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D. KOPYCIŃSKI*, E. GUZIK*, A. SZCZĘSNY*

EQUIAXED AND ORIENTED MICROSTRUCTURE IN HIGH CHROMIUM CAST IRON

RÓWNOOSIOWA I ZORIENTOWANA MIKROSTRUKTURA W ŻELIWIE WYSOKOCHROMOWYM

It has been proved that an addition of boron carbide and shredded steel scrap introduced as an inoculants to the chromium white cast iron changes the microstructure of castings. The operation increases the number of crystallization nuclei of M_7C_3 carbides. In this case the B_4C carbides act as substrates for the nucleation of M_7C_3 (chromium carbides). Castings after B_4C inoculation have fine grain fracture surface. Primary precipitates of chromium carbide also appeared, lowering the mechanical properties of as-cast parts. Additionally, in order to increase the mechanical properties of chromium cast iron, unidirectional solidification was used. In this case, 0.3 wt. % cerium was used as inoculant.

Keywords: Inoculation, bulk and unidirectional solidification, mechanical properties

W pracy wykazano, że wprowadzenie do żeliwa chromowego dodatków modyfikatora w postaci węglika B_4C oraz złomu stalowego w postaci rozdrobnionej powoduje zmianę struktury odlewu oraz właściwości wytrzymałościowych. Wprowadzenie B_4C zwiększa liczbę zarodków krystalizacji węglika chromu M_7C_3. Struktura odlewu po zabiegu modyfikacji węglikiem boru charakteryzowała się drobnoziarnistym przełomem. W pracy wyjaśniono problem pojawienia się pierwotnych wydzieleń węglika chromu w strukturze, które to węgliki wpływają na obniżenie właściwości wytrzymałościowych surowych odlewów. Dodatkowo w pracy zastosowano kierunkową krystalizację, w celu zwiększenia właściwości mechanicznych żeliwa chromowego. W tym przypadku jako modyfikatora użyto 0,3% mas. ceru.

1. Introduction

Chromium cast iron is the material well-known and widely used in numerous sectors of industry. From the data given in literature it follows that there are still various problems that occur during manufacture of this material and have not been properly solved until the present day [1-15]. Hence every attempt is welcome if only it can improve the properties of chromium iron castings. One of the methods improving the final properties of castings is controlling their microstructure through changes in the physicochemical 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 microstructure. These parameters include the temperature of overheating and pouring, holding time, chemical composition, charge materials, refining treatment, and wall thickness of the casting.

The microstructure of casting can be changed by introducing to the metal melt some additives commonly known under the name of inoculants. The role of the inoculants is to increase the number of the grains, leaving the chemical composition unchanged. Another method, which significantly affects the microstructure of the cast iron is unidirectional solidification [16,17]. Unidirectionally solidified high chromium cast iron is playing an increasingly important role in the development of new materials. This material is possessing unusual and highly anisotropic mechanical properties derived from their fiber-like structure. In particular they are materials with potential applications in high temperature environments (e.g. gas turbine components) or under severe loads.

2. Experimental procedure

Applying the conditions typical in foundry casting industry, two melts chromium white cast iron was made (No. 1÷5 in Table 1). 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 the charge, ferrochromium and ferromolybdenum were added. After dissolving of ferrochromium, ferrosilicon was added and the melt was overheated to 1500°C and held at that temperature for 5 minutes. After that, the content of manganese was enriched with ferromanganese and the melt was hold for next 3 minutes. During holding and before tapping, the melt temperature was monitored with a thermocouple. Molten cast iron was poured into a ladle, on the bottom of which the inoculants

* AGH, UNIVERSITY OF SCIENCE AND TECHNOLOGY, FACULTY OF FOUNDRY ENGINEERING, AL. A. MICKIEWICZA 30, 30-059 KRAKÓW, POLAND

(No. 3÷5 in Table 1) was introduced and handled to a pouring stand and moulds were poured.

