

Peculiarity of Producing Ferritic Ductile Iron Castings

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In the present investigation, the effects of charge materials, melting conditions, section size, spheroidizing and inoculation methods on the chemical composition of melt and the matrix microstructure of ductile iron castings have been investigated. Results showed that the increase of temperature and holding duration of the melt in an induction furnace decrease the carbon content and increase the silicon content. The intensity of spheroidizing effects on the carbon and residual magnesium contents in the ductile iron castings. This investigation has shown that the castings of ductile iron will be ferritic as-cast only when large amount of pig iron in the charge are used. However, the producing as-cast ferritic thin-section ductile iron castings needs in addition some-steps inoculating treatment.

Keywords: ferritic ductile iron, charge, spheroidizing, inoculation.

1. INTRODUCTION

In the recent years, nodular graphite (ductile) iron has become one of the most important engineering materials, in view of its excellent castability, significantly better mechanical properties and low cost. The material can be tailored to fit an unusually broad diversity of needs, which remarkably, has opened new vistas for its application in the manufacture of automobile, construction, agricultural, mining, military and railroad components, which traditionally produced by expensive forging processes involving high grade alloy steels [1 – 4].

The output characteristics depend on the matrix structure and the shape, size and distribution of the graphite spheroids. Matrix and spheroids, in turn, depend on the chemical composition of the melt, on the desulphurising, spheroidizing and scorifying methods applied in the treatment ladle, on the inoculation method and finally, on the time elapsing between these events and the casting in the mould [5, 6].

Production of ductile iron is influenced by a large number of metallurgical, technological, heat transfer and designing parameters. The first step of the production of ductile iron castings is the careful selection of the charge materials.

Manganese and chromium have the most influence on all mechanical properties [7]. For this reason, their concentration in metal is of particular importance. These elements arise in the charge from steel scrap, iron units and returns. It is recommended practice to purchase steel scrap so that the average Cr content remains below 0.1 percent. Ideally, the same advice would be given for Mn but, unfortunately, all steel scraps contain Mn, the majority being at the 0.5 percent level. The amount of steel scrap in the charge must be that amount which will give castings that are as free of carbides as possible [8]. It is particularly important for the production of ferritic ductile iron [9].

Charge materials result in the average size of graphite spheroids. For instance, if the amount of steel scrap in the

charge is higher than 50 percent then an average spheroids diameter is 33 μm , if it is 30 percent then the average diameter is 57 μm . The amount of steel scrap affects metallic matrix structure too. It increases the pearlite formation [10].

The graphite structure is affected by the carbon content as well. If initial metal does not contain the enough amount of the carbon then graphite particles are of compact shape [11]. The metallic matrix structure is affected not only by carbon equivalent but by C/Si ratio too. As increasing this ratio in ductile iron the proportion of ferrite decreases and the proportion of pearlite increases [12].

It also must be pointed out that charge materials contain elements that decrease the quantity of spheroids and effect on the matrix structure. For instance, to achieve a ferritic casting in as-cast condition, chemical composition of charge materials should not contain more than 0.01 % Sn, 0.02 % As, 0.1 % $\Sigma\text{V} + \text{Mo}$, 0.04 % Cr, 0.02 % S and 0.05 % P [13].

The formation of graphite spheroids is obtained through a special treatment during which spheroidizing elements are added to the melt. Mg and various Mg alloys are the most commonly used for spheroidization of ductile iron [14]. The choice of a treatment method (open ladle, sandwich, tundish cover, in-mould, plunger, converter, injection and others) (which are described in details elsewhere [15]) for an individual foundry must be based on the circumstances present in foundry.

Inoculation, which may take place at different process in combination or separately, is a necessary step for production of ductile iron castings. Most inoculants are ferrosilicons. An inoculant grade FeSi always contains elements in relatively low concentration which are active inoculants, such as Ca, Al, Zr, Ba, Sr and Ti [16]. These elements are used to increase the solubility and the potency of the alloys. There are three methods to inoculate the metal which are used individually or in combination [17]: in the ladle, in the stream while pouring and in the mould.

This very brief survey shows that, although considered as a mature technology, recent process and product developments open new avenues to this family of

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materials. In this study, efforts have been focused on the melting and modification aspects of producing ferritic as-cast ductile iron castings.

2. EXPERIMENTAL

The charge materials, including the percentages used for the production, are listed in Table 1. They are melted in the standard line frequency induction furnace of capacity the 10 t.

Table 1. Details of the charge materials

Charge materials	Percentage for ductile iron	
	Experimental	Basic
Iron units	10 – 70	60
Mild steel	10 – 20	10
Return scrap	20 – 50	26
FeSi75	1 – 3	1.5
Carburizing agent	2 – 3	2.5

Spheroidizing treatment was carried out in the special ladle [18] by means of the Sandwich method at about 1500 °C. The treatment ladle was preheated to avoid temperature losses. Spheroidizing was performed by means of 2.1 % of FeSiMg7. After spheroidizing, the top of the ladle was lifted and the melt was deslagged and poured into the casting ladle.

