**A. A. AKBERDIN, A. Z. ISSAGULOV, S. S. KVON, YE. P. CHSHERBAKOVA,
D. R. AUBAKIROV, G. H. ADAMOVA**

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MODIFIER EFFECT ON MECHANICAL PROPERTIES OF LOW-CHROMIUM CAST IRON

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The results of studying the properties of prototypes obtained at the production site of the QazCarbon LLP (Karaganda, Republic of Kazakhstan) are presented. Grinding balls were smelted of low-chromium cast iron treated with modifiers of various nature. Boron-barium-containing materials were used as modifiers. It was found that the use of boron-barium-containing additives as modifiers qualitatively and quantitatively changes the structure of the alloy under study. After modification, the structure becomes more dispersed, the quantitative ratio between the main structural components:ledeburite, pearlite and carbide phase, changes. Such changing the structure has a positive effect on the impact resistance of the samples.

Keywords: chromium cast iron, boron-barium-containing additives, modification, wear resistance, structure.

INTRODUCTION

The issue of improving wear-resistant characteristics of grinding bodies used for crushing and grinding ore, coal, etc. without significantly increasing their cost is one of the most important for the developing and functioning of the mining and metallurgical industry [1]. A number of specific requirements are imposed on grinding bodies depending on the working conditions, but the general requirementsinclude high wear resistance, hardness, strength and impact resistance [2].

One of the most common grinding ball materials is chromium white cast irons. For example, the Belgian company Magotteaux [3] produces grinding bodies made of high-chromium cast iron grades MAXICROM®, HARDALLOY®, DUOMAX®, DUROMAX®, etc. In France, Canada and the USA, nickel-containing low-chromium (0,5% Cr) martensitic cast iron of the Nihard type is widely used for the production of grinding balls [4].

In the Republic of Kazakhstan, chromium cast irons are used less frequently for the producingof grinding media, because the products obtained, with high hardness and wear resistance, have rather low impact resistance. Increasing their impact resistance while maintaining hardness and wear resistance is a promising trend in improving the quality of grinding bodies.

At present, there is a fairly large number of studies [5-6], which show the positive effect of various modifiers on the properties and changes in the structure of chromium cast irons, however, studies that are dealing with the effect of modification with boron-barium-containing additives often contain conflicting results [7-9].

For example, it is known that boron has a strong effect on crystallization of cast iron as a surface active element, improves the state of grain boundaries, refines them and additionally deoxidizes the metal, which has a positive effect on the alloy properties. Boron also reduces the size of eutectic colonies and transcrystallization in white cast irons. Treating cast iron with boron strengthens the alloy by increasing itsmicrohardness, uniform distribution, grinding of the carbide phase and transition of carbides from the lamellar to the hexagonal shape. However, there is different data of the amount of boron-containing modifier introduced, as well as the way of its introducing.

Barium in the composition of modifiers enhances formation of graphitization centers and increases the modifier duration. Modification with silicobarium makes it possible to improve strength of cast iron by 10-15 %, which is explained by formation of a finer-grained and dense structure of the metal in the casting and increasing the purity of the metal due to the producing of highly dispersed non-metallic inclusions [10]. However, modification with barium in the silicobarium composition increases the silicon content in the alloy, which contributes to the graphitization phenomenon, which is undesirable in white cast irons.

The purpose of this work is to study the properties and structure of chromium cast iron used for the producing of grinding bodies, after modification with boron-barium-containing additives to improve the operational characteristics of the alloy.

EXPERIMENTAL STUDIES

Low-alloy chromium cast iron, which is currently used for the producing of grinding balls at the QazCarbon LLP (Kazakhstan), was used as an object of research. The composition of cast iron is shown in Table 1.

