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The Influence of Aluminium on the Spheroidization of Cast Iron Assessed on the Basis of Wedge Test

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Abstract

The paper discusses the influence of aluminium in quantities from about 1.9% to about 4.7% on both the alloy matrix and the shape of graphite precipitates in cast iron spheroidized with cerium mixture (added in the quantity of 0.11%) and inoculated with ferrosilicon (1.29%). The metallographic examinations were carried out for specimens cut out of the wedge test castings (22 mm base width, 120 mm height, 180 mm length) halfway along their length. It was found that the highest susceptibility to graphitization exhibits the cast iron containing about 2.8% Al. The alloy matrices were classified and the degrees of graphite spheroidization were determined. Microscopic observations were carried out along the wedge test casting height at several places, the first distant by 20 mm from the specimen apex, the next ones every 20 mm farther. Precipitates of nodular and vermicular graphite were found in the cast iron structure. The results of examination allow to state that cast iron spheroidized in the way described here is characterised by the degree of spheroidization which increase with an increase in aluminium content within the examined range.

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

1. Introduction

The presence of aluminium in cast iron counteracts the crystallization of graphite in the form of nodular precipitates [1]. S. Hasse [2] states on the ground of analysis of a series of research works that the maximum allowable aluminium content for which the spheroidization of graphite is still possible falls within 0.04% to 0.30%. M. Jonuleit [3] is of the opinion that the allowable aluminium content in cast iron accounts for 0.020%, and total elimination of the harmful influence of Al is possible if its content is restricted to 0.012%. The negative effect of aluminium on crystallization of the nodular graphite is confirmed also in Ref. [4-9].

Examination results presented for example in Ref. [10-12] reveal a significant relationship between the quantity of aluminium in cast iron and its harmful influence impeding the cast iron spheroidization. It should be stressed that despite the pernicious effect of aluminium present in cast iron on the graphite spheroidization, the increased rate of alloy crystallization influences favourably the occurrence of nodular graphite precipitates in the material [13]. The relationship between the cast iron cooling rate and the ability of the alloy to precipitate nodular graphite was examined by T. Dumitrescu [10]. He observed microstructures of aluminium cast iron (containing 2% of Mg) over the longitudinal cross-sections of the 36 mm high conical specimens with base diameters equal to 24 mm. He found nodular graphite in regions close to the cone vertices for all types of the examined cast iron. The distance from the top of the specimen to the farthest section where nodular graphite was still observed significantly decreased with an increase of aluminium content in cast iron. The distance varied from 14 mm to 3 mm for aluminium content ranging from 0.46% Al to 10.90% Al, respectively.

It was thought reasonable to determine the correlation between the aluminium content (up to 5% of Al) and the possibility of occurring of the nodular (or vermicular) graphite precipitates in cast iron, thus continuing the research work concerning spheroidization of aluminium-containing cast iron carried out with the use of cerium mixture, presented already elsewhere [6-9, 14]. It was assumed that the separately cast wedge specimens would be used for the purpose of the experiment. They allow to examine the alloy of a constant chemical composition during solidification and cooling proceeding at various rates.

2. The purpose, methods and results of authors' investigations

The purpose of this research work was the determination of influence of aluminium added in quantities ranging from about 2% to about 5% on the structure of cast iron treated with cerium mixture and inoculated with 75% ferrosilicon. It was assumed that aluminium content would be risen by about one percent from one melt to the next. Experiment was held for four test melts. The alloy was melted in the laboratory induction furnace, which inductor was supplied with 10 kHz electric current from the thyristor converter of the Leybold-Heraeus IS1/III-type induction vacuum furnace. All melts were accomplished using the same charge material, composed of the specially prepared cast iron and ferrosilicon. The content of basic elements in both components is shown in Tables 1 and 2, 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 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

After the initial charge iron and ferrosilicon (used to increase the silicon content to the assumed level) had been melted, the alloy was overheated up to 1400°C. Next the proper amount of aluminium was introduced into the induction furnace crucible, beneath the metal mirror. The melt was heated up to 1360-1380°C again, then cerium mixture was added; its chemical composition is given in Table 3. Five minutes later the cast iron was inoculated with ferrosilicon. The quantities of cerium mixture and ferrosilicon were equal to 0.11% and 1.29% of the achieved cast iron mass, respectively. These quantities were found optimal during investigations concerning the spheroidization process of cast iron containing about 3% Al [14]. Another five minutes being passed after the introduction of ferrosilicon, the molten metal was poured into moulds prepared of loose self-hardening moulding sand with sodium silicate binder. One wedge test casting of dimensions and shape presented in Fig. 1 was obtained from every melt.