In laboratory conditions one melt (No. 6 and 7 in Table 1) of Fe-Cr-C alloy was prepared in vacuum furnace using high purity elements. After melting the bath was kept at 1550°C and 0.15 Pa for about 25 minutes. Ten quartz tubes were used to extract the liquid metal in order to obtain rounded bars of approximately ø5 mm in diameter and 100 mm in length. Solidified unidirectionally was carried out by the apparatus shown in works [16-18]. The temperature gradient dT/dx at liquid/solid interface was approximately 150°C/cm. After that, specimens for mechanical tests and metallographic examinations were prepared.

TABLE 1

Test samples

No.	Cast iron chemical composition						Inoculant	
	C	Si	Mn	P	S	Cr		
	wt. %						type	wt.%
1	3,2	0,7	0,7	0,03	0,05	16,3	–	–
2							–	–
3	3,4	0,5	0,7	0,05	0,07	24,5	B_4C	0.4
4							SSS	0.4
5							B_4C + SSS	0.8
6	3,01	-	-	-	–	28,82	-	-
7							Ce	0.3
SSS – shredded steel scrap								

3. Results and discussion

The mechanical and casting properties of chromium cast iron are shown in Table 2.

TABLE 2

Chromium cast iron mechanical and casting properties

No.	Castability, mm	Bending strength, MPa	Tensile strength, MPa	Hardness, HRC	Casting Temperature T, °C
1	1000	950	700	45	1460
2	1050	1030	708	48	

Figure 1a (hypoeutectic) and 1b (eutectic) shows the microstructure of cast iron marked by No. 1 and No. 2 (Table 1 and 2). The microstructure of eutectic cast iron characterised by the highest amount of M_7C_3 type carbides which gives the microstructure of the highest possible abrasion wear resistance and hardness. Shapes of eutectic grains in high-chromium cast iron and scheme of γ – $(Fe,Cr)_7C_3$ eutectic grain are shown in Figure 1c and d.

It was assumed that the introduction of small additions of boron carbide B_4C combined with fine pieces of the steel scrap should change the microstructure of high-chromium cast iron. In this case, the inoculant particles can act as substrates for the nucleation of primary austenite and chromium carbide particle.

Figure 2 compares the values of HRC hardness and bending strength obtained in samples of the chromium cast iron (No. 2÷No. 5). Introducing the B_4C as inoculant to liquid cast iron (No. 3) slightly increases its hardness, but at the expense of much lower bending strength. The addition of shredded steel scrap (SSS) to the cast iron (No. 4) melt slightly increases the hardness of cast iron, while keeping bending strength practically unchanged. Only the addition of inoculants in the form of a B_4C+SSS packet (No. 5) leads to significant hardness increase, although mechanical properties of the alloy are inferior to available by the alloy before inoculation (No. 2) but superior than application B_4C as inoculant (No. 3).

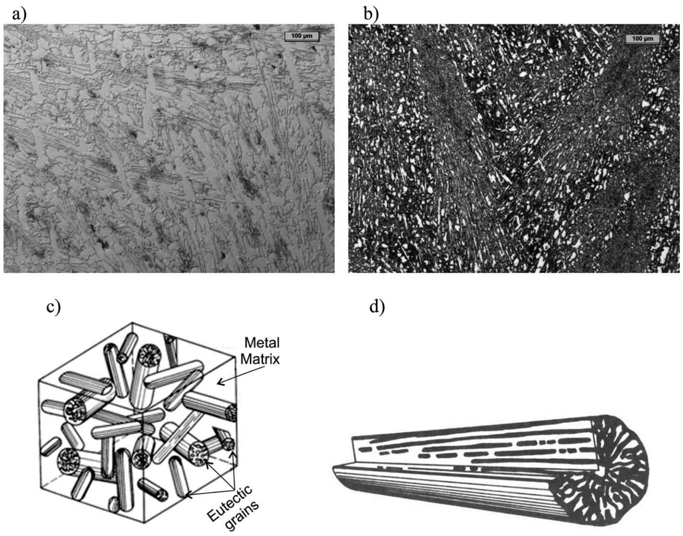


Fig. 1. Microstructures high chromium castings made from: melt No. 1 – (a), melt No. 2 – (b), shapes of eutectic grains in high-chromium cast iron [18] – (c), and scheme of γ – $(Fe,Cr)_7C_3$ eutectic grain [19] – (d)

