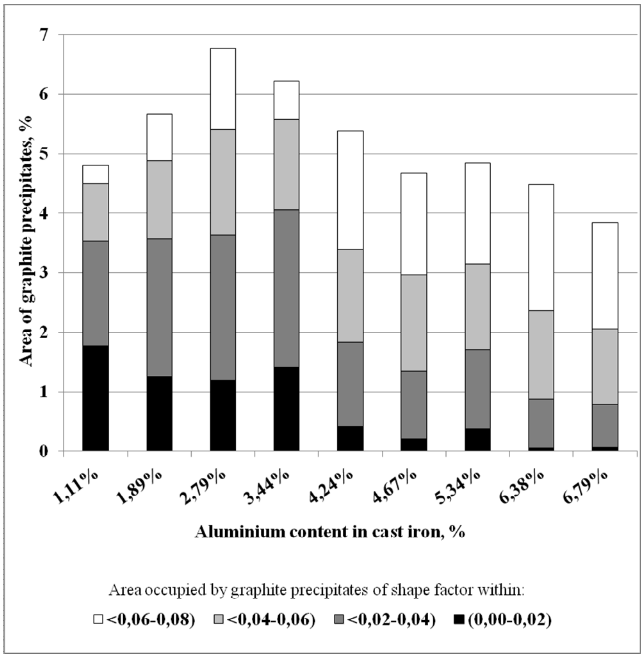

Fig. 7. The influence of aluminium content in cast iron on the area occupied by graphite precipitates

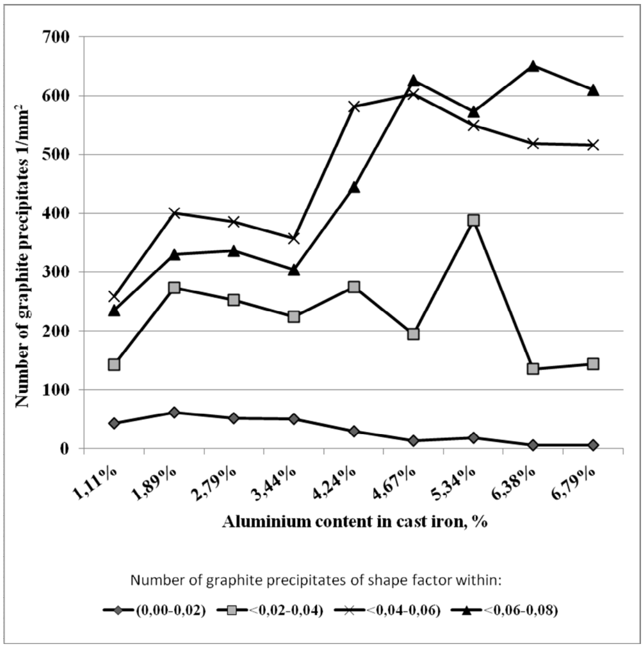

Fig. 8. The influence of aluminium content in cast iron on the number of graphite precipitates

Fig. 9 presents the relationships between aluminium content in cast iron and the size of graphite precipitates in the four assumed classes of shape factor, as well as the average size of these precipitates.

