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Investigation on Phase Composition and Microstructure of High Chromium White Cast Irons Alloyed with Boron

Julieta Kaleicheva
Institute of Metal Science, Equipment and Technologies with the Center for Hydro- and Aerodynamics "Acad. A. Balevski"
Bulgarian Academy of Sciences
Sofia, Bulgaria
jujakaleich@gmail.com

Rumyana Lazarova
Institute of Metal Science, Equipment and Technologies with the Center for Hydro- and Aerodynamics "Acad. A. Balevski"
Bulgarian Academy of Sciences
Sofia, Bulgaria
r.lazarova@ims.bas.bg

Georgi Avdeev
Institute of Physical Chemistry
Bulgarian Academy of Sciences
Sofia, Bulgaria
g_avdeev@ipc.bas.bg

Valentin Mishev
Faculty of Industrial Technology
Technical University of Sofia
Sofia, Bulgaria
v_mishev@ tu-sofia.bg

Zdravka Karaguiozova
Space Research and Technology Institute
Bulgarian Academy of Sciences
Sofia, Bulgaria
karazuzi@yahoo.com

Krassimir Kirov
College Sliven
Technical University of Sofia
Sliven, Bulgaria
kirov_krasimir_1966@abv.bg

Abstract. **The microstructure and phase composition of high chromium white cast iron with composition: 2.6÷3.1%C; 0.88÷1.12%Si; 0.74÷0.98% Mn; 0.85÷1.16% Mo; 11.11÷14.11% Cr, additionally doped with boron in an amount 0.002%, 0.92% and 1.34% is investigated. The microstructure of the white cast irons was studied by optical metallographic analysis, and the phase composition – by qualitative XRD analysis. An impact toughness test was conducted. The hardness HRC was tested by the Rockwell method. The microhardness $HV_{0.1}$ of the metal matrix and of the carbide phase was determined. It was found that in samples containing boron, the amount of the carbide phase increases and the chromium boride phase Cr_3B_4 appears in them. This results in a decrease in impact toughness from 1.88 J/cm^2 for the sample with 0.002% boron to 0.98 J/cm^2 with 0.92% boron and 0.68 J/cm^2 with 1.34% boron. The samples containing 0.92% and 1.34% boron have a higher microhardness of the metal base (824 and 766 $HV_{0.1}$) compared to those with 0.002% boron (672 $HV_{0.1}$).**

Keywords: high chromium white cast iron, boron, hardness, impact toughness, X-Ray Diffraction (XRD)

I. INTRODUCTION

High chromium white cast irons are materials, used in different industrial applications that require string wear resistance. They contain large amounts Chromium carbides with high hardness to which the exceptional characteristics of these alloys are due. The wear resistance and strength of cast iron depend on the type, size and morphology of these carbides. By changing their chemical composition, by controlling the cooling rate during casting or by additional specific heat treatment, the microstructural characteristics of these alloys, and therefore their properties, can be significantly changed. White cast irons with a high chromium content are iron alloys containing 10÷30% Cr and 1.8÷3.6% C. The exceptional resistance to abrasive and erosive wear is mainly due to the presence of a large amount of chromium carbides with high hardness. The carbides represented in the alloys of the Fe–Cr–C system is M_3C, M_7C_3 and $M_{23}C_6$. The type and shape of the eutectic carbides changes from M_3C to M_7C_3 with increasing chromium content. At Cr contents above 10%, eutectic carbides of the M_7C_3 type are formed, not of the M_3C type. M_7C_3 carbides are interrupted and surrounded by an austenite matrix or by austenite transformation products – pearlite, martensite, bainite [1]-[10].

The metal matrix supporting the carbide phase in these alloys can be adjusted by introducing additional alloying elements and by conducting heat treatment. Thus, a balance is achieved between abrasive wear resistance and the required strength of high chrome white cast irons [2],[4],[5].

Heat treatments of high-Cr white cast irons are essential to change their microstructure and properties in order to meet the requirements of an individual

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application. The commonly applied heat treatment consists of heating the alloys at temperatures of 800÷1100°C, holding at these temperatures, followed by air cooling at room temperature. During holding at high temperatures, carbon and chromium from the matrix form small carbide particles. The new austenitic matrix, depleted of chromium and carbon, readily transforms into martensite during subsequent cooling. Therefore, the final structure after heat treatment consists of M_7C_3 eutectic carbides, a martensitic matrix with secondary carbides distributed in it, and residual austenite [2],[5]

High chromium white cast irons can be additionally alloyed with elements such as molybdenum, manganese, copper, nickel, titanium, vanadium, boron, etc. Carbide-forming elements form new carbide phases that increase the hardness and wear resistance of alloys. Literature data on boron alloying indicate that borides and carboboride phases are formed in these cast irons, which have a higher hardness than carbides [4]-[10].