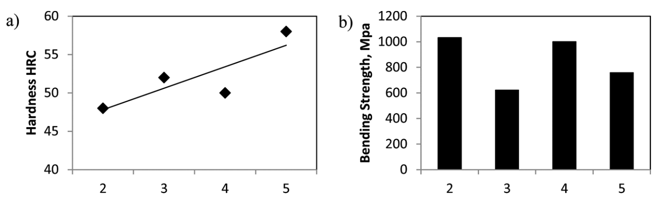
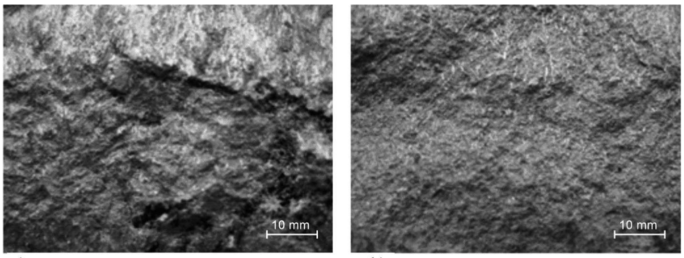


Fig. 2. Hardness HRC – (a) and bending strength – (b)

Figure 3 shows fractures of the studied castings (No. 2 and 5). Comparing the result of macrostructural analysis of the cast iron before (No. 2) and after inoculation (No. 5) it can be stated that in this case macrostructure in Figure 3a shows the coarse-grained fracture, while image in Figure 3b reveals the predominant role of bulk solidification prevailing in the process of casting. Due to the process of inoculation, this macrostructure is a much more fine-grained nature, which will result in increased abrasion wear resistance of the casting. Additionally, by examination of the fracture surface, it has been proved that the inoculation with boron carbide B_4C and shredded steel scrap not only refines the casting macrostructure, but also changes the physical and chemical state of the melt, resulting in the manufacture of castings free from defects. Figure 3a shows the shrinkage cavity observed on a fracture surface; this defect has not occurred in the inoculated cast iron (Fig. 3b).



a) b)

Fig. 3. Macrostructures of the fracture surface: without inoculation No. 2 – (a), with inoculation No. 5 – (b)

This differences are definitely related with the number and macrostructure of the primary austenite dendrites and eutectic grains included in the cast iron microstructure. The microstructure of high-chromium cast iron sample before inoculation shows the presence of several austenite primary grains and eutectic grains, as shown in Figure 4.

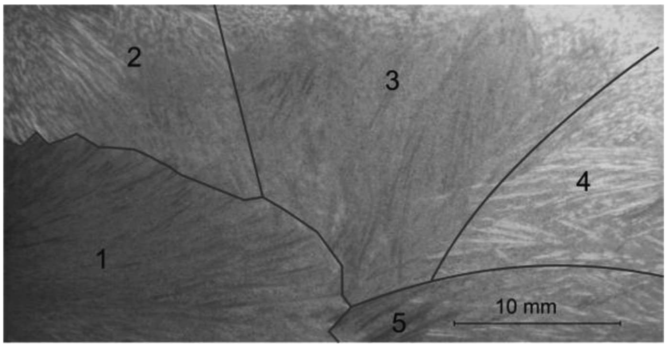
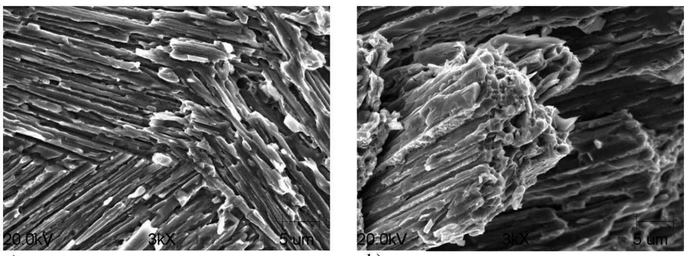