A. A. Akberdin, Chemical-Metallurgical Institute, A. Z. Issagulov, S. S. Kvon, Ye. P. Chsherbakova, D. R. Aubakirov, G. H. Adamova, Karaganda Technical University, Karaganda, Kazakhstan, e-mail: dastan_kstu@mail.ru

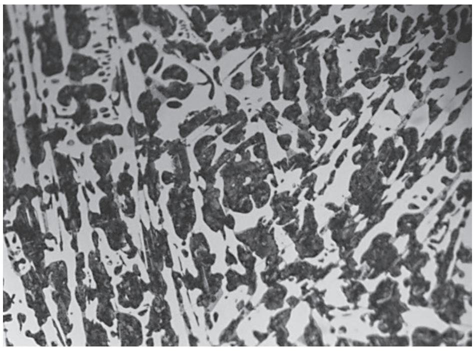


Figure 1 Microstructure of the basic (unmodified) cast iron, ×400

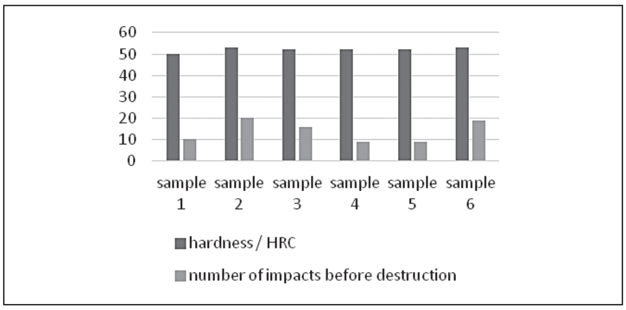


Figure 2 Diagram of the cast iron properties after modification

Pilot melts of cast iron for casting grinding balls were carried out at the production site of the QazCarbon LLP, according to the current technological process of the enterprise, in an induction furnace with the crucible capacity of 5,0 tons.

The microstructure of unmodified low-chromium cast iron is shown in Figure 1.

It is seen in the Figurethat the metal base of low-chromium unmodified cast iron is pearlite + ledeburite + cementite. The area occupied by pearlite is about 75 %, ledeburite 5 %, cementite about 20 %.

Hardness of cast iron is achieved due to the presence of Fe_3C, Cr_3C and Mn_7C_3 carbides in the structure; however, at the same time, cast iron has low impact resistance, which is due to the coarse structure of pearlite and the uneven distribution of carbides of the Me_3C type over the volume. Despite rather high hardness, this cast iron has rather low wear resistance during operation due to uneven hardness over the section: a relatively hard but brittle surface layer and a softer loose core.

In order to eliminate these shortcomings, cast iron was modified with the following materials:

- ferrosilicobarium grade FSi60Ba20 produced by the Aksu Ferroalloy Plant;
- ferroboron of the pilot batch obtained by the carbothermal method in the BOR laboratory of the Zh. Abishev ChMI;
- borbarium modifier (BaB_6) of the experimental batch [11] melted also by scientists of the BOR laboratory of the Zh. Abishev ChMI;

The composition of the modifiers is shown in Table 2.

The modifiers were introduced into different melts separately, the temperature of molten iron in the furnace before tapping was ~ 1 480-1 510 °C and was controlled by Positherm thermocouples.

Table 1 **Chemical composition and properties of cast iron**

Composition / %							Properties	
C	Si	Mn	Cr	S	P	Fe	HRC	Impact resistance
3,3	0,5	0,7	0,7	0,04	0,4	rem.	49,5	Not more than 10 impacts

Table 2 **The composition of modifiers used**

Modifier	Element content / %								
	C	Si	Al	Ba	S	P	B	Ca	Fe
FSi60Ba20	-	56,24	2,51	20,52	0,014	0,024	-	-	rem
Carbothermal ferroboron	0,78	4,05	0,40		0,011	0,030	14,63	-	rem
BaB_6	0,31	19,56	-	3,92	-	-	8,88	1,87	rem

Table 3 **Mechanical characteristics of experimental samples of modified cast iron**

Parameters	Sample					
	1	2	3	4	5	6
	Modifier					
	unmodified	FeB, B ≈ 0,006 %*	FeB, B ≈ 0,02 %	FeSiBa, Ba ≈ 0,005 %	FeSiBa, Ba ≈ 0,01 %	BaB6, B ≈ 0,006 %, Ba ≈ 0,002 %
Average hardness on the sur-face of the ball, HRC unit	49	53	52	52	52	53
The number of impacts before destruction	to 10	20	16	9	9	19

