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CHROMIUM-NICKEL CAST IRON COMPOSITION EFFECT ON PROPERTIES AND GRAPHITIZATION PROCESS

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The paper considers the cast iron based on nihard-2 composition effect on the properties and process of graphitization. It is shown that changing the Cr:Si ratio equal to 2:1 leads to the development of the graphitization process, as a result of which lamellar graphite appears in the structure. Subsequent modification leads to changing the shape of the graphite into the nodular one, which leads to some decrease in hardness but increases resistance to abrasive wear by about 20-25 %.

Keywords: cast iron Cr-Ni, hardness, wear resistance, structure, graphit

INTRODUCTION

Chromium-nickel-based cast irons are widely used as wear-resistant materials used for manufacturing parts and equipment for the mining-and-smelting complex; cast iron of the Nihard class is used particularly often for manufacturing cyclones, mill linings, rolls, etc. The term “Nihard” is understood as white cast irons on the chromium-nickel base, which have high hardness and wear resistance. The chromium content usually does not exceed 9 %, and the ratio between silicon and chromium must be strictly maintained in the range of Cr:Si = 2,5:1 in order to avoid the graphitization process. Table 1 shows the compositions of “classic Nihard”.

However, today the possibilities of improving the composition of Ni-hards by simple alloying are practically exhausted.

At the same time, new ideas of wear mechanisms expand the understanding of the properties that are applied to wear-resistant materials.

The global trend in the improvement of wear-resistant materials is the development of a structure consisting of both a hard matrix and a relatively soft second phase. The presence of such a structure provides increasing the slip coefficient between surfaces and therefore, reduces the level of wear. For white cast irons, graphite can be such a relatively soft phase. In this case, the partial development of the graphitization process is a necessary condition, which can be regulated by the composition of cast iron.

It is known that the silicon content must be balanced by a certain chromium content, because otherwise, the process of free carbon deposition begins. The optimal ratio is the ratio Cr:Si = 2,5:1, and the silicon content below 0,5 % is undesirable, because it reduces fluidity of cast iron and increases the risk of casting defects [1]. In work [2] it was shown that when the ratio Cr:Si = 1,4:1, graphite inclusions appear in Nihard cast iron, and the volume, shape and length of the lamellas largely depend on the Cr:Si ratio. As an indicator of quality, the matrix viscosity was assessed while maintaining certain hardness, the best indicators corresponded to the ratio Cr:Si = 1,5:1. However, in this study, Nihard cast iron was intended for manufacturing rolls of hot rolling mills, where toughness, alongside with hardness and wear resistance, is the most important property. For other Nihard applications (mill linings, cyclones) the viscosity indicator can be reduced.

Table 1 **The composition of Nihard cast irons**

Element / %	Nihard 1	Nihard 2	Nihard 3
C	3-3,6	≤2,9	2,6-3,2
Si	0,3-0,5	0,3-0,5	1,8-2,0
Mn	0,3-0,7	0,3-0,7	0,4-0,6
Ni	3,3-3,8	3,3-5,0	4,5-6,5
Cr	1,5-2,6	1,4-2,4	8,0-9,0
S	≤0,15	≤0,15	≤0,15
P	≤0,3	≤0,3	≤0,3
Mo	0-0,4	0-0,4	0-0,4

Thus, by reducing the ratio between silicon and chromium, it is possible to obtain some content of free graphite in the Nihard structure.

Titanium carbide has a great effect on the properties of cast iron. One of the trends in improving the properties of Nihard is the production of metal matrix composite (MMC) alloys, the so-called metal matrix composites, which are known as Tinox alloys [1]. Titanium is not present in the composition of classical Nihard, but a number of studies [3, 4] consider the effect of titanium introduction on the properties of Nihard. Titanium forms titanium carbides in Nihard, the presence of

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which increases its hardness and wear resistance. In this work, it is proposed to introduce titanium carbide rather than titanium as the master alloy. Titanium carbides have a high melting point (3 140 °C) and do not melt, retaining their phase identity. Due to their low density, titanium carbides float up during the casting process and are evenly distributed over the casting section. The introduction of titanium carbide into cast iron compensates for the decreasing of hardness that occurs as a result of the free graphite precipitation and decreasing the volume of chromium carbides.

