

# Inoculation of chromium white cast iron

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## Abstract

It has been proved that an addition of boron carbide introduced as an inoculant to the chromium white cast iron changes the structure of castings. Castings after inoculation revealed a different structure with numerous grains. 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, Structure, Mechanical Properties, Boron Carbide, Chromium Carbide

## 1. Introduction

Chromium cast iron is the material well-known and widely used in numerous sectors of industry. From the data given in literature [1-7] it follows that there are still various problems that occur during manufacture of this cast material and have not been properly solved until the present day. Hence it can be concluded that every attempt is welcome if only it can improve the utilisation properties of chromium iron castings. One of the methods improving the final properties of castings is controlling their structure through changes in the physico-chemical state of molten metal.

Various methods have been used for this purpose, involving mainly changes in basic parameters of the metallurgical process of melt preparation, directly affecting the casting structure. These parameters include the temperature of overheating and pouring, holding time, chemical composition, charge materials, refining treatment, and casting modulus.

The structure of casting can be changed by introducing to the metal melt some additives commonly known under the name of inoculants. The role of the inoculant is to raise the number of the grains, while leaving the cast iron chemical composition unchanged. 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 microstructural 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°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 inoculant, i.e. boron carbide, had been previously placed. The ladle was next handled to a pouring stand and moulds prepared previously were poured with molten metal.

Test bars of  $\phi$  15 mm and plates shown in Figure 1 were cast.



Fig. 1. The appearance of a test casting with the gating system immediately after knocking out from mould

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°C, holding at that temperature for 2 hours and cooling in air.

### 3. Results and discussion

Figure 2a 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 2b shows microstructure of the same cast iron after introducing the addition of 0,4 % inoculant at a temperature of 1480°C.

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 2b appear as dark spots. The morphology of the primary carbide precipitates is shown on a microphotograph in Figure 2c. The chemical analysis of the cast iron phase constituents (Figure 2d), 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 in cast iron structure.

Figure 3 shows fractures of the test bars. Basing on the results of macrostructural 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 3a shows a coarse-grained fracture, while the photograph in Figure 3b 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 3c shows the shrinkage cavities present in the fracture of casting poured without inoculation; these defects were not formed in castings (Figure 1) made from the inoculated chromium iron.

The microstructure of the test bars cast 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 2e,f.

As follows from the investigations, in this particular case, when conducted under industrial conditions, the heat treatment had practically no effect on the mechanical properties of test castings made from the high abrasion wear resistance chromium iron; the castings are shown in Figure 4. The bending strength was similar in castings with and without the heat treatment (Figure 5). Heat treatment, on the other hand, increased the hardness values (Figure 6). The process of inoculation with boron carbide reduced the mechanical properties of castings, while refining their structure quite considerably (Figure 3) and raising the hardness values (Figure 6). The highest values of the hardness HRC were obtained in the chromium cast iron inoculated and heat treated. Additionally, the heat treatment of castings made from the inoculated chromium iron restored the high values of mechanical properties these castings had before inoculation (Figure 5). 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. 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.