The purpose of the conducted research is to study the microstructure, phase composition and mechanical properties of high chromium white cast irons additionally alloyed with 0.002%, 0.92% and 1.34% boron.

II. MATERIALS AND METHODS

The chemical composition of the investigated samples of high-chromium white cast iron in the as cast condition is presented in Table 1. These cast irons contain more than 10% chromium, about 1% molybdenum and are additionally alloyed with 0.002%, 0.92% and 1.34% boron.

The microstructural analysis was carried out using an optical metallographic microscope MIT 500 of the Cnoptec company. The microstructure was revealed in a reagent with the following composition: 4% HNO_3 in ethyl alcohol.

The hardness HRC for the studied samples was determined by the Rockwell method. A test was conducted to determine the microhardness $HV_{0.1}$ of the metal matrix and the carbide phase in the cast iron structure with a load of 100 g.

The impact toughness testing was conducted with a Sharpie hammer. For this purpose, samples with dimensions of 10x10x55 mm without a notch were used. The results from the experiments conducted are presented in Table 2.

TABLE 1 CHEMICAL COMPOSITION

Sample	**Chemical composition (wt %)**							
	C	***Mn***	***Si***	***P***	***S***	***Cr***	***Mo***	***B***
1	3.105	0.985	0.885	0.058	0.029	14.108	1.16	0.002
2	2.899	0.758	1.029	0.057	0.021	12.564	0.936	0.923
3	2.622	0.745	1.128	0.053	0.02	11.112	0.846	1.342

TABLE 2 MECHANICAL PROPERTIES

Sample	**Mechanical properties**			
	HRC	***KC (J/cm²)***	***$HV_{0.1}$***	
			metal matrix	***carbide phase***
1	53.5	1.88	672	1415
2	57	0.98	824	1749
3	57.5	0.68	766	1783

The high-chromium white cast iron samples are tested by X-Ray diffraction analysis. For a phase identification X-ray diffraction powder patterns are recorded in the angle interval 20÷90°(2θ), on a Philips PW 1050 diffractometer, equipped with Cu Kα tube and scintillation detector. The data for cell refinements is collected in θ÷2θ, step-scan mode in the angle interval from 20 to 90° (2θ), at steps of 0.03° (2θ) and counting time of 3 s/step.

III. RESULTS AND DISCUSSION

The microstructure of the investigated cast irons with 0.002%, 0.92% and 1.34% boron are presented in Fig. 1, Fig. 2 and Fig. 3. The metal matrix of cast high-chromium white cast irons, in addition to pearlite transformation products (Fig. 1, 2, 3), also contains structures such as martensite and bainite (Fig. 2 b). Boron increases the resistance of supercooled austenite to decomposition, and upon cooling to room temperature, the formation of structures such as martensite and bainite becomes possible.

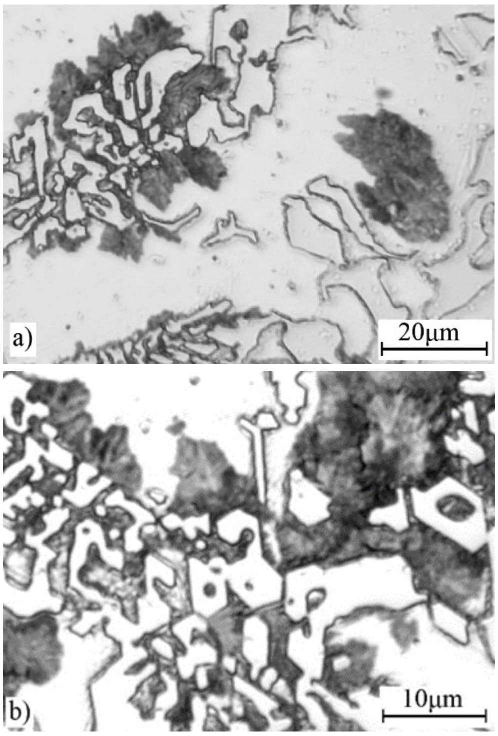

Fig. 1. Microstructure of high chromium white cast iron alloyed with 0.002% boron in as-cast conditions, a) x500 and b) x1000.

