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Relation between Section Thickness, Microstructure and Mechanical Properties of Ductile Iron Castings

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Our experimental works are conducted to establish the conditions required to produce a desirable structure of the castings of various section sizes. The main factors of influence on the structure that one needs to address are: chemical composition, cooling rate, liquid treatment and heat treatment. This investigation was focused on the study of the influence of section size and holding time after spheroidizing on the structure and mechanical properties of the ductile iron plates cast in sand molds of vertical and horizontal configuration. Melts of eutectic and hypoeutectic composition were used to cast plates of thickness ranging from 3 mm to 50 mm. The results showed that the wall thickness of ductile iron castings and holding time after spheroidizing had very strong effect on the microstructure of the castings. The holding time had significant effect on the elongation, but insignificant effected on the tensile strength and hardness of castings.

Keywords: ductile iron, section size, microstructure, mechanical properties.

INTRODUCTION

Ductile iron is not a single material, but a family of materials offering a wide range of properties obtained through microstructure control. It has many advantageous characteristics which combine high strength, fatigue, wear resistance, and higher performance at lower cost. If the yield stress/cost ratio of various materials is considered as-cast ductile iron is most of time the winner [1]. The manufacture of thin wall castings would not only prevent the transfer of ductile iron parts to light metals but would make possible the conversion of many steel assemblies to ductile iron [2, 3]. An attractive properties makes it convenient for instance in the automotive industry. Producing thin wall ductile iron castings is an important method for saving energy and materials. Take an automobile for example: a reduction of 100 kg in weight saves 0.5 liter of petrol per 100 km driven [4]. Ductile iron is widely used for heavy construction equipment and safety relevant components in the fields of nuclear related too. Examples of safety relevant applications are turbine casing, rotating parts of transport systems like railway wheels or transport and storage casks for radioactive materials [5, 6].

Chemically ductile iron is the same as grey iron and is iron-carbon-silicon alloy. The superior performance of ductile iron over grey iron has been attributed to the dissimilarity in graphite morphology of the graphite particles between the two materials. The common feature that all ductile irons share is the roughly spherical shape of the graphite nodules. These graphite nodules are nucleated on small inclusions during the solidification [7]. The relative possibilities for nucleation and growth depend upon foreign particles or solutes present in the liquid, whether as trace impurities or as deliberate additions [8]. The amount and form of the graphite in ductile iron are determined during solidification and cannot be altered by subsequent heat treatment. The principal factor in determining the different grades of ductile iron in the specifications is the matrix structure. In the case as-cast condition, the matrix will consist of varying proportions of pearlite and ferrite. The matrix structure can be changed by heat treatments, and those most often carried out are annealing to produce a fully ferritic matrix and normalizing to produce a substantially pearlitic matrix [9, 10].

When discussing the metallurgy of ductile iron, the main factors of influence on the structure that one needs to address are: chemical composition, cooling rate, liquid treatment and heat treatment [11 – 13]. The main effects of chemical composition to nodular iron are similar to those described for grey iron, with quantitative differences in the extent of these effects and quantitative differences in the influence on graphite morphology. When changing the cooling rate, effects similar to those discussed for gray iron also occur in ductile iron, but the section sensitivity of ductile iron is lower. This is because spheroidal graphite is less affected by cooling rate than flake graphite. But pouring very thin sections in ductile iron presents danger of massive carbides as-cast [14]. The liquid treatment of ductile iron is more complex than of gray iron. The two stages for liquid treatment of ductile iron are: modification, which consists of magnesium or magnesium alloy treatment of the melt, with the purpose of changing graphite shape from flake to spheroidal, and inoculation to increase the nodule count or to suppress carbide formation. [15].

The goal of the metallurgist is to design a process that will produce a structure that will yield the expected mechanical properties. Designing materials with a specific microstructure, especially in the case of polyphase systems, is one of the great tasks of modern materials science [16]. The purpose of the present work was to investigate the relationship between section thickness, microstructure and mechanical properties of ductile iron castings.