Fig. 4. The macrostructure of cast iron without inoculation (No. 2)

In the chromium cast iron after inoculation recognition the number of primary grains was not possible on the optical microscope (LM). Microstructure with a large quantity of the eutectic grains γ+ M_7C_3 shown in Figure 5.



a) b)

Fig. 5. SEM microstructures of fracture surface (No. 2), eutectic grains – (a), eutectic grain – (b)

The UTS of high-chromium cast iron (unidirectional solidification) with eutectic microstructures are presented as growth rate v. It is found that addition of cerium as inoculant an appreciable improvement tensile strength in Fe-C-Cr alloys (Fig. 6). Metallographic observations indicated that the increase in high-chromium cast iron strength is related to a decrease in fiber (carbide M_7C_3) interspacing below corresponding values for the Fe-C-Cr alloys. Figure 7 shows cast iron microstructure (No. 7) obtained as a result of unidirectional solidification.

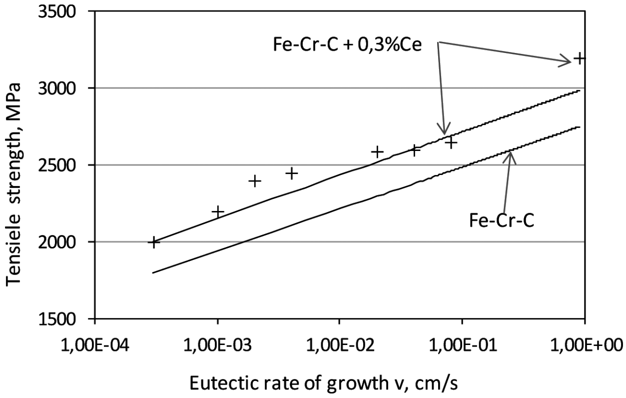
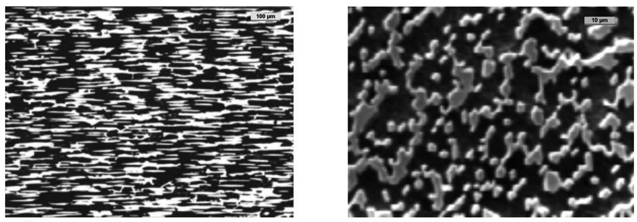


Fig. 6. UTS of the unidirectionally solidified Fe-Cr-C and Fe-Cr-C + 0.3% Ce eutectic alloys as a function of eutectic growth rate v



a) b)

Fig. 7. Microstructures of high chromium cast iron (No. 7) after unidirectional solidification; longitudinal – (a) and transverse – (b) sections with respect to the planar liquid/solid interface

4. Summary

The mechanical and technological properties of cast iron depend on its microstructure, and therefore on the type, shape and volume of the crystalline phases present in this material. The microstructure of cast iron is undeniably influenced by the physical and chemical state of the molten metal, cooling rate and the subsequent unidirectional solidification. The inoculation of high-chromium cast iron done with boron carbide B_4C and shredded steel scrap was observed to reduce the bending strength of this material. On the other hand, hardness of the casting increased and casting defects such as porosity were no longer present. It should be noted that the casting fracture after inoculation had a fine-grained character, which can lead to increased abrasion wear resistance. In addition, the mechanical properties increase when the alloy solidified directionally. Maximum tensile strength were present in high chromium cast iron with eutectic microstructure. For this microstructure cerium additions increases UTS to about 3200 MPa. Thus, in subsequent studies, cerium will be used to improve the mechanical properties of cast iron as inoculant.

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