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Influence of Tungsten and Titanium on the Structure of Chromium Cast Iron

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Abstract

The paper analyses the as-cast state structure of chromium cast iron designed for operation under harsh impact-abrasive conditions. In the process of chromium iron castings manufacture, very strong influence on the structure of this material have the parameters of the technological process. Among others, adding to the Fe-Cr-C alloy the alloying elements like tungsten and titanium leads to the formation of additional carbides in the structure of this cast iron, which may favourably affect the casting properties, including the resistance to abrasive wear.

Keywords: Chromium cast iron, Chromium carbide, Titanium carbide, Tungsten carbide

1. Introduction

A review of the literature [1-4] shows that increasing the abrasion wear resistance of cast iron is achieved by a deliberate change in the characteristics of cast iron metal matrix, raising its hardness and providing an effective control of the content, size and distribution of carbides. Cast iron in the structure of which carbon is bound into carbides is known as white cast iron. High-chromium cast iron according to PN-EN12513 is the grade resistant to abrasion and corrosion, characterised, moreover, by good impact strength.

The properties of white cast iron are strongly influenced by the type, shape, distribution and volume fraction of carbides present in the structure [5-6].

Carbides in white cast iron can be divided into two groups:

- interstitial carbides with simple, close-packed structure;
- interstitial carbides with complex hexagonal, close-packed structure.

The first group includes carbides of the MC type, e.g. WC, VC, TiC, NbC and of the M₂C type, e.g. W₂C, Mo₂C. The second

group includes carbides of the M₃C – (Cr,Fe)₃C type, of the M₇C₃-(Cr,Fe)₇C₃ type, and of the M₂₃C₆ - (Cr,Fe)₂₃C₆, Fe₂₁Mo₂C₆ as well as (Cr,Fe)₆C – Fe₃W₃C, Fe₄Mo₂C types.

High melting point and hardness are the characteristics most typical of carbides [1-6]. This is related with the structure of crystalline carbides, as shown in Table 1.

Table 1.
Comparison of carbide-related parameters

Carbide	Crystal type	Max. melting point, °C	Hardness, max. HV
(Cr,Fe) ₇ C ₃	Hexagonal	1780	1800
(Cr,Fe) ₂₃ C ₆	Complex cubic	1520	1650
W ₂ C	Hexagonal	2750	2000
WC	bcc	2867	2400
VC	fcc	2830	2800
TiC	fcc	3150	3200

High-chromium cast iron can have the structure hypoeutectic, eutectic and hypereutectic (Fig. 1). In this type of structure,

besides the eutectic M_7C_3 carbide precipitates, there are also the hypereutectic (primary) precipitates, shown in Figure 1.

