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The structure of abrasion-resisting castings made of chromium cast iron

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Abstract

In this study presents the analyse of chrome iron cast structure (as-cast condition) which are used in rugged conditions abrasion-percussive and high temperature. While producing the casts of chrome iron major influence has been preserve the structure of technological process parameters. The addition to Fe-C-Cr alloy Ni, Mo or Cu and then proper heat treatment leads to the improvement of functional and mechanical cast qualities. Then it is possible to develop high mechanical properties which are recommended by PN-EN12513. As can it be seen from the above research silicon is an adverse chemical element in this kind of alloy cast iron. However, the reason of cracks appearing in chrome iron casts are phosphorus eutectic microareas. When the compound of Si and P reach the critical point, described in PN-88/H-83144 outdated standard, the microareas might appear.

Keywords: High-chromium cast iron; Low-chromium cast iron; Chromium carbide; Phosphorus eutectic

1. Introduction

Choosing the proper cast iron that would work in rugged conditions abrasion-percussive is extremely important. According to the development of power, building and extractive industry, there are high expectations of mechanical properties. The solution is chrome iron. As the analysed literature [1-4], structure (graphite, carbides and metallic matrix) and hardness change of cast iron affects the improvement of abrasion resistance. It is possible to divide these casts into to two groups. The first group consists of grey cast iron and mottled cast iron. Chromium white cast iron belongs to the second group. Basically, this division is included in PN-EN12513 (Dec. 2003). In this document describing types of cast iron: low alloy and Ni-Cr alloy, and chrome white high alloy. High chrome white cast iron has four areas of chrome content: 11%<Cr<14%, 14%<Cr<18%, 18%<Cr<23%, 23%<Cr<28%. Because of that three kinds of abrasion-resisting cast iron exist. Additionally this cast works in high temperature. In table 1 these kinds of cast iron are mentioned.

Table 1.
The specification of cast iron kinds according to standard PN-EN12513

Symbol EN-GJN-	Skład chemiczny, %mas.								
	C	Si	Mn	P max.	S max.	Cr	Ni max.	Mo max.	Cu max.
-HV350	2.4-3.9	0.4-1.5	0.2-1.0	-	-	do 2.0	-	-	-
-HV600(XCr14)	1.8-3.6	do 1.0	0.5-1.5	0.08	0.08	14-18	2.0	3.0	1.2
-HV600(XCr23)	1.8-3.6	do 1.0	0.5-1.5	0.08	0.08	23-28	2.0	3.0	1.2

However, in table 2 only chose cast iron kinds from PN-88/H-83144 outdated standard are mentioned. It should be emphasized that this document is currently often used by casting house. The aim of this work is to evaluate the structure and mechanical and casting properties which were developed according to both quoted PN standards.

Table 2.
The specification of cast iron kinds according to standard PN-88/H-83144

Symbol	Skład chemiczny, %mas.								
	C	Si	Mn	P max.	S max.	Cr	Ni max.	Mo max.	Cu max.
ZlCr1.5	3.0-3.8	2.0-3.0	do 1.0	0.3	0.12	1.0-2.0	-	-	-
ZlCr16	2.4-3.6	0.5-1.5	1.5-2.5	0.1	0.05	13-19	-	2.0	1.5
ZlCr28	1.6-3.2	1.5-2.5	1.0	0.1	0.08	25-30	-	-	-

The seconds 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 was manufactured. The manufactured cast iron had the following chemical composition is show in table 3.

Table 3.
The chemical composition cast iron, %mas.

Nr wytopu	C	Si	Mn	P	S	Cr
			%, mas.			
1	3.0	2.1	0.3	0.30	0.11	1,52
2	3.2	0.7	0.7	0.03	0.05	16.3
3	3.4	0.5	0.7	0.05	0.07	24.5
4	2,0	0.6	0.8	0.05	0.06	27.8
5	2.1	2.0	0.7	0.04	0.06	28.6
6	1,6	1.2	0.8	0.03	0.05	27.8

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. The ladle was next handled to a pouring stand and moulds prepared previously were poured with molten metal. Test bars of ϕ 15 mm were cast according to production cycle HARDKOP foundry. As a next step, specimens for mechanical tests and polished sections for metallographic examinations were prepared. The chromium iron 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.

The chemical analysis of the cast iron phase constituents was carried out on a JEOL 500LV scanning microscope with EDS attachment for X-ray analysis.