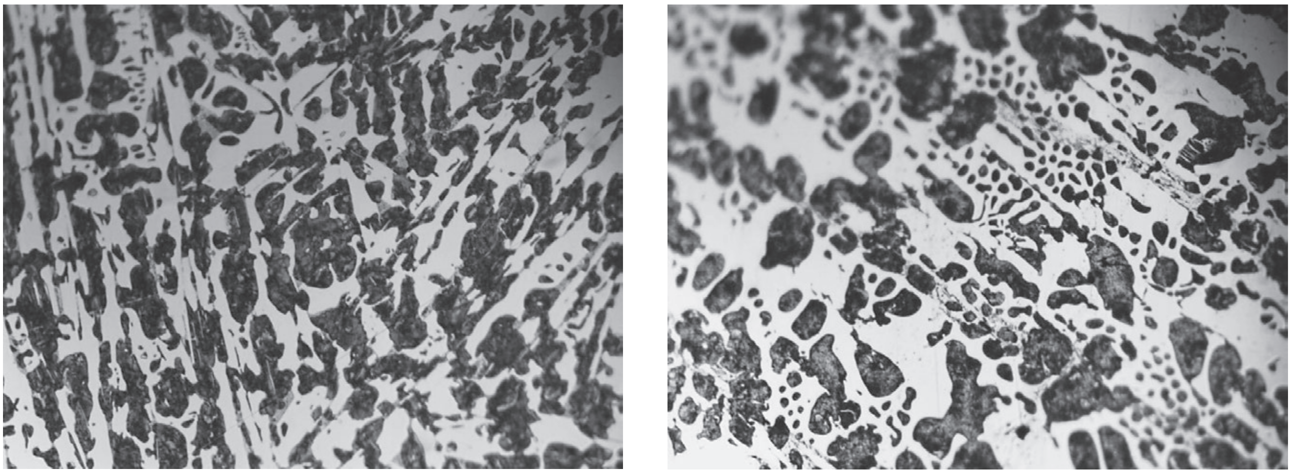
* in brackets there is indicated the element content % in cast iron after modification

Portions of modifiers were calculated taking into account the assimilation of active elements (boron and barium) of about 50 % and the residual content in cast iron B ≈ 0,006 and 0,02 %, Ba ≈ 0,005 and 0,01 %. The fraction of modifiers was as follows: FeB ~ 1,0 ÷ 3,0 mm, FeSiBa and $BaB_6 \leq 1$ mm. The indicated dosages of modifiers were previously tested in the laboratory conditions [12].

The calculated portions of the modifiers were fed into the metal stream in the overflow chute of the distributing ladle at the cast iron temperature of ~ 1 380 – 1 420 °C (portable optical pyrometer “Luch”).

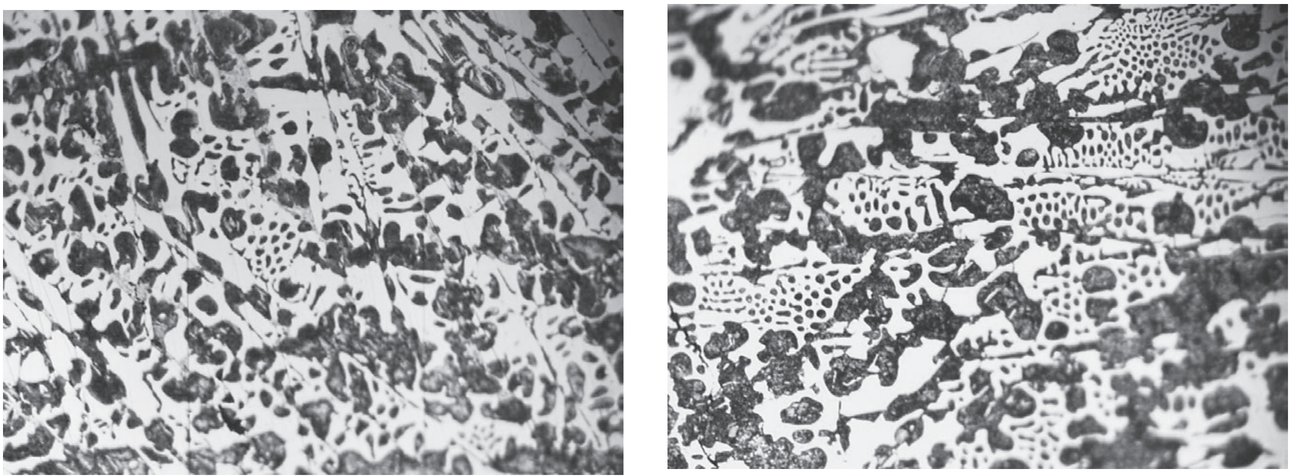
Of the cast irons obtained after modification, grinding balls ø40 mm were cast; after complete cooling, samples were prepared of them for testing for hardness and impact resistance, as well as for carrying out metallographic studies. Impact tests were carried out on an eccentric hammer with the striker weight of 30 kg, hardness tests were cattied out on a Wilson VH 1150 hardness tester. The test results obtained are shown in Table 3 and Figure 2.