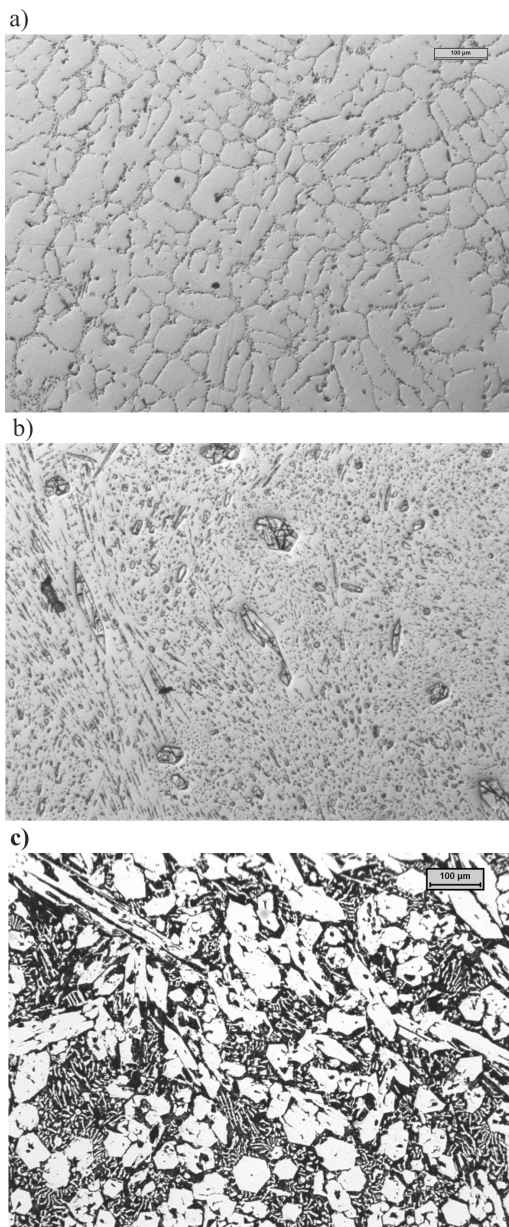


Fig. 1. Microstructure of high-chromium cast iron – hypoeutectic – a), near-eutectic – b) and hypereutectic –c) [7,own studies]

From Figure 1 it follows that the primary M_7C_3 carbides have a characteristic cubic cross-section or slightly more elongated structure. Hence, for this particular type of carbides, one can distinguish two morphologies, i.e. a rod-like morphology and a plate-flake like morphology. When the carbide crystal has a hexagonal crystal lattice, its morphology assumes a rod-like shape. But when the lattice assumes a rhombic shape, carbide morphology is of a plate-flake character.

The aim of this study was to evaluate the structure of chromium cast iron after the introduction of tungsten and titanium. The structure of chromium cast iron was evaluated in terms of the possible formation, besides the M_7C_3 type carbides, also of titanium and tungsten carbides. The results presented here are of a preliminary character. The study was conducted under industrial conditions.

2. Methodology

Castings from chromium iron were poured under industrial conditions. The chemical composition of the obtained cast iron is shown in Table 2. In this composition, an excess content of carbon was assumed as necessary for the formation of tungsten and titanium carbides.

Table 2.
Chemical composition compared for the examined cast iron

Melt No.	C	Si	Mn	P	S	Cr	W/Ti
	wt.%						
1	4.00	0.52	0.44	0.02	0.006	19,83	5.02
2	4.10	0.56	0.41	0.02	0.005	19,91	5.08

Melting was carried out in an induction furnace with crucible of 250 kg capacity, adopting the following process route: pig iron and steel scrap were placed on the bottom of the crucible, followed by iron scrap. After melting down of the charge, ferrochrome and ferromolybdenum were introduced (for high-chromium grades). After the dissolution of ferrochromium, the charge composition was completed with ferrosilicon. Then the melt was overheated to 1500°C and held at that temperature for 5 minutes. At the final stage, the content of manganese was made up with an addition of ferromanganese and the melt was held for 3 minutes. During holding of the melt and before tapping, the temperature of liquid iron was measured with a thermocouple. The melt was transferred to a ladle, which was next transported to the casting stand and molten metal was poured into the previously prepared moulds. Test bars with a ϕ 15 mm diameter and castings were made following the production regime adopted by HARDKOP Foundry at Trzebinia. As a next step, specimens were prepared for metallographic examinations. Chemical composition of the cast iron phase constituents was examined using a JEOL 500LV scanning electron microscope with attachment for X-ray microanalysis (EDS).

3. Results and discussion

Figures 2 and 3 show the microstructure of high-chromium iron castings obtained in experimental melts. The spatial arrangement of a structure of this type can be compared with interpenetrating phases that are connected together in the eutectic. One of these phases is composed of elongated faceted crystals of chromium carbide $(Cr, Fe)_7C_3$, and the space between the crystals is filled with non-faceted transformed austenite phase. Between the above mentioned phases in melt no. 1 appear precipitates of tungsten carbide, while in melt no. 2, TiC carbides are also

present. In the former case, the measurements of the hardness of the microstructure taken with a MODEL HV-1000B microhardness tester have yielded the values from 1500 to 2300, which means that the values typical of tungsten carbides given in Table 1 have not been reached (tests will continue.) The presence of titanium carbides in the structure of chromium cast iron is indisputable – see Figure 3.