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EXPERIMENTAL

Melting was performed using a high-frequency induction furnace with a nominal holding capacity of 160 kg. The charge material consisted of pig-iron, mild steel, return scrap and carburizing agent. The chemical composition of the base irons of two heat series is shown in Table 1. The first heat series were of eutectic composition with high content of silicon were been applied to produce ferritic matrix of the samples and the second series the hypoeutectic composition with lower silicon content and higher manganese and chromium were been applied to produce ferritic-pearlitic matrix. High silicon content in the first heat had ensured a fully ferritic matrix in all samples because silicon reduces the carbon diffusion path during the eutectoid transformation and prevents formation of carbides [17]. Higher manganese and chromium contents and lower silicon in the second heat had ensured formation of pearlite in the matrix of the samples [2, 11].

Table 1. Chemical composition of the melts

Melt	C	Si	Mn	Cr	P	S
A	3.42	2.81	0.19	0.04	0.042	0.027
B	3.32	2.05	0.45	0.13	0.050	0.032

The melts (70 kg) were treated in a preheated transfer ladle containing 1.4 kg of lanthanum bearing MgFeSi alloy *Lamet*. The spheroidizing process was carried out by applying the sandwich method. Treatment temperature was 1450 °C–1470 °C. The temperature of molten iron was measured by thermocouple using Pt-Rh thermocouple. In order graphite precipitation which reduces the undercooling and formation of carbides the melt was inoculated with 0.3 wt% of calcium bearing FeSi alloy *Alinoc* after the nodularization. The inoculation was realized by in-stream technique. The pouring temperature range for the first and the last molds were 1300 °C–1310 °C and 1270 °C–1280 °C, respectively.

The treated melts were poured into greensand molds. The test castings consisting of joined strips different wide (from 25 mm to 140 mm) by 100 mm long. The thicknesses of the strips were nominally 3, 5, 10, and 24 mm. Two different molds were used to obtain test plates of vertical and horizontal configuration (Fig. 1). The 50 mm thickness plate was cast separately.

Microstructure was observed with an optical microscope. Tensile strength, elongation and Brinell hardness were measured using the 30 mm diameter specimens cast separately in sand molds. The chilled samples were also obtained for chemical analysis.

RESULTS AND DISCUSSIONS

The effect of the sections size of the vertical and horizontal specimens on the diameter of the graphite spheroids was evaluated. The results for samples taken from the moulds cast from the melt A are shown in Figure 2. As the section size increases, the average spheroids diameter decreases. This effect can be explained by different cooling rate of plates [12]. As in the case of vertical molds, there is no noticeable difference between the average size of graphite nodules in the samples taken from top and bottom of plates.