We investigated the influence of the time of spheroidizing treatment in the ladle on the graphite content in the liquid ductile iron. Three kinds of spheroidizing process have been studied: very fast (with evaporation and burning of the magnesium) (4 seconds), medium (15 seconds) and very slow (100 seconds).

Inoculation was performed by means of 0.40 % of FeSi-Ba (60 – 65 % Si, 2.0 % Ca, 5 – 6 % Ba). After inoculation the temperature was measured and part of the melt was poured into the chill mould for the spectrographic analysis of the produced ductile iron. Liquid metal temperature has been measured by device MIKRON and thermometer W50A with S type thermocouple (Pt and 10 percent Rt-Pt). During in-mould inoculation the inoculant (0.1 – 0.2 % of FeSi-Ba) was placed in a reaction chamber within the gating system of the individual mould.

The metal stream, ladle and in-mould inoculation methods were applied to obtain different nodularity and metallic matrix structure.

All castings were produced in green sand moulds. Standard test pieces for microstructural and mechanical properties testing were machined from the samples which were cast separately in sand moulds under representative spheroidization and inoculation treatments. Test pieces were prepared in accordance with LST EN1563:2001. The microstructure of castings have been determined by common optical microscope, by analogous camera, computer and original software. This method permits quick identification of the graphite and metallic phases.

Effect of section size on the metallographic structure was carried out with 6 – 30 mm-thick sections. During the tests the metallic matrix was only examined because it is known [4] that graphite spheroids are larger and usually less well formed in heavy sections than in thin ones.

3. RESULTS AND ANALYSIS

The initial chemical composition of the melt has been changed of its temperature and holding time in a furnace. It can be seen (Fig. 1) that the carbon content decreases from 3.90 to 3.65 percent (at temperature of 1480 °C) or to 3.53 percent (at temperature of 1580 °C) if melt is held in the furnace 3 hours. However, silicon content at the same time increases from 1.47 to 1.70 percent. That is why it is necessary to control the chemical composition of the melt in furnace and to regulate it. Therefore it is introduced the inoculation carried out in the furnace and in the ladle before spheroidizing treatment.

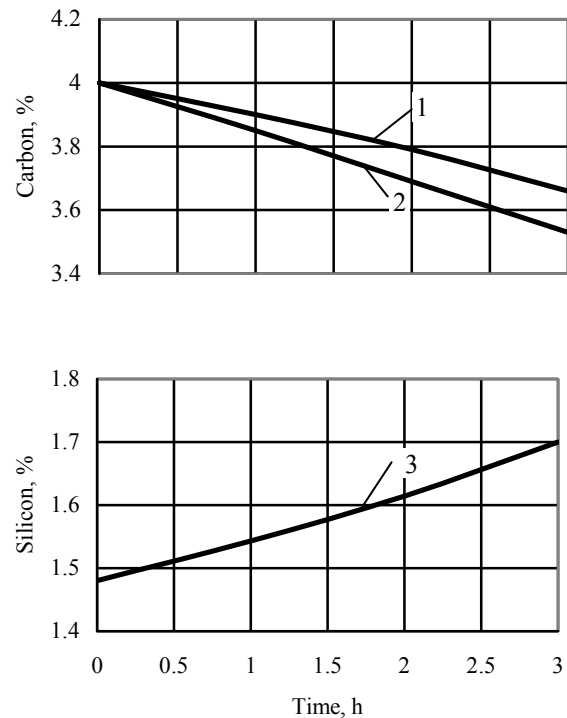


Fig. 1. The change of the carbon and silicon contents of melt held in a furnace: 1 – at 1480 °C; 2 and 3 – at 1580 °C

Carbon content also depends on the intensity of the spheroidizing as shown in Figure 2. It is evident from this one, that carbon content decreases with increasing spheroidizing continuance.

The spheroidizing intensity effects also on content of the residual magnesium. This content is the highest (about 0.05 percent) when the spheroidizing time is about 15 seconds. When the spheroidizing time is very short (4 s) or very long (100 s) then residual magnesium contents are 0.024 and 0.027 percent, respectively.

Figure 3 shows the relationship between the amount of pig iron in the charge and the metallic matrix or mechanical properties (tensile strength and elongation). It is evident, that ferritic ductile iron requires larger amount of pig iron. Kapilevich et al. [19] have also obtained the similar results. According to authors the charge for the increased plasticity ductile iron has to content from 50 to 70 percent of pig iron.

The amount of ferrite in the different section thickness is shown in Figure 4. It shows that it is very difficult to pour thin section of ferrite ductile iron as-cast. It is

associated with high solidification rate and formation of carbides.