Table 3.
Chemical composition of cerium mixture

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

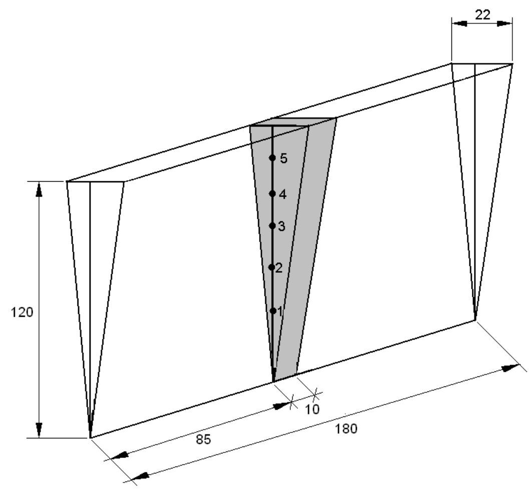

Fig. 1. Wedge test casting; the shadowed area is the place from which the samples for metallographic investigation were taken; numbers 1 to 5 denote places of microscopic investigation, distant by 20, 40, 60, 80, and 100 mm from the specimen apex

Table 4 presents chemical composition of the obtained cast iron.

Table 4.
Chemical compositions of the examined cast iron

No. of melt	Content of elements, %					
	Al	C	Si	Mn	S	P
1	1.89	3.08	3.79	0.1	0.017	0.050
2	2.79	2.89	3.68	0.11	0.022	0.055
3	3.77	2.72	3.61	0.11	0.015	0.045
4	4.67	2.57	3.87	0.10	0.010	0.041

The shapes of graphite precipitates found during metallographic observations are presented in Fig. 2 (next page).