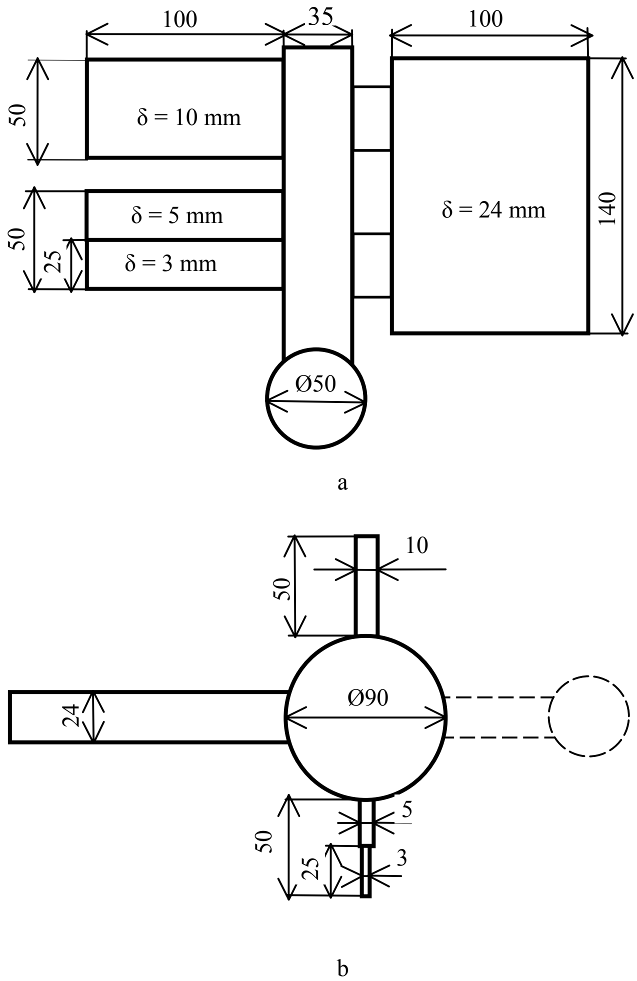

Fig. 1. Horizontal (a) and vertical (b) test castings (dimensions in millimetres)

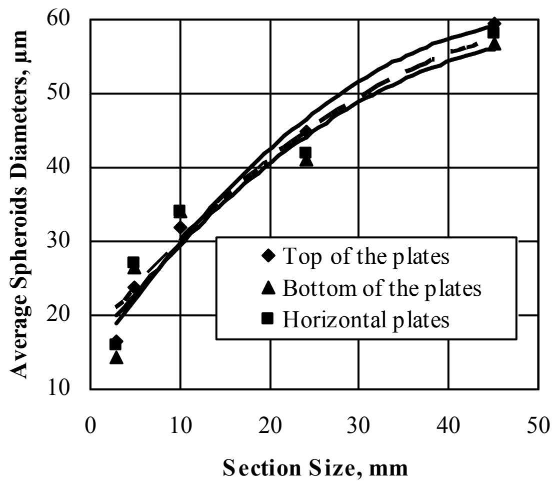

Fig. 2. Effect of the sections size of the vertical and horizontal specimens on the diameter of the graphite spheroids

The effect of the holding time after spheroidizing treatment on the size of the graphite spheroids was been cared out on the 10 mm thick plates cast from the melt A. It was established that the graphite size had not varied after

5, 10 and 15 minutes but after 20 and 25 minutes it was appeared strong non-homogeneous size of graphite spheroids (from 20 µm to 55 µm) (Fig. 3). Additionally after 25 minutes it was appeared irregularly shaped graphite spheroids. Respectively, such microstructure changes are of major importance in mechanical ductile iron properties (Table 2).

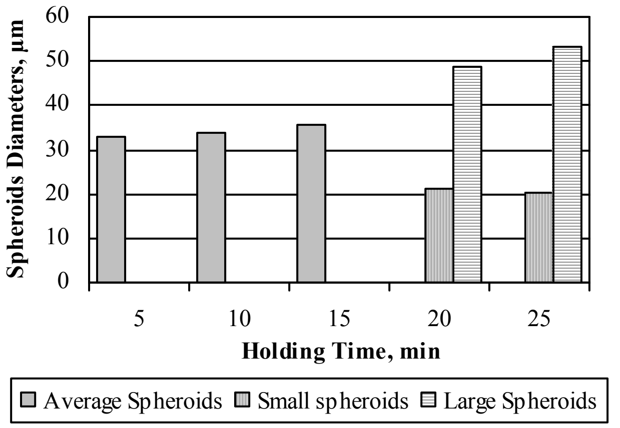

Fig. 3. Size of the graphite spheroids diameters in 10 mm thick plates as a function of the time after spheroidizing treatment

Table 2. Effect of holding time after spheroizing treatment on the mechanical properties of ductile iron

Parameter	Holding time, min				
	5	10	15	20	25
Tensile strength, MPa	572	562	582	585	588
Elongation, %	12.8	12.8	11.4	8.6	5.7
Hardness, HB	192	187	199	197	192

It is well known that all inoculants effects fade with time after addition. Usually 20 minutes is the maximum time to insure any residual effect of spheroidizing [19, 20]. According Table 1 data, 15 minutes is the maximum time to insure ductility of ductile iron castings. It is advisable therefore to pour the molds as quickly as possible. However, the practical controlling factor of strength and hardness is temperature rather than the effect of inoculants fading, thus this conclusion give more latitude to the time between spheroidizing and pouring. These observations were attributed to the fully ferritic ductile iron only. The approach used in this investigation can be further extended to applications in more general cases for optimization of design of ductile iron casting technological process.