The data in Table 3 and Figure 2 show that modification, as well as the natureof the modifier, does not practically affect hardness. Both before and after modification, the surface hardness of the samples is about 50-52 HRC. However, the effect of modification on impact resistance is very strong. After modification



Sample No.1 (without modification)

Sample No. 4 (modified with ferrosilicobarium)



Sample No. 2 (modified with ferroboron)

Sample No. 6 (modified with BaB_6)

Figure 3 Microstructure of cast iron before and after modification, ×400

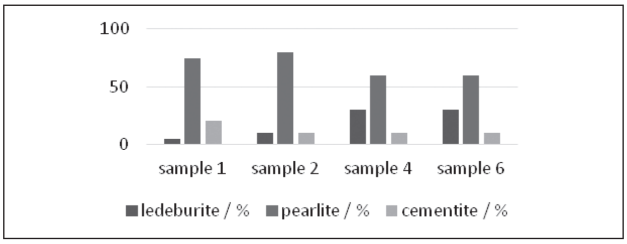


Figure 4 Ratio of the structural components in cast iron after modification

with ferroboron and borbarium, this indicator almost doubled. The reason for this change in impact resistance can be explained by changing the structure of cast iron after modification. Figures 3 and 4 show the alloy microstructures after modification and the quantitative ratio of the structural components. The quantitative analysis was performed using the Thixomet Pro software, the structure was studied using an Altami MET 5D microscope.

Figures 3 and 4 show that depending on the nature of the modifier, both the ratio of the structural components and the nature of the structure change. After modification, the proportion of cementite in all the samples decreased, which, in all likelihood, explains increasing impact resistance of the modified samples.

The ratio of the structural components in samples No. 4 and No. 6 is practically the same, but the morphology of the structure is different. In sample No. 6, the structure is more dispersed, cementite lamellae are thin, pearlite zones are more spheroidal and have a smaller size. These differences in the structure of samples No. 4 and No. 6 can explain increasing impact resistance of sample No. 6 by more than 2 times in comparison with sample No. 4.

CONCLUSION

The results obtained make it possible to assert that modification with the ferroboron or borbarium modifier significantly improves such an important characteristic of grinding balls as impact resistance. After modification with these materials, impact resistance increased by more than 2 times in comparison with unmodified cast iron or cast iron modified with ferrosilicobarium.

A noticeable improvement in the mechanical properties of cast iron after modification is associated with changing the ratio of structural components (decreasing the proportion of cementite), the nature of distribution and refinement of structural components, and presumably, due to changing the formed carbides shape.

The optimal amount of the supplied borbarium modifier is determined by the limits of the specified boron content in cast iron = 0,006 %, barium ≈ 0,002 %, which was determined in the course of the experimental heats.

The low mechanical properties of cast iron modified with ferrosilicobarium can be explained by graphitization of cast iron due to a high silicon content in the additive.

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