EXPERIMENTAL STUDIES

Equipment and tools

To test these assumptions, the following experiments were performed. Experimental alloys were melted in a laboratory furnace of the UIP-25 type with an enhanced cooling system. Ferrosilicon and ferrochromium were introduced into the Nihard-2 cast iron composition to change the silicon and chromium content in the ratio Cr:Si = 1,5-2,5:1. The composition of the charge was calculated according to the generally accepted methodology and according to the accepted rate of the elements loss.

In the process of crystallization in Nihard with an increased silicon content, lamellar graphite of various morphology is formed. However, to increase the complex of wear-resistant properties in the structure, the presence of nodular graphite is necessary [5-7]. For this purpose, a modifier was introduced. Modification was carried out with mishmetal MC50Zh3 in the amount of 1 % by weight [8-11]. The melts were poured in the temperature range of 1 450-1 460 ^{0}C into crucibles having the shape of test specimens. Table 2 shows the compositions of the experimental alloys. The chemical composition was controlled using a spectrometer of the NITONXL2-100G and Argon-5SF type). The finished castings were subjected to the classic Nihard-2 treatment: tempering at 250 °C.

Table 2 **The experimental alloys composition / wt. %**

Element	Sample			
	1 (Nihard-2)	2	3	4
C	2,4	2,6	2,8	3,0
Cr	2,3	1,5	4,0	5,0
Mn	0,6	0,6	0,6	0,5
TiC	-	0,5	0,8	1,0
Ni	3,3	4,0	4,5	5,0
Si	0,4	1,5	2,0	2,5
Mo	0,3	0,5	0,5	0,5
Cu	0,1	0,2	0,2	0,2
Ce	-	0,1	0,1	0,1
Fe				
S	0,1	≤0,05	≤0,05	≤0,05
P	0,2	≤0,09	≤0,09	≤0,09

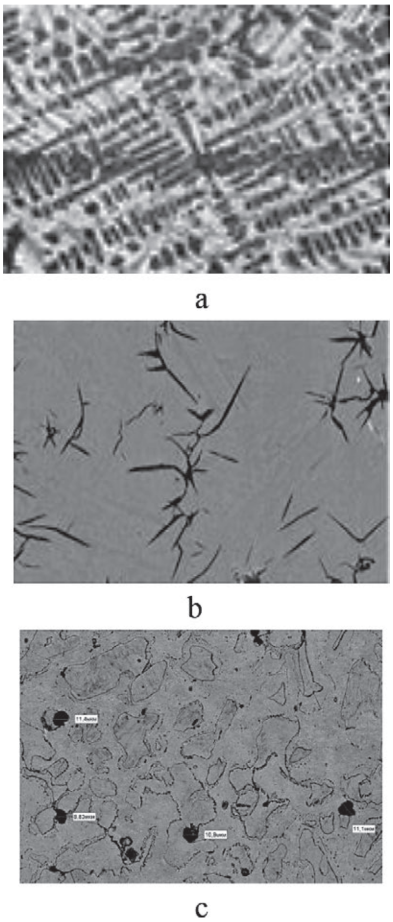


Figure 1 Macrostructure of alloys, x500:
a) Nihard-2; b) experimental alloy No. 3 after casting (non-etched); c) experimental alloy No. 3 after modification (non-etched)

Hardness and wear resistance were determined on the experimental alloys samples (Table 1). Wear tests were carried out on a TABER ABRASER 352G instrument. Tungsten carbide was used as an abrasive, the test period was 10,000 cycles. Wear resistance was determined by the relative changing of weight:

$$L = \frac{M_1}{M_2} * 100\%,$$

where M_1 is the weight after testing;

