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EVALUATION OF PRODUCING TECHNIQUE FACTORS AFFECTING THE MATRIX MICROSTRUCTURE OF AS-CAST DUCTILE IRON CASTINGS

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The objective of this paper was to investigate some important parameters related to ductile iron matrix microstructure. Ductile iron round bars of various diameters in order to achieve various cooling rates were obtained in different conditions. None heat treatment was used to obtain different pearlite contents in the microstructures. The correlation between kind of inoculants, specimens size, carbon equivalent, and matrix microstructure was investigated. The results demonstrated that the slow cooling rate, inoculants with rare earth elements, and relatively little residual magnesium content decreased the pearlite content. This study is of great importance for the development of new economical methods for production of ductile iron castings.

Key words: ductile iron, inoculants, cooling rate, metallic matrix

Istraživanje utjecaja procesnih parametara na mikrostrukturi odljevaka od nodularnog lijeva u lijevanom stanju. U radu je istraživan utjecaj nekoliko značajnih procesnih parametara na mikrotrukturu nodularnog lijeva. Od nodularnog lijeva odlivene su ispitne palice različitih promjera da bi se ostvarile različite brzine hlađenja. Različiti udjeli perlita u mikrostrukturama nisu dobiveni toplinskom obradom. Istraživane su koleracije između vrste cjepiva, veličine uzoraka, ugljičnog ekvivalenta i mikrostrukture nodularnog lijeva. Dobiveni rezultati pokazuju da niska brzina hlađenja, cjepiva s elementima rijetkih zemalje i relativno niski rezidualni udjeli magnezija smanjuju udio perlita. Ovo istraživanje je od velike važnosti za razvoj novih ekonomičnih metoda za proizvodnju odljevaka od nodularnog lijeva.

Ključne riječi: nodularni lijev, cjepiva, brzina hlađenja, metalna osovina

INTRODUCTION

The matrix structure of ductile iron can be ferritic, pearlitic, ferritic-pearlitic, martensitic, austenitic or bainitic [1]. The importance of matrix in controlling mechanical properties is emphasized by the use of matrix names to designate the types of ductile iron [2]. Ferritic, pearlitic, ferritic-pearlitic ductile irons are normally produced and usually used in the as-cast condition.

A number of variables including chemical composition, cooling rate, amount of residual magnesium, type, amount and method of post inoculation, pouring temperature, addition of rare earth element and the content of pig iron in the charge can control the matrix structure of as-cast ductile iron [2-4]. The right chemical composition is the easiest to define. This will be the desired final composition of the casting, less alloys added during treatment and inoculation plus C loss during Mg treatment. It should be pointed out that all ductile irons are low in S (0,02 percent maximum) and in P (0,08 percent maximum). Most ductile irons have a near-eutectic composition, extending far into strongly hypereutectic region for thin walled castings only [5]. The carbon equivalent affects the grain size and nodule count [6]. On the other hand, increasing nodule count provides more sites for ferrite nucleation and growth, resulting in increasing amounts of ferrite [7].

The cooling rate is largely determined by size of the casting in cross-section. Faster cooling rates associated with thin sections promote pearlite formation; slower cooling rates favour ferrite formation [8].

The production of ductile iron means for adding magnesium to molten metal. The magnesium content which is required to produce spheroidal graphite usually ranges from 0,03 to 0,07 mas.%. Compacted graphite structure with inferior properties may be produced if magnesium is low, while too high magnesium content may promote dross defects and carbide formation. An optimized magnesium content is thus required to obtain a high nodule count and a good nodularity [9, 10].

Inoculation is one of the main factors affecting the properties of ductile iron. Inoculation effectiveness depends on many operating conditions, including chemistry. It is established that inoculation mechanisms vary widely between inoculants. An inoculant grade FeSi always contains elements in relatively low concentration

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which are active inoculants, such as Ca, Al, Zr, Ba, Sr and Ti. These elements are used to increase the solubility and the potency of the alloys [11].