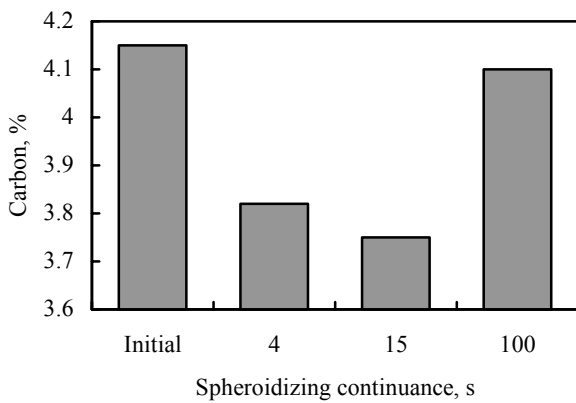


Fig. 2. Effect of spheroidizing continuance on the carbon content

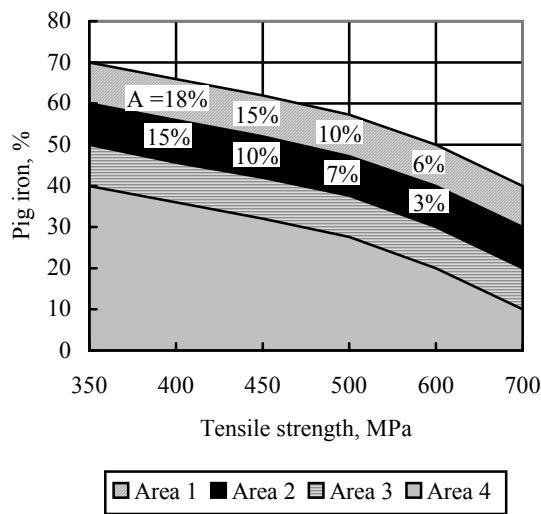


Fig. 3. Recommended amount of pig iron in the charge for the different ductile iron grades (tensile strength and elongation A). Areas 1 and 2 represent the stable process

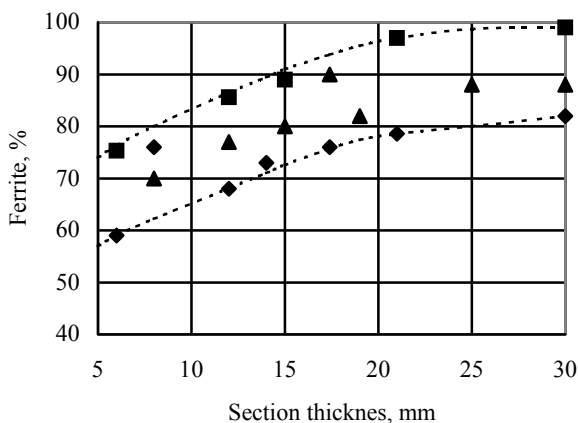


Fig. 4. The effect of the section thickness on the content of ferrite

Producing thin section ferritic ductile iron castings required the shortening of holding time of the melt in the furnace, lowering overheating temperature, using complex inoculation, increasing amount of pig iron in the charge,

using spheroidizing alloys with minimal content of magnesium and high purity charge materials.

Figure 5 shows the various methods of the melt treatments we used during our investigations.

- a) $S_3 \Rightarrow G_4$;
- b) $G_1 \Rightarrow S_3 \Rightarrow G_4$;
- c) $S_3 \Rightarrow G_6$;
- d) $S_3 \Rightarrow G_7$;
- e) $G_2 \Rightarrow S_3 \Rightarrow G_4$;
- f) $G_2 \Rightarrow S_3 \Rightarrow G_7$;
- g) $G_3 \Rightarrow S_3 \Rightarrow G_4$;
- h) $G_3 \Rightarrow S_3 \Rightarrow G_6$;
- i) $G_3 \Rightarrow S_3 \Rightarrow G_7$;
- j) $G_3 \Rightarrow S_3 \Rightarrow G_4 \Rightarrow G_7$;
- k) $G_3 \Rightarrow S_3 \Rightarrow G_6 \Rightarrow G_7$;
- l) $S_7 \Rightarrow G_7$.

Fig. 5. Schematic flowsheets of the melt treatments. Letters show the method of treatment: S – spheroidizing; G – inoculation. Numbers show the place of treatment: 1 – the furnace; 2 – the furnace stream during filling a transfer ladle; 3 – a treatment ladle; 4 – the ladle stream during filling a pouring ladle; 5 – the pouring ladle; 6 – a stream while pouring; 7 – a mould

The results of industrial experiments show that the most effective treatment technique of the melt for the pouring 6 – 12 mm-thick sections consists of four steps. It is *j*-variant (Fig. 5): inoculation in the treatment ladle, spheroidizing in the treatment ladle, inoculations the treatment ladle stream during filling a pouring ladle and in the mould or *k*-variant (Fig. 5): inoculation in the treatment ladle, spheroidizing in the treatment ladle, inoculations in the stream while pouring and in the mould.

Based on research results, ferritic as-cast ductile iron castings with 6 – 12 mm wall thickness have been introduced into production.

4. CONCLUSIONS

1. The initial chemical composition of the melt has been changed from its temperature and holding in an induction furnace time. High temperature and long holding time decrease carbon content but increase silicon one.
2. It is found that very intensive and very slow spheroidizing process decreases carbon and residual magnesium contents in the ductile iron.
3. The present investigation has shown that the castings of ductile iron will be ferritic as-cast only when large amount (more than 50 percent) of pig iron in the charge were used. However, the production of as-cast ferritic thin-section ductile iron castings needs in addition some-steps inoculating treatment.

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