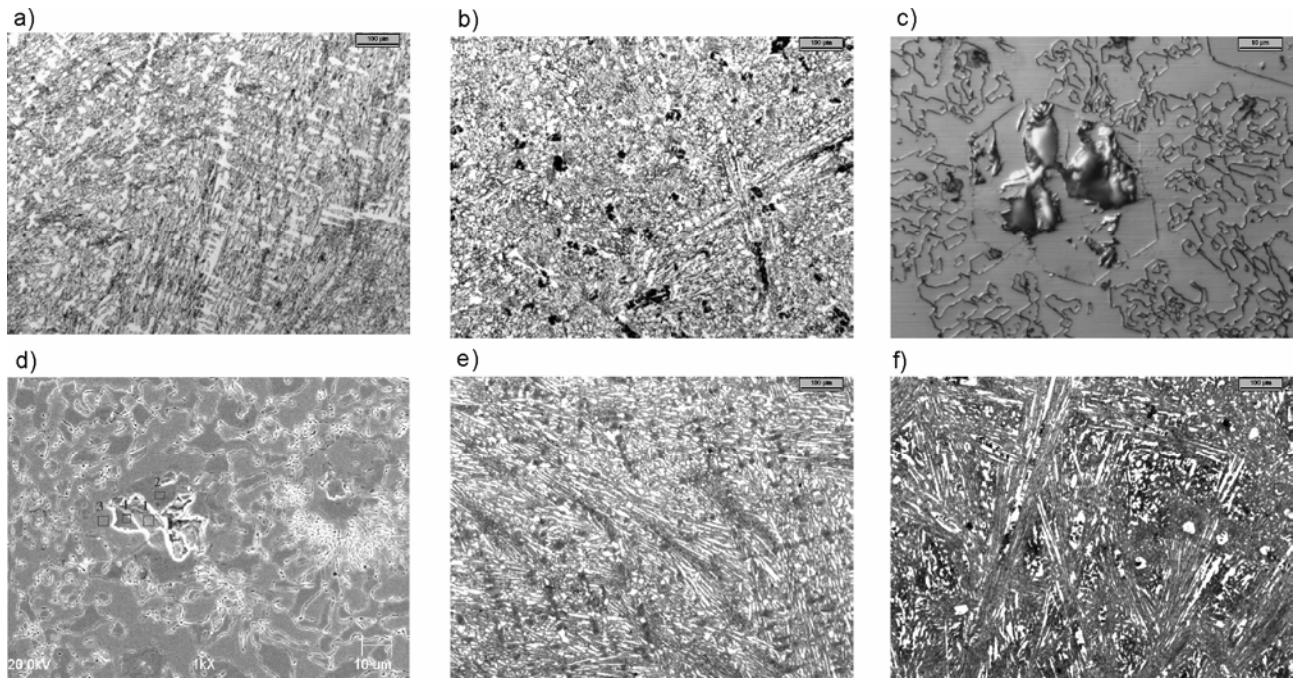


Fig. 2. Microstructures of castings made from chromium iron: plain – (a), inoculated – (b), primary carbide precipitates  $(Cr, Fe)_7C_3$  (c,d), plain after heat treatment– (e), and inoculated after heat treatment–(f)

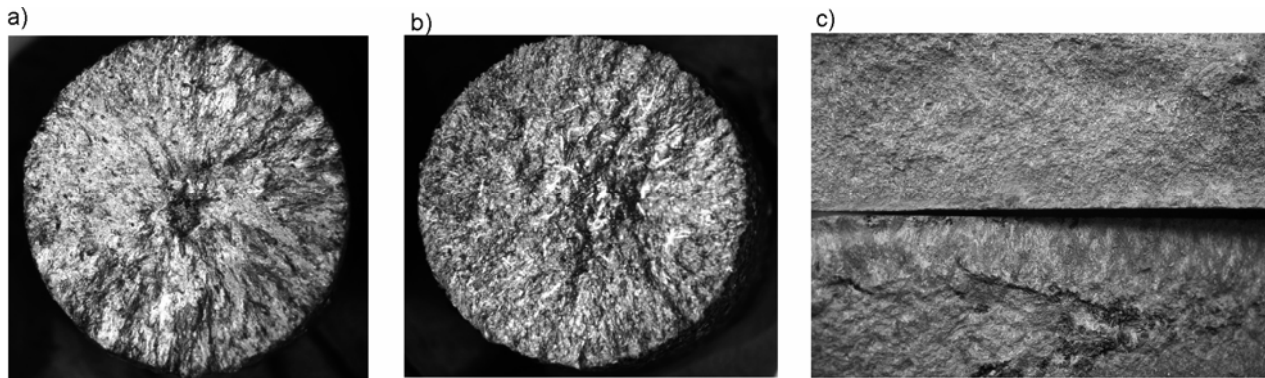


Fig. 3. Macrostructures observed in fractured test bars of chromium iron castings: test bar before inoculation – (a), test bar after inoculation – (b), and comparison of macrostructures obtained in test castings made from chromium iron without inoculation (lower fragment of the photograph) and with inoculation (upper fragment of the photograph) – (c)