3. Results and discussion

Figure 1 and Figure 2 shows the microstructure of high chromium cast iron obtained from a trial melt. 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 $(Cr,Fe)_7C_3$.

a)

b)

c)

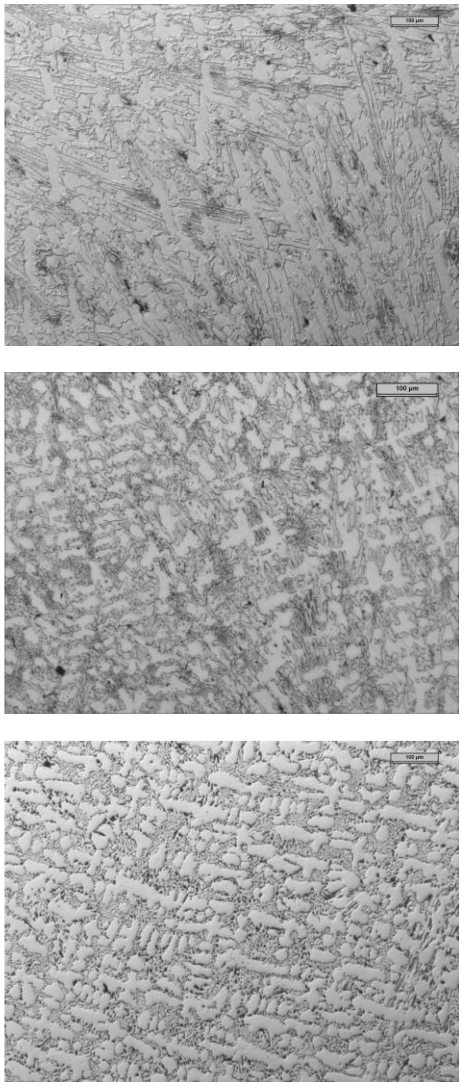

Fig. 1. Microstructures of castings made from high chromium cast iron: melt No 2 - (a), melt No 3 - (b), melt No 4 - (c)

a)

b)

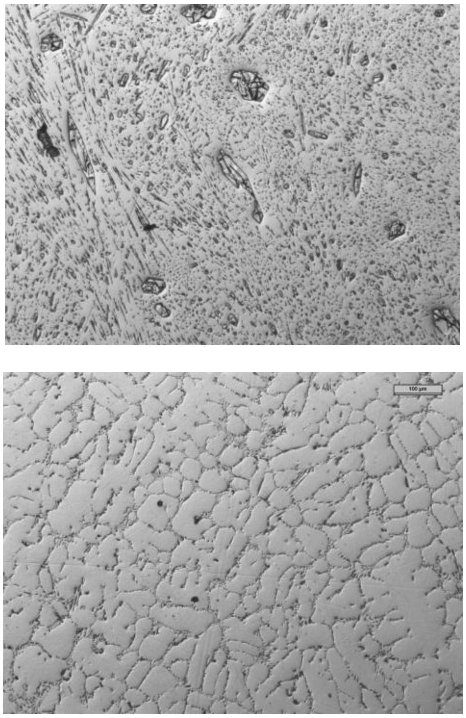

Fig. 2. Microstructures of castings made from high chromium cast iron: melt No 5 - (a), melt No 6 - (b)

In table 4 show the mechanical and casting properties of chromium cast iron specimens from the test melt conducted under industrial conditions.

Table 4.
The specification mechanical and casting properties chromium cast iron

No	L, mm	UBS MPa	UTS MPa	HRC	HV	KVC J/cm^2	T ^oC
1	1500	310	210	27-33	350	-	
2	1000	900	700	39-43/60*	450/700*	60	
3	1050	800	700	41-44/60*	450/700*	55	1460
4	750	780	550	29-33	350	45	
5	900	800	550	34-37	380	30	
6	700	750	450	23-27	300	40	

(*) – value after heat treatment (0.8% Mo),
L – castability.

As a result of the comparison of hardness in researched Fe-C-Cr alloys was found out that only low chrome iron (melt No 1) is compliant to PN-EN12513. After mixing the heat treatment and proper chemical compounds (alloy additions Mo, Cu, Ni and Table 1 and Table 3) positive results of hardness HV for high chrome cast iron were produced. In this condition heat treatment is defined as hardening, tempering and soft annealing.