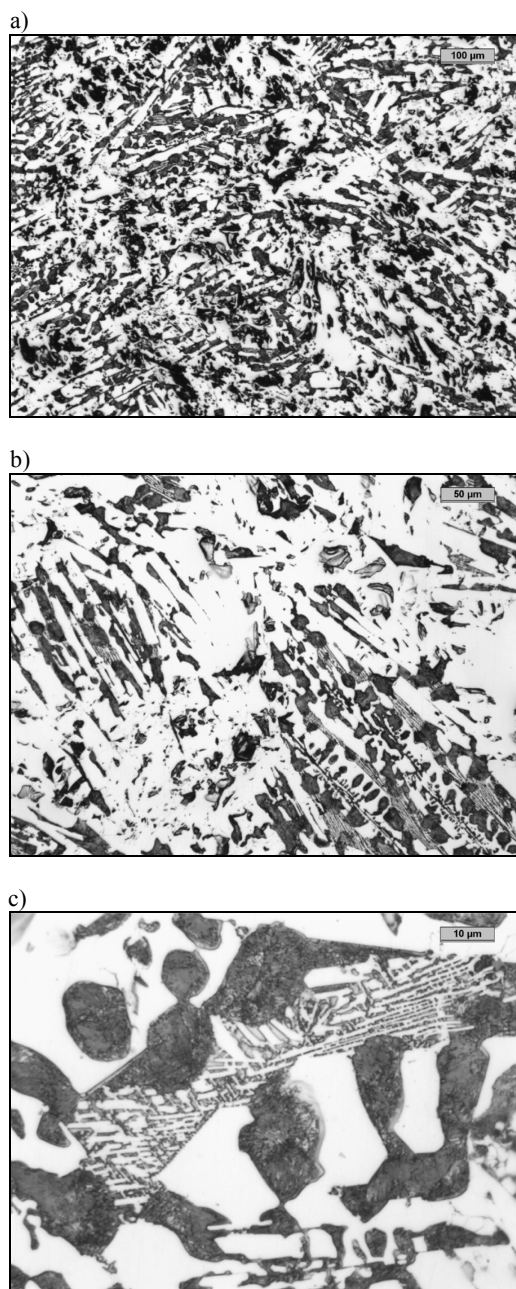


Fig. 2. Microstructure of casting made from chromium iron obtained in melt no. 1; different magnifications - (a, b, c)

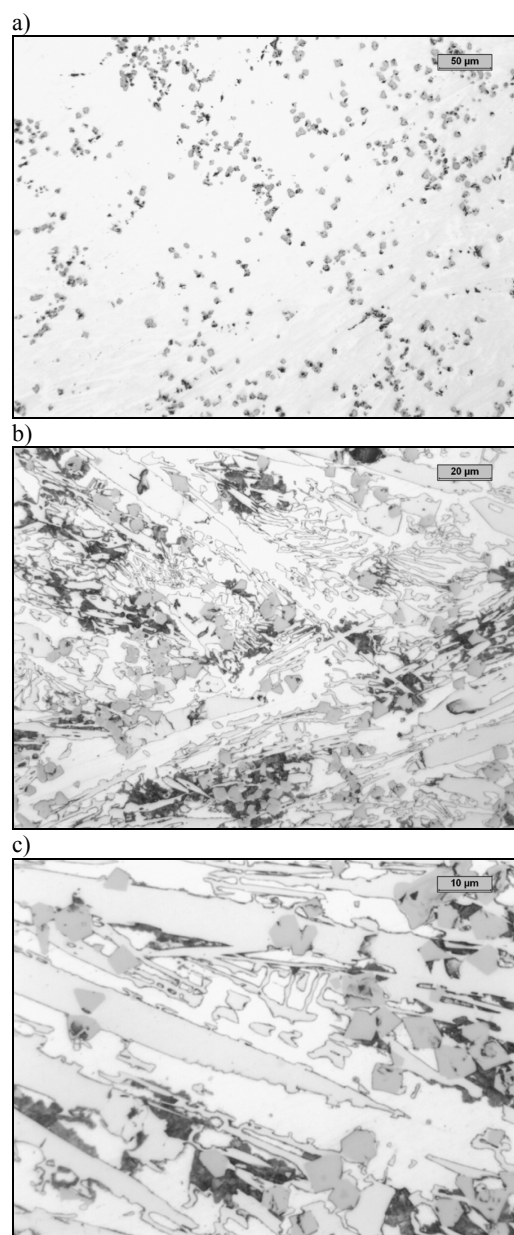


Fig. 3. Microstructure of casting made from chromium iron obtained in melt no. 2; different magnifications - (a, b, c)