The required pouring temperature basically determines the treatment temperature for the ductile iron. Normally the iron treatment temperature is from 1480°C to 1510°C. The higher temperature gives the more vaporisation and lower recovery of magnesium and is accompanied with increased pearlite content, a higher carbide formation, decreased eutectic cell count and increased liquid shrink [12].

Information in the literature indicates that the rare earth elements cleanse the iron of elements that prohibit spherical graphite growth, increase the graphite nodule count, counter micro-shrinkage appearance, minimize the formation of primary iron carbides [13]. However, the optimum rare earth content varies significantly according to different investigators.

The fraction of pearlite, as well as the fineness of the lamellar structure itself, influences the mechanical properties of the steel [14]. The pearlitic microstructure has been widely reported [14-16]. However, only limited information is available on detailed analysis of perlitic microstructure of ductile iron.

This review is not intended to be complete. There have been many other experiments demonstrated that metallic matrix structure of as-cast ingots is affected of many factors. The objective of the present work has been to investigate the correlation between kind of inoculants, cooling rate, and matrix microstructure in order to provide the proper matrix structures of ductile iron castings.

EXPERIMENTAL

Charges used in this work consisting of pig iron, ductile iron returns, steel, carbon and 75 % foundry grade ferrosilicon were melted in an induction furnace with melting capacity of 160 kg. Several melts having carbon equivalent (CE) ranging from 4,3 to 4,8 % were poured. Irons with different residual magnesium contents ranging from 0,025 to 0,062 % were obtained by controlling the amount of spheroidizer.

The melt was superheated to 1530 °C before being poured into a preheated ladle for magnesium treatment with Fe-Si-Mg nodulizer using a tundish sandwich method. The temperature was measured with Pt and 10 percent Rh-Pt thermocouple. The postinoculation, using various ferrosilicon alloys presented in Table 1, was perform by adding the inoculant into the stream when reladling from the treatment ladle to a pouring ladle. The basic inoculation was performed with inoculant containing cerium.

The pouring temperature was about 1360 °C. The molten metal was poured into chilled mould to produce a sample for chemical analysis and the green sand mould in which five specimens with equal height of 310 mm but unequal diameters, 3, 5, 10, 25, and 50 mm, respectively, were produced (Figure 1). Various diameters cylindrical bars were cast in order to examine the effect of cooling rate on the pearlite content and its hardness.

Table 1 **The chemical composition of inoculants**

Inoculant	Chemical composition / mas. %			
	Si	Al	Ca	Other element
Alinoc	70–75	~4,0	~1,0	-
Ultraseed	70–76	~1,0	~1,0	1,5–2,0 Ce
Germalloy	70–78	~3,8	~0,9	-
*SB*5	65–70	~1,2	~1,2	2,0–2,5 Ba

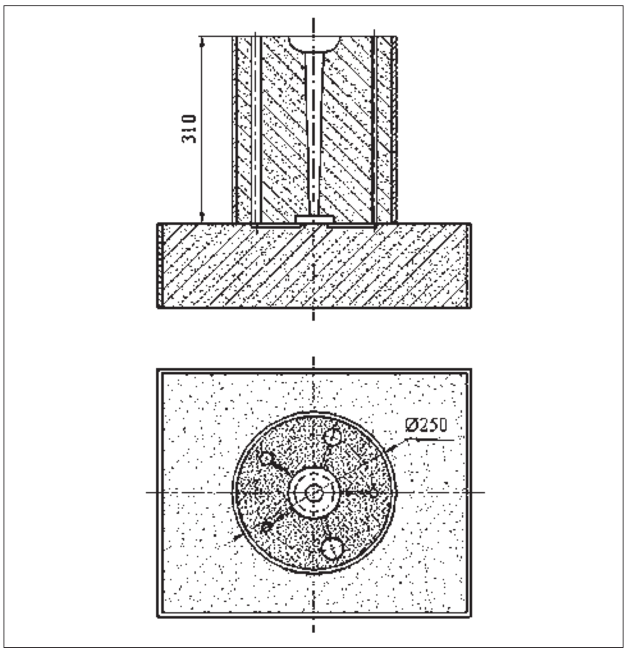

Figure 1 Mould used for casting specimens (dimensions in millimetres)

Chemical composition of the cast iron has been determined by spectrometer. Metallographic samples were prepared in the sequence of grinding, polishing and etching (with 3 % Nital) for microscopic examinations by light microscope with digital camera and image analysis system. Pearlite microhardness was tested using Vickers indenter with 0,49 N load.