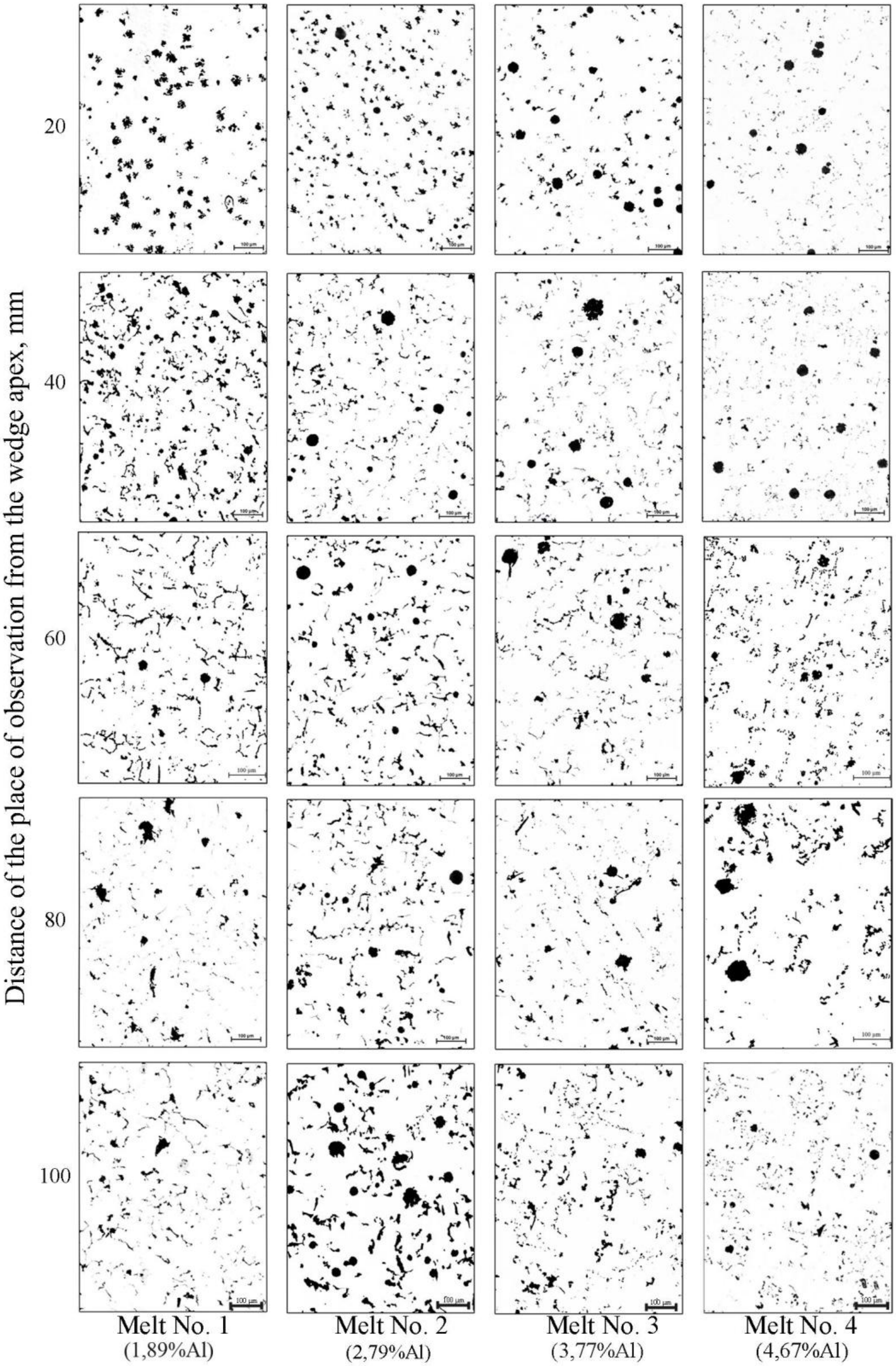

Fig. 2. Graphite precipitates in the investigated cast iron. Aluminium content is given in brackets.

The images shown above were recorded during the metallographic observations carried out at some points along the wedge test casting height, schematically marked in Fig. 1. The examination performed by means of the Nikon Eclipse MA-200 optical microscope 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 results are gathered in Table 5.

The measurements taken by means of the NIS-Elements computer image analyser using MultiScan program made possible the determination of area occupied by graphite precipitates and the assessment of the degree of cast iron spheroidization. Also the shape factor F was automatically calculated for each separate graphite precipitate according to the formula:

$$F = \frac{P}{C^2} \qquad (1)$$

where: P – area of a graphite precipitate, mm^2;
C – perimeter of the graphite precipitate, mm.

The degree of graphite spheroidization η_{sph} was found according to the formula:

$$\eta_{sph} = \frac{\sum P_{(F \geq k)}}{\sum P} \cdot 100\% \qquad (2)$$

where: k – the critical value of shape factor.

It is worth mentioning that 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.

Fig. 3 depicts changes in the area occupied by graphite precipitates in successive examined regions of wedge test castings.

The following two figures (4 and 5) illustrate the degree of graphite spheroidization in the analysed regions of wedge test castings, the critical values of the shape factor used in calculations of the η_{sph} value being assumed as $k \geq 0.04$ (Fig. 4) or $k \geq 0.06$ (Fig. 5).

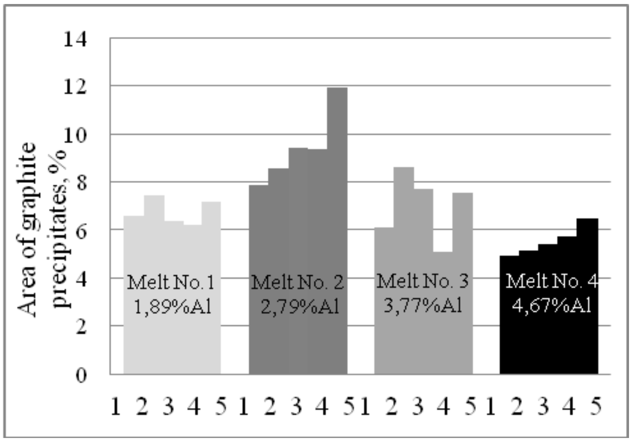

Fig. 3. Area percentage of graphite precipitates in cast iron in the analysed regions of wedge test castings; examined areas (1-5) designated according to Fig. 1

