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Analysis of the structure of castings made from chromium white cast iron resistant to abrasive wear

D. Kopyciński
AGH-University of Science and Technology, Faculty of Foundry Engineering, Kraków, Poland
Corresponding author. E-mail address: djk@uci.agh.edu.pl

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Abstract

It has been proved that an addition of boron carbide and disintegrated steel scrap introduced as an inoculant to the chromium white cast iron changes the structure of castings. The said operation increases the number of crystallization nuclei for dendrites of the primary austenite. In this case, the iron particles act as substrates for the nucleation of primary austenite due to a similar crystallographic lattice. The more numerous are the dendrites of primary austenite and the structure more refined and the mechanical properties higher. Castings after B_4C inoculation revealed a different structure of fine grained fracture. Primary precipitates of chromium carbide also appeared, reducing the mechanical properties of as-cast parts. Properly established heat treatment regime makes chromium iron castings regain their, originally high, mechanical properties.

Keywords: Inoculation, Chromium cast iron, Boron carbide, Chromium carbide

1. Introduction

Inoculation is nowadays a commonly applied metallurgical treatment carried out by foundries to improve the mechanical properties of commercial alloys. The essence of the cast iron inoculation consists in changing the physico-chemical state of molten metal. The change is obtained by introducing to the cast iron of low graphite nucleation power, shortly before mould pouring, a small amount of inoculant, that is, of a compound capable of increasing the number of active nuclei.

In metalcasting practice, the main criterion used in evaluation of the inoculation effect are changes in the mechanical properties of grey cast iron along with its chilling tendency. From a review of literature [1-9] it follows that the effectiveness of cast iron inoculation is in prevailing part evaluated from a change in: number of eutectic grains, undercooling degree during eutectic crystallization, character of metallic matrix, characteristic of graphite precipitates in grey cast iron. In this study an attempt has been made to interrelate the effect of inoculant with the type of primary austenite precipitates.

To improve the ductility of chromium iron castings, and hence their toughness, it is necessary to produce in the structure of this material a network of fine carbides of the M_7C_3 type, characterised by a uniform distribution. It seems that raising the quality of castings made from chromium iron is inherently related with the inoculation process. Generally, chromium iron castings, to mention as an example the blades operating in concrete preparation plants, should have a very fine-grained structure ensuring high abrasion wear resistance. Correct technology of melt treatment supported by proper mould preparation technology decides about the utilisation properties of chromium iron castings and favourably affects their crack resistance.

The aim of the present study was to develop, a well adapted to the industrial conditions of casting manufacture, technology of making castings from the alloyed chromium iron resistant to abrasion wear, where the said castings have essentially different properties and micro-structural homogeneity as well as the design and dimensions.

2. Methods of investigation

Applying the conditions normally encountered in industry, high-quality chromium cast iron inoculated with boron carbide was manufactured. To the cast iron having a Cr/C ratio equal to 7, after the melting process carried out according to the previously prepared schedule, an addition of 0,4% inoculant was introduced by placing the said inoculant in the bottom of the ladle. The manufactured cast iron had the following chemical composition: 3,4%C; 0,5%Si; 24,5%Cr; 0,6%Mn; 0,8%Mo. Melting was carried out in an induction furnace of 250 kg capacity, applying the following procedure: in the bottom of the crucible, a charge composed of the pig iron and steel scrap, followed by iron scrap, was placed. After melting down the charge, ferrochromium and ferromolybdenum were added. After dissolving of ferrochromium, ferrosilicon was added. The cast iron was next overheated to a temperature of 1500^{o}C and held at that temperature for 5 minutes. As a next step, the content of manganese was made up with ferromanganese, holding the metal for the next 3 minutes. During holding of cast iron and before tapping, the melt temperature was monitored with a thermocouple. Molten cast iron was transferred to a ladle in the bottom of which an inoculants (Table 1), had been previously placed. The ladle was next handled to a pouring stand and moulds prepared previously were poured with molten metal.

Table 1.
Melt specification

Specimen Number	Inoculation
1.	base cast iron, plain
2.	B_4C
3.	disintegrated steel scrap (DSS)
4.	B_4C + DSS

Test bars of ϕ 15 mm and plates (300x200x30 mm) were cast. As a next step, specimens for mechanical tests and polished sections for metallographic examinations were prepared. The castings were also subjected to a heat treatment, carried out according to the following regime: slow preheating to 950^{o}C, holding at that temperature for 2 hours and cooling in air.

3. Results and discussion

Figure 1 and Figure 2 shows the bending strength and the hardness HRC of chromium iron specimens from the test melt conducted under industrial conditions and subjected to inoculation combined.

Figure 3 shows the microstructure of cast iron obtained from a trial melt without the inoculation treatment. The structure can be defined as „slightly” hypoeutectic. The spatial arrangement in a structure of this type can be compared to a system of the interpenetrating phases bonded together in eutectic. One of these phases is formed of the austenite dendrites that are penetrating into another phase, composed of the faceted crystals of chromium carbide $(Cr,Fe)_7C_3$. Figure 3b,c,d shows microstructure of the same cast iron after introducing the addition of 0,4 % inoculant at a temperature of 1480^{o}C.