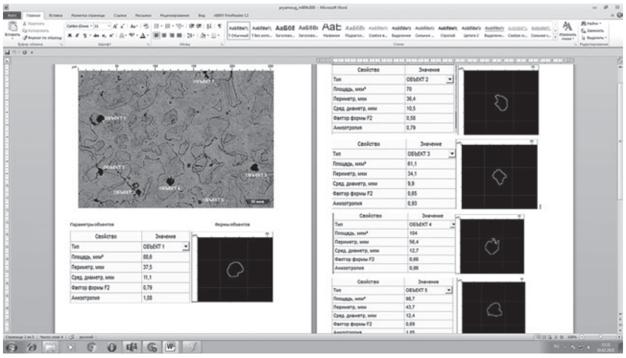
M_2 is the sample initial weight.

Hardness was determined on a Wilson VH1156 device; for convenience, the results are presented on the Brinell scale. Nihard-2 was used as the reference sample. Hardness was determined at least at 5 points, the average results are given in Table 3.

It is seen from the given data that as a result of the composition correction based on Nihard-2 cast iron, hardness decreases slightly but at the same time wear resistance increases by 20 %. Some drop in hardness of the experimental alloys (samples 2-4) in comparison with Nihard-2 is easily explained if we assume that the

Table 3 **Mechanical properties of experimental samples**

No.	Hardness / HB	Wear resistance / %
1 (Nihard- 2)	550	71,5
2	498	89,9
3	502	92,3
4	523	95,2



Параметры объектов

Свойство	Значение
Тип	ОБЪЕКТ 1
Площадь, мкм²	88,6
Периметр, мкм	37,5
Сред. диаметр, мкм	11,1
Фактор формы F2	0,79
Анизотропия	1,08

Свойство	Значение
Тип	ОБЪЕКТ 2
Площадь, мкм²	70
Периметр, мкм	36,4
Сред. диаметр, мкм	10,5
Фактор формы F2	0,58
Анизотропия	0,79

Свойство	Значение
Тип	ОБЪЕКТ 3
Площадь, мкм²	61,1
Периметр, мкм	34,1
Сред. диаметр, мкм	9,9
Фактор формы F2	0,65
Анизотропия	0,93

Свойство	Значение
Тип	ОБЪЕКТ 4
Площадь, мкм²	104
Периметр, мкм	56,4
Сред. диаметр, мкм	12,7
Фактор формы F2	0,66
Анизотропия	0,86

Свойство	Значение
Тип	ОБЪЕКТ 5
Площадь, мкм²	98,7
Периметр, мкм	43,7
Сред. диаметр, мкм	12,4
Фактор формы F2	0,69
Анизотропия	1,05

Figure 2 Example of using the Thixomet Pro software for the quantitative metallographic analysis (sample No. 3)

structure contains free graphite, which leads to decreasing the solid carbide phase.

The microstructure of the samples was studied using an Altami MET-5T microscope, magnification X500. Nital-3 was used as the a general etchant (Figure 1).

Figure 1b shows that in the structure of sample No. 3 (Cr:Si ratio = 2:1), there appears free lamellar graphite. After modification, graphite acquires the nodular shape (Figure 1c), the average size of the inclusions is on average 11 μm, the shape factor is about 0.7 (Figure 2).

For the quantitative metallographic analysis, the Thixomet Pro program was used, which automatically determines the area of graphite inclusions, their shape and size. Figure 2 shows an example of using Thixomet Pro software for the quantitative metallographic analysis.

CONCLUSIONS

Comparing the data in Table 3 and analyzing the microstructure allows establishing a clear relationship. Changing the ratio Cr:Si = 2:1 in Nihard-2 contributes to the graphitization process with formation of lamellar graphite. Further modification facilitates graphite transformation into the nodular shape. The presence of nodular graphite in the structure, despite slight hardness decreasing, has a positive effect on the alloy resistance to abrasive wear.

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Note: Responsible for the English language is Natalya Drak, Karaganda, Kazakhstan