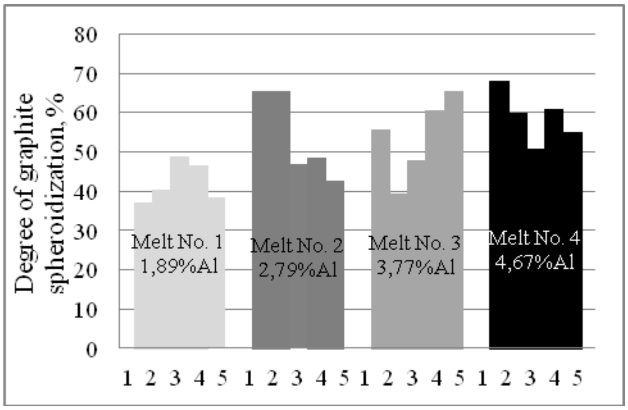

Fig. 4. The degree of graphite spheroidization in the analysed regions of cast iron wedge test castings, calculated for the assumed value of $k \geq 0.04$ (see Formula 2); examined areas (1-5) designated according to Fig. 1

Table 5.
Results of metallographic examination of the produced cast iron carried out by means of optical microscope

No. of melt (Al content)	Features of graphite precipitates determined according to the Standard [15] and the microsection area occupied by pearlite (P) and ferrite (Fe) determined according to the Standard [16], quantified at areas indicated in Fig. 1									
1 (1.89%)	100%V 6	P 50 Fe50	30% VI 6 70%III 6	P0 Fe	20% VI 6 80%III 6	P0 Fe	20%V 6 80%III 6	P0 Fe	30%V 6 70%III 6	P0 Fe
2 (2.79%)	90% VI 6 10% III 6	P 50 Fe50	60% VI 6 40% III 6	P0 Fe	50% V 6 50% III 6	P0 Fe	50% V 6 50% III 6	P0 Fe	40% V 6 60% III 6	P0 Fe
3 (3.77%)	80% VI 6 20% III 6	P 50 Fe50	70% VI 6 30% III 6	P6 Fe94	70% VI 6 30% III 6	P6 Fe94	40% VI 6 60% III 6	P0 Fe	40% VI 6 60% III 6	P0 Fe
4 (4.67%)	60% VI 6 40% III 6	P 50 Fe50	60% VI 6 40% III 6	P20 Fe80	50% VI 6 50% III 6	P20 Fe80	40% VI 6 60% III 6	P20 Fe80	40% VI 6 60% III 6	P20 Fe80

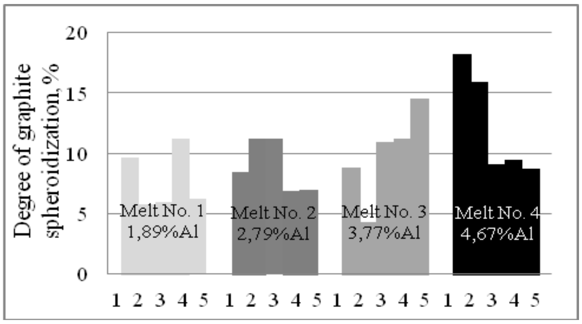

Fig. 5. The degree of graphite spheroidization in the analysed regions of cast iron wedge test castings, calculated for the assumed value of $k \geq 0.06$ (see Formula 2); examined areas (1-5) designated according to Fig. 1

It should be mentioned that microscopic observations of the etched microsections of wedge test castings revealed only small quantities of compound carbides Fe_3AlC_x, and these were found only close to the wedge apex, and only in the case of melts No. 3 and 4 (i.e. containing 3.77% Al or 4.67% Al, respectively).

Figures 6 and 7 show exemplary microstructures of cast iron from the melts No. 1 and 3.

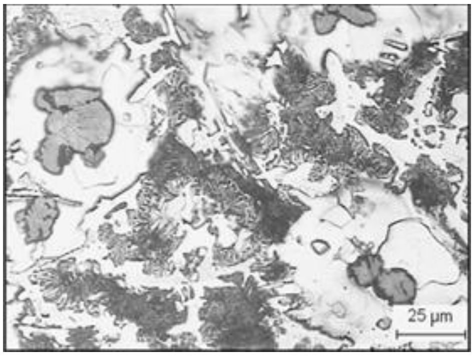

Fig. 6. Microstructure of cast iron from the melt No. 1. The region about 20 mm from the wedge apex. Etched with Nital.

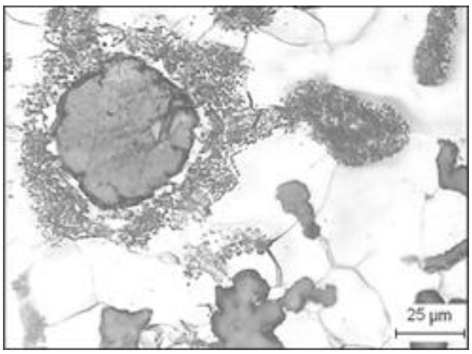

Fig. 6. Microstructure of cast iron from the melt No. 3. The region about 40 mm from the wedge apex. Etched with Nital.