During cooling, the crystallisation of cast iron deviates from the equilibrium state. This means that the austenite gets supersaturated with carbon and chromium, which greatly reduces the temperature of its transformation. Under these conditions, it is possible to obtain at room temperature the matrix of austenitic or austenitic-pearlitic character, as shown by respective microstructures. Total content of the carbide phase can be determined from F. Maratray's [2] formula, namely:

$$W = 12,33C + 0,55Cr - 15,2$$

From this equation it follows that total content of the carbide phase depends primarily on the carbon content in cast iron, as confirmed by the present studies. Chromium, titanium and tungsten have only an indirect effect, influencing at a specific carbon content the type of the crystallising carbides. In this case, the proposed heat treatment is air-hardening from the temperature of 950°C and tempering.

4. Measurement of abrasion wear resistance

Studies were conducted using a T-01M Tester with a ball-on-disc system, designed to evaluate the tribological properties of materials used for parts of machinery and equipment constituting the friction pairs. With this device it is possible to determine the wear resistance and friction coefficient of the material in sliding pairs, depending on the sliding velocity, surface pressure, presence and type of lubricant, contamination and other factors. The study was conducted in accordance with the methods set out in the ASTM G99 and DIN 50324 standards.

In studies of the abrasion resistance, chromium cast iron from melt no. 1 was used. The sample in this study was a 6 mm diameter cylinder. It was abraded by an SiO₂ ball pressing it with a preset force. In this case, it was the force of 27N. The duration of one test was 2000 min.

Figure 4 shows in the form of plotted graphs the abrasive wear behaviour of chromium cast iron and of a reference material, which in this case was low-alloyed ductile iron of the following chemical composition - 3.68% C, 2.41% Si, 0.32% Mn, 0.01% P, 0, 01% S, 1.00% Cu, 0.02% Cr.

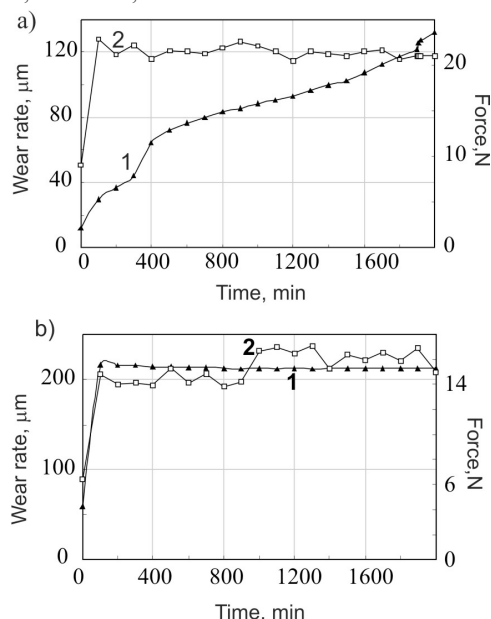


Fig. 4. Linear wear in dry friction: (1) wear rate, (2) force; ductile iron - (a) and the tested chromium cast iron - (b)

Studies showed that in the ductile iron, the abrasive wear rate was proportional to the value of force. With time lapse, the force

of pressure was increasing, causing further abrasion of the material. On the other hand, in the case of high-chromium cast iron, a sudden shift occurred, followed by stabilisation of the abrasive process. At a given load, no further wear of the material was possible.

5. Conclusions

Studies have proved that structure of the chromium cast iron greatly depends on the additionally introduced elements such as titanium and tungsten. Titanium is a carbide-forming element, but in contrast to other elements of this type it does not form complex carbides in the chromium cast iron, but only a TiC carbide, which is formed at high temperature in the liquid metal. Tungsten is also a carbide-forming (and pearlite-forming) element but, like titanium, is rarely used in the manufacture of chromium cast iron. High melting points of tungsten and titanium may cause difficulties in the metallurgical process of chromium cast iron manufacture. Tungsten effect on the mechanical properties is similar to that of molybdenum, although it is weaker. Tungsten increases the hardenability of cast iron. Currently, the use of tungsten can be justified because of its price slightly lower than that of molybdenum.

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