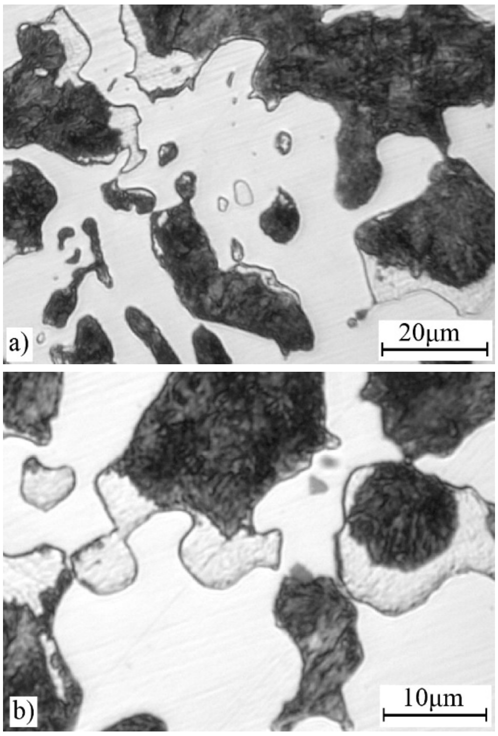

Fig. 2. Microstructure of cast high chrome white cast iron alloyed with 0.92% boron in as-cast conditions, a) x500 and b) x1000.

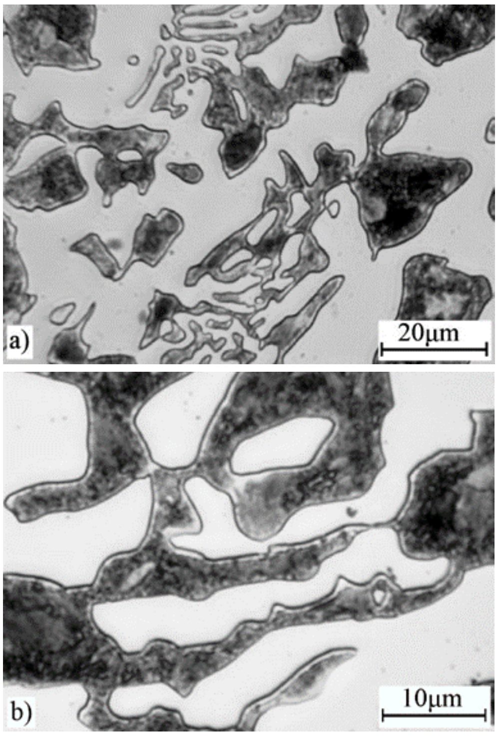

Fig. 3. Microstructure of cast high chrome white cast iron alloyed with 1.36% boron in as-cast conditions, a) x500 and b) x1000.

It is known that in high chromium white cast irons, which contain more than 10% Cr, the eutectic carbides are of the Cr_7C_3 type [1]. The results of the X-ray structural analysis showed that in the investigated white cast irons, which contain 11.11÷14.10% Cr, carbides of the type Cr_7C_3 and Fe_3C are present (Fig. 4). In the structure of cast irons with 0.92% and 1.34% boron, the phase chromium boride Cr_3B_4 is also formed (fig. 4).

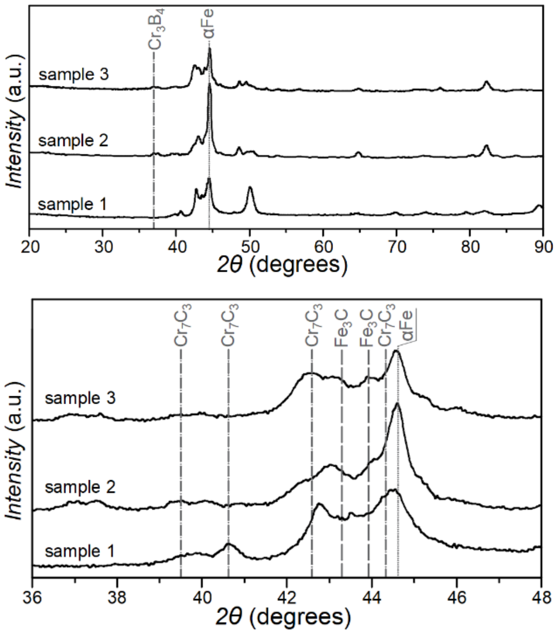

Fig. 4. Diffractometric curves of high chromium white cast irons alloyed with boron (1 – 0.002% B; 2 – 0.92% B; 3 – 1.34% B) in as-cast conditions.

In the table 2 and in Fig. 5 and Fig. 6 presents the results of the studied mechanical characteristics: microhardness HV0.1 of the metal matrix and the carbide phase (Fig. 5), hardness HRC (Fig. 6 a) and impact toughness KC (Fig. 6 b).