Figure 3 shows the microstructure of low chromium cast iron obtained from a trial melt. This is typical mottled cast iron structure. In low chrome cast iron structure (Fig.3) sulphured and phosphorus eutectic can be noticed. It leads to limiting temperature range work of this cast iron. It is necessary to shape triple phosphorus eutectic (steadyt) on the surface of sulphide and carbide lamella Fe_3C. Specific feature of this phosphorus eutectic is low melting temperature (about 950^{o}C).

a)

b)

c)

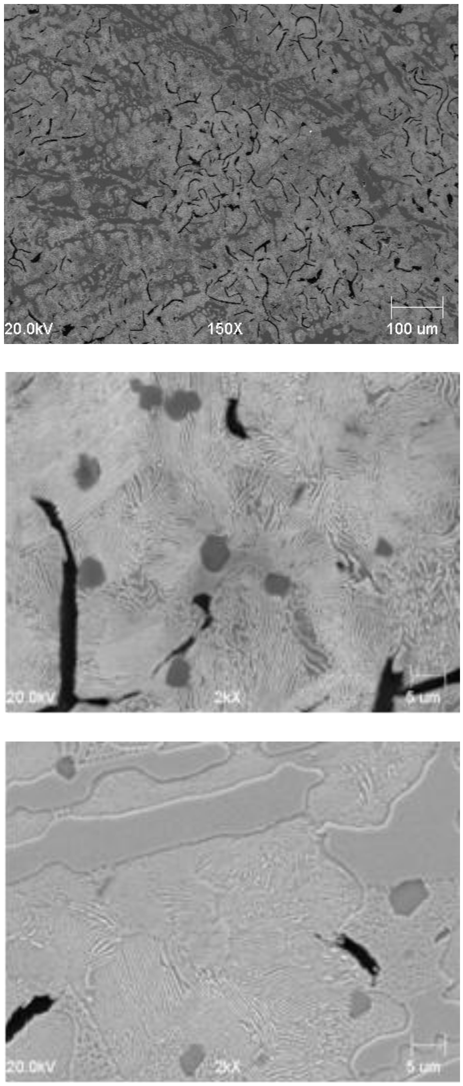

Fig. 3. Microstructures of castings made from low chromium cast iron at melt No 1 - (a) and aspect sulphides or phosphorus eutectic (steadyt) – (b, c)

Therefore, the appearance of phosphorus eutectic in castings structure is compliant to PN-88/H-83144 (high compounds S and P). It can cause with the cracks in the casts, when the temperature enhance the level of 600^{o}C. Thereby in the cast structure melting phosphorus eutectic microareas starts (at the grains boundary). Specific microareas of this eutectic are shown at Fig. 4 (iron samples after annealing).

a)

b)

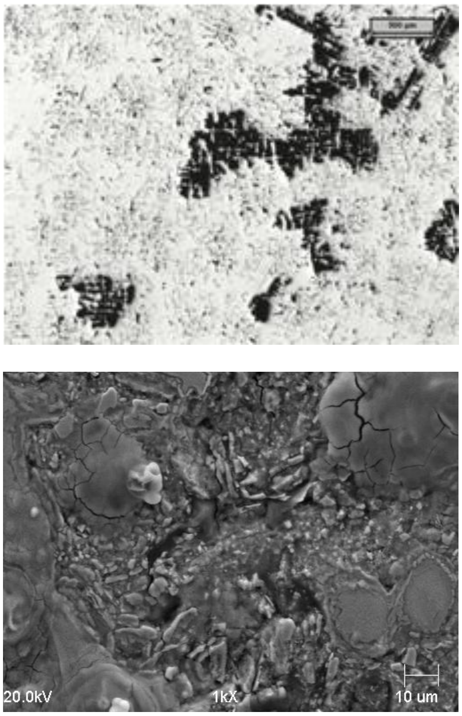

Fig. 4. Microstructures of castings made from low chromium cast iron at melt No 1 after heat treatment - (a) and microstructure SEM specific microareas (b)

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^{o}C). 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 from the alloyed chromium iron resistant to abrasion wear was developed. The castings had basically different properties and homogeneity of microstructure.

The quality requirements for the manufactured cast iron grade are consistent with the EN 12513:2000 standard valid in this respect. It is recommended (at low chromium cast iron) to pay attention to the appearance of two eutectics structure of the cast iron microareas: the first, this with high compound of phosphor (at the grains boundary), the second with the sulphurs (when small compound of Mn in the cast iron). It might cause with the cast cracks, among others, the damages of machines. It especially used in power industry, for example: fire grate, elements heating stove. The higher amounts of S and P are acceptable in cast iron according to PN-88/H-83144 outdated standard. However, in the PN-EN12513 new standard these chemical elements are not mentioned. To crumble the structure of white high chrome cast iron it is recommended to provide inoculation using the B_4C [5-8]. For the same reason, the inoculation on the basis of FeSi should be used in low chrome cast iron [7]. 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.

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