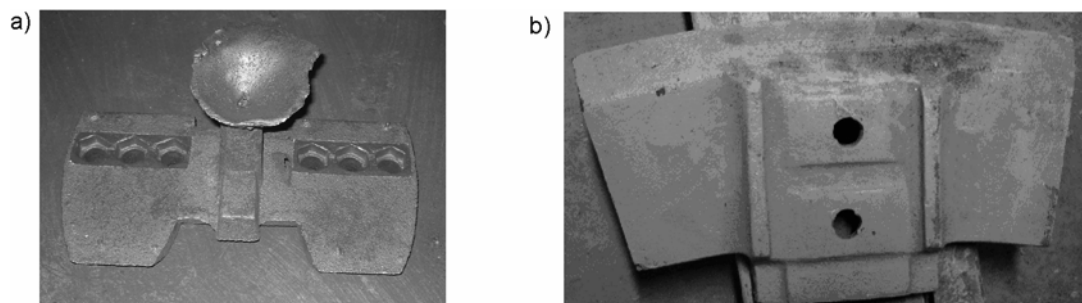


Fig. 4. Examples of castings made from the high abrasion resistance chromium iron – (a,b)

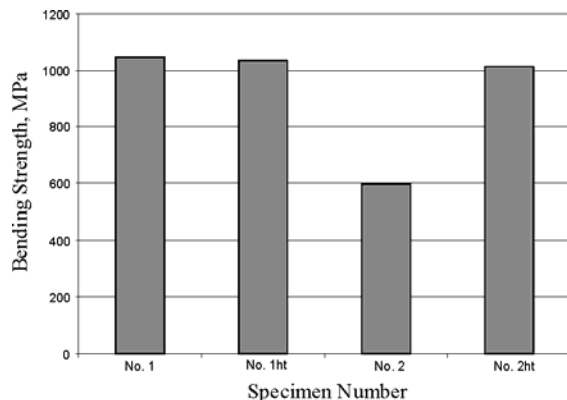


Fig. 5. The bending strength of chromium iron specimens from the test melt after inoculation combined with proper heat treatment. Designations: No. 1 – casting made from plain chromium iron without heat treatment, No. 1ht - casting made from plain chromium iron after heat treatment, No. 2 – casting made from inoculated chromium iron without heat treatment, No. 2ht - casting made from inoculated chromium iron after heat treatment

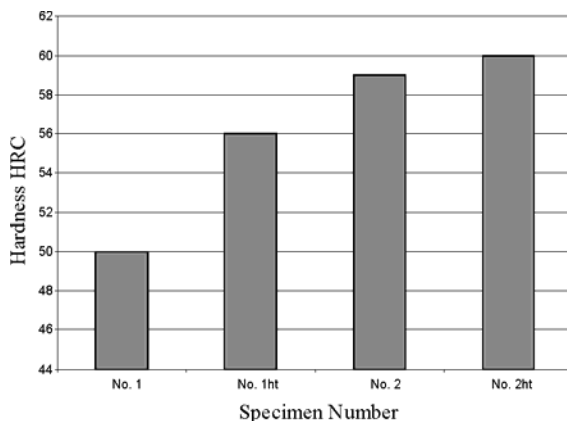


Fig. 6. The hardness HRC of chromium iron specimens from the test melt conducted under industrial conditions and subjected to inoculation combined with heat treatment. Designations: No. 1 – casting made from plain chromium iron without heat treatment, No. 1ht - casting made from plain chromium iron after heat treatment, No. 2 – casting made from inoculated chromium iron without heat treatment, No. 2ht - casting made from inoculated chromium iron after 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.

## 4. Conclusions

The mechanical and technological properties of cast iron depend on its structure, that is, on the type, shape and quantity of crystal phases present in this material. The following factors have an undeniable effect on the cast iron structure: the physico-chemical state of molten metal, the cooling rate, and the heat treatment.

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.

As a result of these investigations, an industrial technology of the manufacture of castings (Figure 4) from the alloyed chromium iron resistant to abrasion wear was developed. The castings had basically different properties and homogeneity of microstructure.

A very handy tool in evaluation of the cast iron inoculation process effectiveness are the cast test bars. They are knocked out from mould immediately after having been cast, and after breaking are subjected to microstructural examinations.

The quality requirements for the manufactured cast iron grade are consistent with the EN 12513:2000 Standard valid in this respect.

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