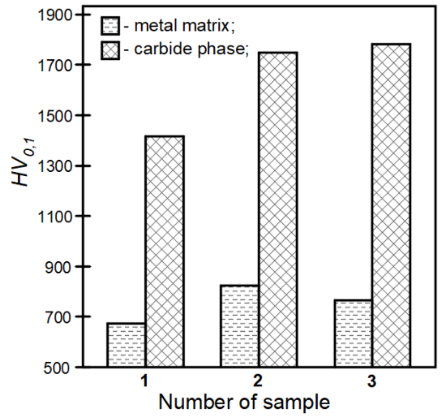

Fig. 5. Microhardness $HV_{0.1}$ of the metal matrix and the carbide phase of high chromium white iron alloyed with 0.002% B (sample 1), with 0.92% B (sample 2) or with 1.34% B (sample 3)

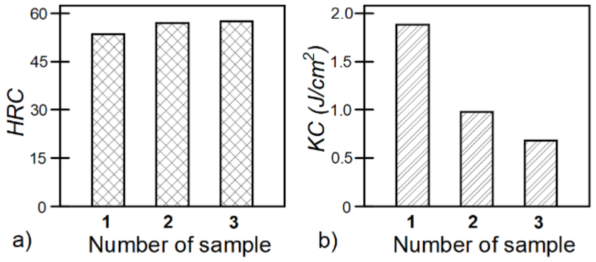

Fig.6. Hardness HRC (a) and impact toughness KC (b) of high chromium white cast iron specimens alloyed with 0.002% B (sample 1), 0.92% B (sample 2) or 1.34% B (sample 3)

The microhardness of the carbide phase increases with increasing boron content from 1415 $HV_{0.1}$ at 0.002% B to 1749 $HV_{0.1}$ at 0.92% B and 1783 $HV_{0.1}$ at 1.34%B (Table 2, Fig. 5). This is explained by the formation of carboborides $M_3(C,B)$ and $M_7(C,B)_3$ in the structure of boron-alloyed high-chromium white cast irons, which have a higher hardness than that of carbides M_3C and M_7C_3 [7].

The microhardness of the metal matrix also increased with increasing boron content from 672 $HV_{0.1}$ at 0.002% B to 824 $HV_{0.1}$ at 0.92% B and 766 $HV_{0.1}$ at 1.34%B (Table 2, Fig. 5). Boron increases the resistance of undercooled austenite to decay and ensures the transformation of austenite into martensite (bainite) during cooling of castings. The presence in the metal matrix of non-equilibrium structures such as martensite and bainite, which have higher hardness than pearlite, increase its microhardness.

The increase in the hardness of the metal matrix and the carbide phase with an increase in the amount of the boron alloying element leads to an increase in the HRC hardness of the investigated cast irons from 53.5 HRC at 0.002% B to 57.0 HRC at 0.92% B and 57.5 HRC at 1.34 % B (Table 2, Fig. 6 a).

The increase in the hardness of the investigated high chromium white irons with increasing boron content in them decreases the impact toughness of the alloys from 1.88 J/cm^2 (0.002%B) to 0.98 J/cm^2 (0.92%B) and 0.68 J/cm^2 (1.34% B) (Table 2, Fig. 6 b). In the structure of the alloys with 0.92% and 1.34% boron, the chromium boride phase Cr_3B_4 is formed, which has high hardness and can also affect KC in the direction of its decrease.

IV. Conclusions

1. Through qualitative X-ray structural analysis, it was established that the alloying of the studied high-chromium white cast irons with 0.92% and 1.34% boron leads to the formation of the chromium boride Cr_3B_4 phase in their structure.

2. The alloying of the investigated high-chromium white cast irons with 0.002%, 0.92% and 1.34% boron changes the microhardness of the carbide phase as follows: 1415 $HV_{0.1}$ (0.002%B); 1749 $HV_{0.1}$ (0.92%B) and 1783 $HV_{0.1}$ (1.34%B). The carbide phases of the type M_3C and M_7C_3 registered by X-ray structural analysis represent carboborides $M_3(C,B)$ and $M_7(C,B)_3$. They have a higher hardness than that of the carbide phases and this explains the measured higher microhardness in the 0.92% and 1.34% boron alloys compared to the microhardness in the 0.002% boron alloys.

3. The formation in the structure of the studied high-chromium white cast irons of phases with high hardness such as chromium boride Cr_3B_4 and carboboride phases of the type $M_3(C,B)$ and $M_7(C,B)_3$, lead to a decrease in the impact toughness of the alloys as follows: 1.88 J/cm^2 (0.002%B); 0.98 J/cm^2 (0.92%B) and 0.68 J/cm^2 (1.34%B). Impact toughness is also influenced by the structure of the metal matrix, which with increasing boron content has a higher microhardness as a result of the formation of larger amounts of non-equilibrium phases (martensite, bainite) from austenite upon cooling.

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