EXPERIMENTAL RESULTS AND DISCUSSIONS

The effect of the type of inoculant and the diameter of the specimens on the content of pearlite is given in Figure 2. It is apparent that for various conditions the thinner specimens contain more pearlite than thicker ones and the type of inoculant does not seem to affect the pearlite content for a thin and large specimen sizes. It has noticeable effect for common specimen sizes. It can be seen that the inoculant containing Ce is especially

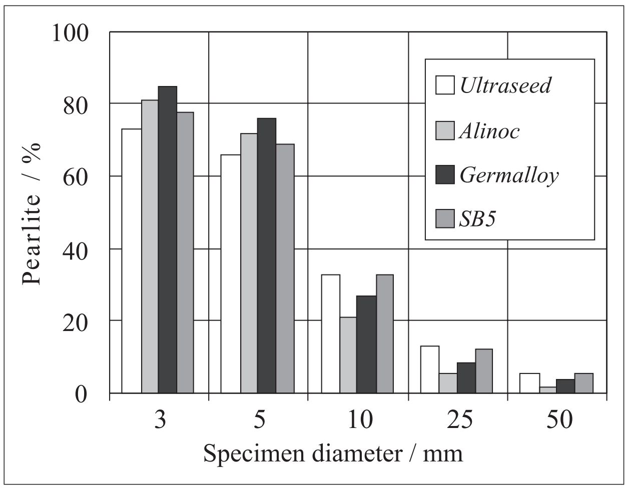

Figure 2 Effect of the type of inoculant and the casting diameter of the specimens on the content of pearlite

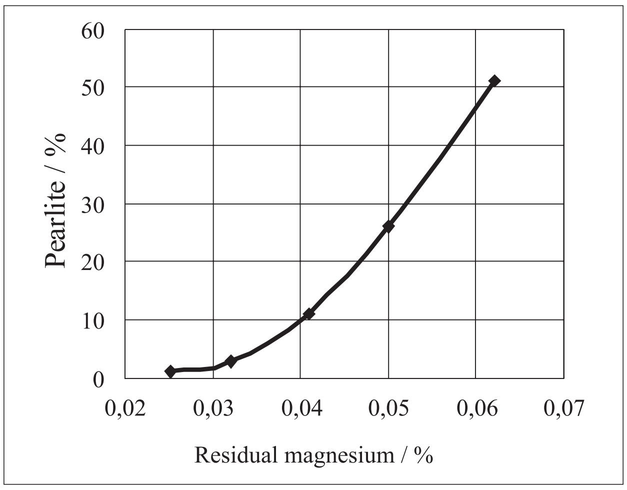

Figure 4 Effect of the content of residual magnesium on the content of pearlite in the specimen with 25 mm diameter

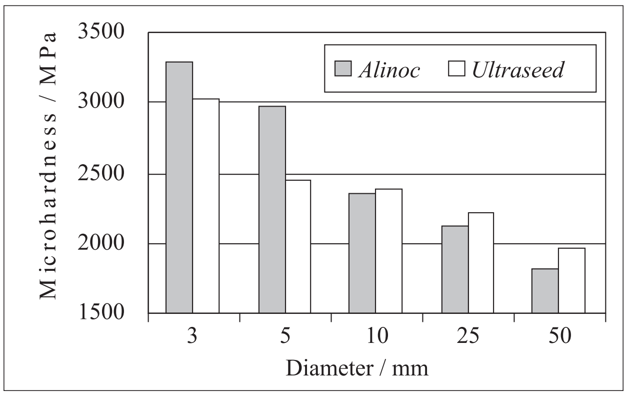

Figure 5 Effect of size of specimens and type of inoculants on the microhardness of pearlite

beneficial for castings with various section sizes because it slightly equalizes pearlite contents in various section sizes. Barium containing inoculant also reduces pearlite formation but to a lesser extent. Compared to other inoculants, these both inoculants produce a higher initial number of nucleation sites and provided better chill reduction. This is due to the fact that the additions of cerium and barium cause a higher number of graphite nodules [3] and consequently decrease the pearlite amount in thin samples [7].