3. Conclusion

All the melts were carried out with the use of the same basic charge materials being expended in the same quantities. It is worth noticing that despite this fact, the carbon content in the resulting alloy decreased with the increase in aluminium content in cast iron (see data in Table 4). It results from the decrease of carbon solubility in cast iron due to presence of aluminium [11]. An increase of aluminium content in cast iron by about 3% (from about 1.9% to about 4.7%) yielded the decrease of carbon content by about 0.50% (from 3.08% to 2.57%). This decreasing quantity of carbon in the low-aluminium cast iron seems to be close related to the increase of efficiency of the spheroidization treatment carried out with the use of cerium mixture.

Analysis of data gathered in Tables 4 and 5, of photographs depicting the shape, the size, and the arrangement of graphite precipitates in the analysed regions of wedge test castings (Fig. 2) along with those showing cast iron microstructures (exemplary Figs. 6 and 7), as well as the bar charts presented in Figs. 3-5 gives intimate insight into the influence of aluminium, present in the material in quantities from about 1.9% to about 4.7%, on cast iron graphitization and the effectiveness of the alloy treatment with cerium mixture (added in the quantity of 0.11%) with regard to the obtaining of nodular or vermicular graphite.

The data shown in Table 5 indicate that cast iron from melts No. 1 and 2 contain significant amounts of pearlite only close to the apex of the wedge test castings (about 50% at 20 mm distance from the apex). Other examined regions, 40 mm or more from the apex, are purely ferritic. The tendency to pearlite generation is much greater in cast irons from melts No. 3 and 4. Cast iron from the melt No. 3 (containing 3.77% Al) still revealed the trace quantities of pearlite at a distance of 60 mm from the wedge apex, and cast iron from the melt No. 4 (Al content equal to 4.67%) exhibited 20% fraction of pearlite at a distance of 100 mm from the wedge apex.

The data shown in Fig. 3 represent the cast iron susceptibility to graphitization assessed in particular regions of wedge test castings. This tendency is the largest for the cast iron from the melt No. 2 (containing 2.79% of aluminium). Both cast iron from the latter melt and the alloy from the melt No. 4 reveal a distinct rise in the degree of graphitization for the increasing distances from the wedge apex (i.e. for the increasing ‘wall; thickness). One can hardly speak about such tendencies in the case of cast irons from melts No. 1 or 3.

Data concerning the characteristics of graphite precipitates in the examined cast iron, cited in Table 5, indicate that the precipitates were of various shapes. Nodular precipitates (shape denoted IV according to the Standard [15]) along with vermicular ones (shape denoted III according to the same Standard) were predominant. Flake graphite was not found in the examined alloys. Bar charts in Figs. 4 and 5 depict the degree of graphitization at various points of wedge test castings. The obtained data, however, do not reveal any regular dependence between the degree of spheroidization and the cooling rate of the wedge test castings, irrespective of the melt (naturally, this is valid for the examined volume of specimen).

Table 6 gives the average values of areas occupied by graphite precipitates in the examined wedge test castings and the average values of the degree of graphite spheroidization. They were found for each melt taking into account the data coming from the five formerly indicated areas (see Fig. 1).

Table 6.
Average values of areas occupied by graphite precipitates in the examined cast iron and the average values of the degree of graphite spheroidization

No. of melt	Al content in cast iron [%]	Average values of areas occupied by graphite precipitates [%]	Average values of the degree of graphite spheroidization η_{sph} [%] determined for the value of coefficient k:	
			$k \geq 0.04$	$k \geq 0.06$
1	1.89	6.76	42.2	7.8
2	2.79	9.42	50.3	8.9
3	3.77	7.01	53.7	9.9
4	4.67	5.53	58.9	12.3

The data quoted in Table 6 confirm the earlier observation that the largest susceptibility to graphitization among the four examined alloys exhibits the cast iron from the melt No. 2 (Al content of 2.79%). Moreover, there can be seen an inclination to develop a greater degree of graphite spheroidization for a greater aluminium content in cast iron (for the examined Al content range from about 1.9% to about 4.7%). This tendency occur for the η_{sph} value determined for the critical value of shape factor coefficient assumed as either $k \geq 0.04$ or $k \geq 0.06$. The latter value corresponds to the nearly nodular graphite precipitates.

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