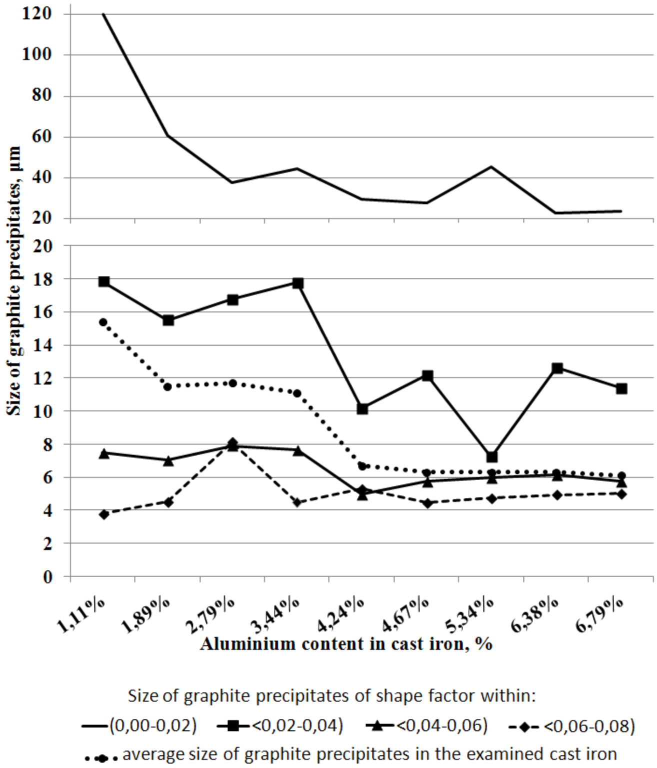

Fig 9. The influence of aluminium content in cast iron on the size of graphite precipitates

3. Conclusion

The treatment of cast iron containing aluminium in the amount from about 1.1% to about 6.8% with cerium mixture and graphitizing it with ferrosilicon resulted in occurring of compact graphite precipitates in the alloy (cf. Figs. 1 to 6). The detailed data coming from the quantitative analysis performed on the non-etched microsections by means of the computer image analyser (see Table 2) allow to determine the relationship between the aluminium content in cast iron and the area occupied by the graphite precipitates, as well as their number and size. The results were classified according to the assumed four classes of shape factor (0,00-0,02); <0,02-0,04); <0,04-0,06); <0,06-0,08). The shape factor ξ was calculated as a ratio of the graphite precipitate area to the square of its perimeter. Shape factor determined in such a way takes e.g. the value of 0.080 for a circle, of 0,063 for a square, and of 0.048 for the equilateral triangle.

The data shown in Fig. 7 allow to state that if the aluminium content in cast iron rises up to about 2.8%, the area occupied by graphite precipitates also increases; further increase in Al content, however, leads to the reduction of the area occupied by graphite. The fraction of precipitates of shape factor within the range (0.00-0.02) is the largest in cast iron containing 1.1% Al (it reaches about 37% of the total area occupied by graphite); in cast iron containing from about 1.9% to about 3.4% Al its value falls within the range of 18-23%. Cast iron containing Al in the amount from about 4.2% to about 6.8% exhibits even lower values. It should be noticed that as the aluminium content in cast iron increases, a distinct tendency of increasing the fraction of graphite precipitates for which the shape factor ξ falls within <0.04 – 0.08). This fraction is regarded in some References [18, 19] as the degree of cast iron spheroidization. For the examined cast iron, the percentage of area occupied by graphite precipitates of shape factor ξ ranging from 0.04 to 0.08 is equal to 30%-40% of total area occupied by graphite in the case of alloys containing aluminium in the amount from 1.1% to 3.4%, and then increases up to 65%-80% as the aluminium content rises from 4.2% to 6.8%.

The number of graphite precipitates is the smallest in the case of cast iron containing 1.1% Al (about 700 precipitates per mm^2). As the aluminium content increases up to about 3.4%, the number of graphite precipitates also increases up to about 1000 precipitates per mm^2; for the higher Al content (4.2% to 6.8%) it reaches 1300-1500 precipitates per mm^2. The distinct increase in the number of precipitates, observed for the Al content increasing from about 3.4% to about 4.2%, is accompanied, naturally, by the significant reduction in the size of precipitates (see data in Table 2 and Figs. 7 and 8). The average diameter of a graphite precipitate is equal to 11-15 μm in cast iron of aluminium content from 1.11% to 3.44%. In the case of cast iron with aluminium content ranging from 4.2% to 6.8%, the average diameter is reduced to about 6 μm.

The largest graphite precipitates were characterised by the shape factor ξ from the range of (0.00-0.02) and occurred in cast iron containing 1.11% Al. Graphite precipitates of the shape factor from the same range are significantly smaller in cast iron with higher aluminium content.

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