Figure 3 shows the influence of CE on the pearlite content in the speciments of various diameters. The increase in carbon equivalent results in a significantly decrease in the pearlite content in specimens with 3 and 5 mm diameter, whereas the pearlite content in thick specimens does not significantly vary despite changes in the carbon equivalent. The results of our experiments show that silicon significantly effects on the pearlite content than carbon. Previously [17, 18] have been shown a strong effect of silicon in decreasing the pearlite content but only in thin sections. When silicon is added as an inoculant, it raises the number of nucleation sites and the nodule count. As a result, it reduces the carbon diffusion path during the eutectoid transformation and increases the amount of ferrite in the structure [19].

The effect of the residual magnesium content on the metallic matrix formation in the specimen with 25 mm diameter is shown in Figure 4. Experimental results indicate that the amount of pearlite increases with increasing residual magnesium content. The reason of pearlite increase is the carbide stabilizing effect of magnesium in ductile iron [9].

From Figure 5 it can be seen that the microhardness of pearlite increases with the decreasing specimens diameter. This is due to the increase of cooling rate, which influencing the lamellar spacing of carbides that was observed in as-cast specimens. Fine pearlite spacing was obtained by increasing this one. Hardness of pearlite is a function of lamellar microstructure [20, 21]. Thus, microhardness can be used for evaluating the pearlite spacing. The difference of hardness is more significant in the inoculated with *Alinoc* inoculant specimens than in the specimens inoculated with *Ultraseed* inoculant bearing cerium. Thus, this inoculant reduces section sensitivity of castings on the hardness values.

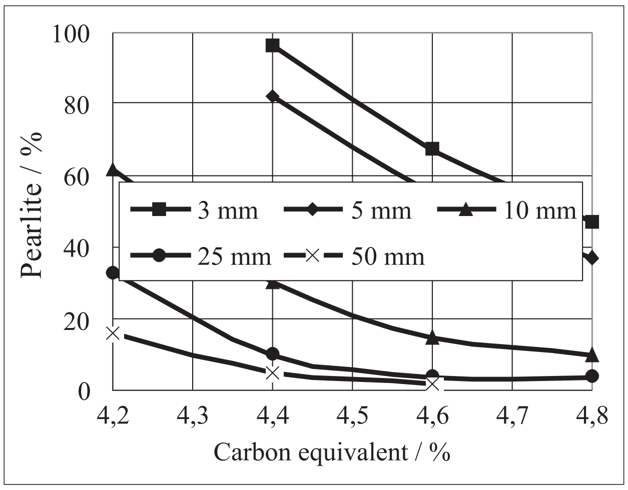

Figure 3 Effect of carbon equivalent and the casting diameter on the pearlite content

CONCLUSIONS

Analysis of the microstructure of different size specimens cast in different conditions indicates that the specimens size has very strong effect on the pearlite content and microhardness but only to a certain limit, which equals approximately to 25 mm.

Type of inoculant has noticeable effect only for common specimens sizes. Compared to other inoculants, the inoculant containing cerium addition more significantly equalizes pearlite contents in various specimens size.

There is strong correlation between carbon equivalent and the pearlite content but only in the specimens whose diameter is in the range of 3-10 mm.

Increasing residual magnesium content in ductile iron castings causes an increase of the amount of pearlite.

The microhardness of pearlite decreases as the specimens diameter increases. The cerium bearing inoculant equalizes the difference between the hardnesses of different samples sizes.

The present results stimulate further investigation on this field.

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Note: The responsible for English language is Regita Bendikiene, Kaunas University of Technology, Lithuania.