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COMPARATIVE ANALYSIS OF GRAPHITE INCLUSIONS IN CHROME CAST IRON STRUCTURE

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The paper presents the results of a quantitative metallographic analysis of graphite inclusions in the structure of chrome cast irons including cast iron of the Nihard class, as well as after treatment with titanium carbide. The ThixometPro software was used for the analysis. The shape, size, perimeter, distribution density of graphite inclusions, as well as the area occupied by the structural components and their dispersion were evaluated. It is shown that the introduction of titanium carbide has a favorable effect on the pattern of graphite inclusions and some parameters of the structure in general.

Keywords: chrome cast irons, microstructure, graphite inclusions, size, distribution density

INTRODUCTION

To obtain parts with high wear-resistant properties, alloyed chrome cast irons are often used including cast irons of the Nihard class. The chemical composition of these grades and some mechanical properties are shown in Table 1.

It is seen from Table 1 that despite rather close elemental composition, the discrepancy in the properties of these alloys is quite significant: in ultimate strength it is about 30 %; in hardness almost 2 times.

Analyzing the difference in the chemical composition of these alloys, it is seen that they differ by almost 2 times in the content of nickel and silicon, and almost 4 times in chromium, the carbon content differs slightly. Nickel and silicon are not carbide-forming elements; they are present in the alloy as a solid solution. Dissolving in the α- or γ-solution, these elements change its properties. In particular, the increased nickel content increases the matrix toughness. This unique ability of nickel was used to develop wear-resistant white cast iron with increased toughness [1]. In addition, nickel somewhat increases strength of the alloyed matrix solution.

Silicon also contributes to increasing the matrix strength however, as shown in [2], increasing the structure strength due to dissolution of silicon in ferrite is insignificant and amounts to 1–2 %, especially since the silicon content in this alloy is rather low.

Thus, we can conclude that a significant difference in the properties of the studied alloys is associated only with the different content of chromium. Chromium is known, firstly, to be a fairly strong carbide-forming agent, and it forms carbides not only of the cementite type but also of the Me_7C_3 type. Secondly, it promotes whitening, i.e. transferring graphite to the bound state. It is logical to assume that it is the presence of Cr_3C and $Cr_7 C_3$ type carbides that will determine high hardness and wear resistance of the ChN_4H_2 alloy.

In works [3-5] it was shown that introducing refractory substances as a modifier significantly changes the structure of the alloy. It is obvious that introducing such a refractory substance as titanium carbide into the composition of cast iron can also change its structure and therefore, its properties.

In this study titanium carbide is introduced as a component that should ensure the presence of titanium carbides in the structure, as a hardening interstitial phase. In addition, since titanium carbide is a refractory compound, it is logical to assume that it also affects the primary crystallization process acting as additional centers of crystallization.

Table 1 **Chemical composition and properties of chrome cast irons**

Grade		ChN_2H	ChN_4H_2
Elements / %	C	3-3,6	2,8-3,6
	Ni	1,5-2	3,5-5
	Cr	0,4-0,6	0,8-2,5
	Si	1,5-2	0,1-1,0
	S	to 0,12	to 0,15
	P	to 0,25	to 0,3
Hardness / HB		215-280/230	400-650/420
Ultimate strength / MPa		290	200

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EXPERIMENTAL PART

To check this assumption, titanium carbide was introduced into the ChN_2H cast iron during casting. For this, carbide grade F 500 (TS 6-09-492-75) was used. In this case, titanium carbide was introduced with the fineness comparable to the size of graphite inclusions. The size of graphite inclusions in gray cast irons varies within a fairly wide range: from 15 (PGd15) to 1 000 microns (PGd1 000). The size of 500 µm was taken as the conditional value of the graphite inclusion. It should be noted that with increasing the size of graphite inclusions, cast iron hardness decreases; therefore, limiting the size of graphite to 500 µm is quite justified.