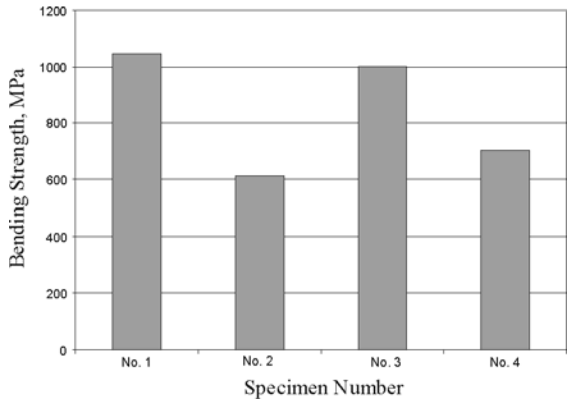


Fig. 1. The bending strength of chromium iron specimens from the test melt conducted under industrial conditions and subjected to inoculation combined (Table 1 shows the specimen number).

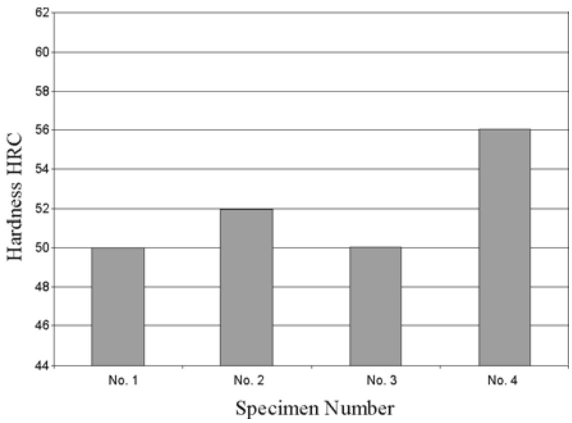


Fig. 2. The hardness HRC of chromium iron specimens from the test melt conducted under industrial conditions and subjected to inoculation combined (Table 1 shows the specimen number).

The examinations of cast iron structure after inoculation with boron carbide have revealed the presence of primary carbide precipitates $(Cr, Fe)_7C_3$, which in Figure 3b,d appear as dark spots. The morphology of the primary carbide precipitates is shown on a microphotograph in Figure 4. The chemical analysis of the cast iron phase constituents, including the primary carbide precipitates, was carried out on a JEOL 500LV scanning microscope with EDS attachment for X-ray analysis. The results of these examinations have confirmed the presence of the primary carbide precipitates (Fig. 4) in cast iron structure (publication [7] shows similar morphology).

Figure 5 shows fractures of the experimental castings. Basing on the results of macro-structural analysis of the base chromium cast iron before inoculation, it can be concluded that in this particular case one can speak about the directional solidification proceeding from the mould wall (the presence of large crystals of a directional orientation). The macrostructure in Figure 5a shows a coarse-grained fracture, while the photograph in Figure 5c indicates the predominant role of volume solidification in the process of casting formation. Owing to the process of inoculation, this macrostructure is now of a fine-grained character, and the casting has an improved abrasion wear resistance. The large number of grains is due to the inoculating effect, increasing the number of substrates for the nucleation of structural constituents present in this cast iron. Additionally, by breaking the test casting, it has been proved that the inoculating treatment with boron carbide not only refined the microstructure, but also changed the molten alloy parameters, which enabled manufacture of castings free from defects. Figure 5a shows the shrinkage cavities present in the fracture of casting poured without inoculation; these defects were not formed in castings (Figure 5c) made from the inoculated chromium iron.