The effect of section size on the pearlite content was been investigated with melt B and is given in Figures 4 and 5. It appears that for identical conditions (i. e. five sections for the same casting of five experiments) the thinner sections contain more pearlite than thicker. However, the influence of section size on the pearlite content was lower than most studies concluded [2, 21, 22]. This difference in the results of pearlite content seems to be caused by lanthanum presented in nodulizer. Similar effect of lanthanum on the microstructure was been reported by Skaland [23].

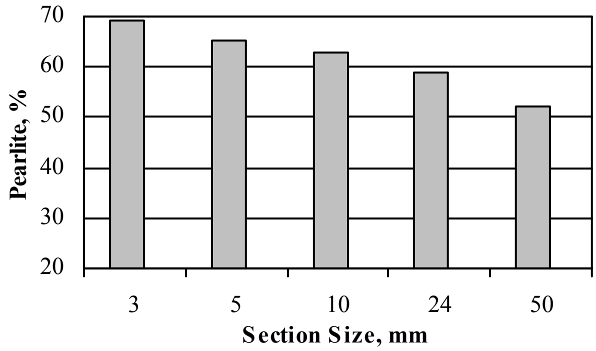

Fig. 4. Effect of section size on the ferrite content in the 24 mm plate section

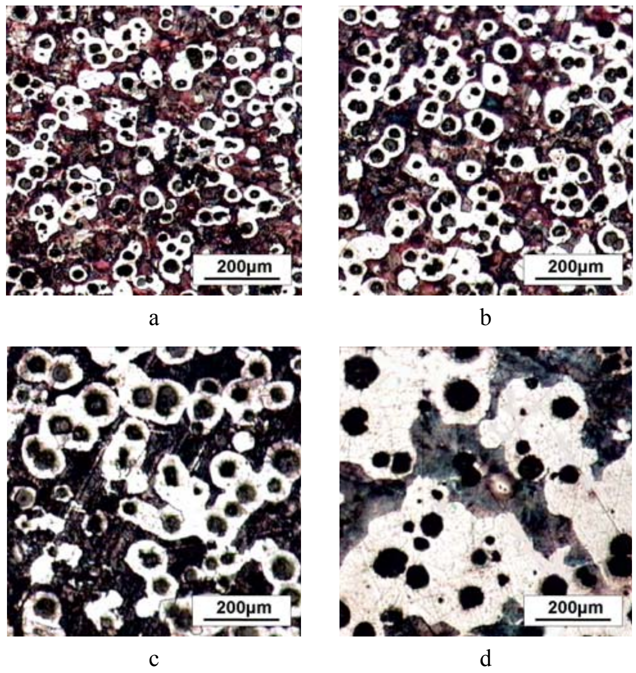

Fig. 5. Microstructure in the 3 (a), 5 (b), 10 (c) and 24 (d) mm plate castings

CONCLUSIONS

Melts of eutectic and hypoeutectic compositions were used to cast plates of thickness ranging from 3 mm to 50 mm. The results showed that the wall thickness of spheroidal graphite cast iron castings had very strong effect on the graphite size and shape of the castings.

Reach results showed that the section size affect on the pearlite content in the matrix of the ductile iron castings was been depended on the chemical composition of melts and nodulizers.

The time after spheroidal treatment had significant effect on the elongation, but insignificant effected on the tensile strength and hardness of castings. The graphite shape is under the sway of the holding time too.

Any effect of the plates position in the molds was not been observed.

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