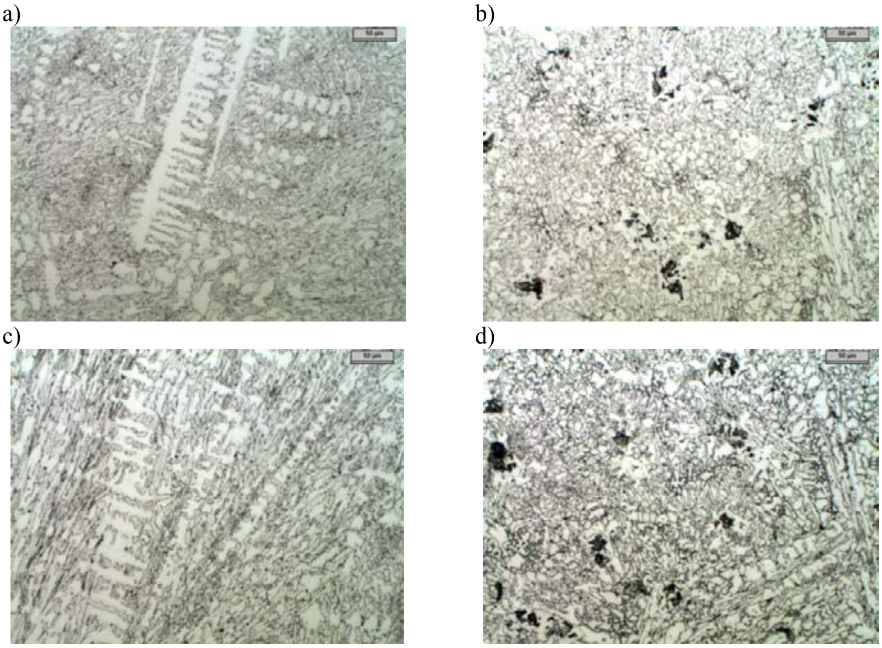


Fig. 3. Microstructures of castings made from chromium iron: plain – melt No 1 – (a), inoculated; melt No 2, melt No 3, melt No 4 – (b),(c),(d)

The microstructure of the experimental castings from the chromium iron in different variants, i.e. plain, inoculated, and heat treated, was composed of martensite and chromium carbides of the $(Cr, Fe)_7C_3$ type. Additionally, heat treatment activated the mechanism of dissolution of the primary chromium carbide precipitates. The microstructures of the test bars cast in chromium iron after the heat treatment are shown in Figure 5b,d.

The heat treatment of castings made from the inoculated chromium iron restored the high values of mechanical properties (over 900MPa) these castings had before inoculation. As can be easily deduced, this is due to the dissolution of the primary chromium carbide precipitates under the effect of temperature.

From the studies conducted so far it follows that the presence of detrimental primary chromium carbides, which appear in the cast iron structure, is caused by insufficient overheating of the metal melt. The chromium cast iron scrap introduces certain amount of the „ready" chromium carbides to metal. This problem becomes very important when the fraction of process scrap in total metallic charge is high.

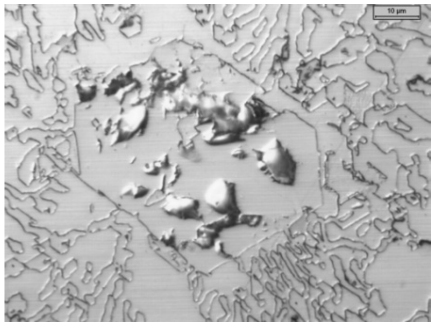


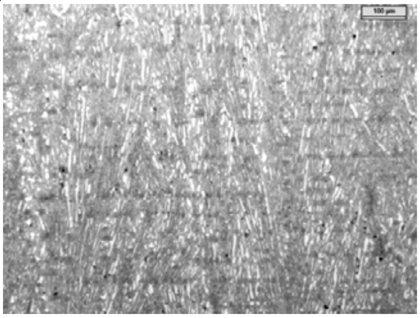
Fig. 4. The primary carbide precipitate $(Cr, Fe)_7C_3$

Additionally, when introduced to liquid metal, the inoculants change the physico-chemical constitution of this metal, stabilising the large precipitates of chromium carbides with subsequent drop of the mechanical properties of castings (Fig 1).

The study proves (for industrial conditions) that introducing the disintegrated steel scrap (DSS) to chromium cast iron doesn't influence inoculation effects in low-sulphur cast iron.

a)

b)



c)

d)

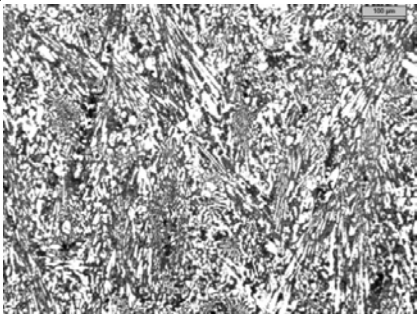


Fig. 5. Macrostructures and microstructures in fractured experimental castings : test casting before inoculation - (a), (b) and test casting after inoculation – (c), (d); test castings after heat treatment

4. Conclusions

It has been proved that inoculation increases the number of crystallization nuclei for dendrites of the primary austenite. In this case, the iron particles act as substrates for the nucleation of primary austenite due to a similar crystallographic lattice.

In this study it has been proved that the manufacturing process of chromium cast iron is, to a great extent, dependent on the following technological parameters: charge materials, pouring temperature (the temperature of overheating should amount to 1550°C), and the operation of inoculation. All these steps directly affect the casting cooling rate and the physico-chemical condition of molten metal. The additional structure-controlling parameter is heat treatment.

To solve the problem of the mechanical properties considerably reduced after the process of chromium cast iron inoculation, two different approaches to the question of how to obtain in casting the final structure free from the primary chromium carbide precipitates can be considered, viz. developing a best technique of the metallic charge melting, maintaining at the same time the metallurgical parameters at an adequately high level, or, when the said carbides do appear in structure, their saturation during proper heat treatment.

Acknowledgements

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