The amount of titanium carbide introduced was 1 %, so that the titanium carbide content corresponded to the possible amount of chromium carbides in the ChN_4H_2 alloy. It was assumed that the entire chromium is consumed for the formation of carbides; the proportion of the carbide component over the area is approximately 5 % [6]. If we assume that titanium carbide should replace chromium carbide in the alloy structure, then its amount should be approximately the same. However, it should be taken into account that chromium carbides are already present in the ChN_2H alloy according to the chemical composition. In addition, titanium carbides are a stronger hardening phase than chromium carbides due to the specific properties of TiC; therefore, one should expect an equivalent effect on the structure with a smaller amount of it. Based on these assumptions, it was proposed to introduce the amount of TiC within 1 %. After cooling the samples were subjected to normalization at 1 100 °C within 1 hour to homogenize the structure.

The purpose of this stage of the study was to study graphite inclusions in the structure, since they had a significant effect on properties. Quantitative metallographic analysis of the structure of the prototypes was carried out using the Thixomet Pro software. Three samples were presented for the analysis; No. 1: cast iron of the ChN_2H grade; No. 2: cast iron of the ChN_4H_2 grade; No. 3: cast iron of the ChN_2H grade treated with titanium carbide in the amount of 1 % with dispersion of 500 microns. Figure 1 shows the structures of the samples under study.

a)
b)
c)

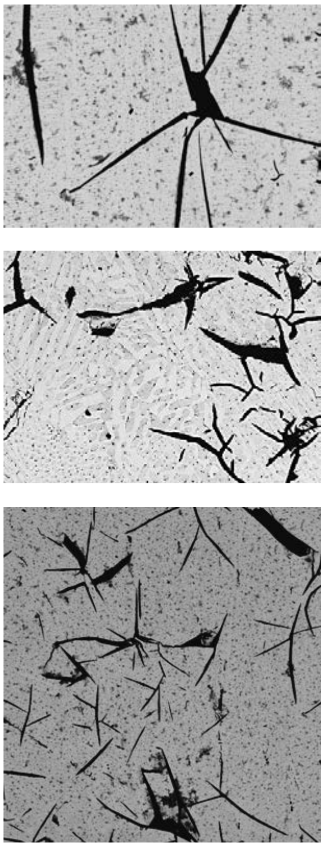

Figure 1 Microstructures of the samples under study:
a) – ChN_2H cast iron, sample No. 1;
b) – ChN_4H_2 cast iron, sample No.2;
c) – ChN_2H cast iron treated with TiC, sample No. 3.

DISCUSSION OF THE RESULTS

The basis of all samples is represented by a metal matrix, in which nickel, chromium and other alloying elements are dissolved according to the principle of substitution. A part of carbon is present in the form of free lamellar graphite.

Even in the visual analysis, differences in the structure of the studied samples are noticeable. In sample No. 1 graphite inclusions look rather large and have an irregular sinuous shape. In sample No. 2, approximately the same picture is observed, in sample No. 3 graphite inclusions look smaller and located relatively evenly over the area of the section.

When studying graphite inclusions, the following parameters were evaluated:

- the share of the area occupied by graphite / %;
- the average diameter of graphite inclusions / microns;
- the average perimeter of graphite inclusions / microns;
- the average area of graphite inclusions / μm^2;
- the shape factor and anisotropy of graphite inclusions; the physical sense of these parameters is discussed above;
- the distribution density of graphite inclusions / pcs/mm^2.

It should be noted that in the analysis of lamellar graphite such factors as the shape factor and anisotropy do not make much physical sense, since by definition the shape of lamellar graphite is far from isometric and spherical. They are automatically included in the results database. A more informative value in this case is such a parameter as the perimeter of a graphite inclusion, because it allows estimating the complexity of the shape (tortuosity, outlines of the inclusion). It is obvious that the higher the value of the inclusion perimeter, the more sinuous and complex the shape of this inclusion.

The complexity of the inclusion shape determines the level of concentration of internal stresses around the in-

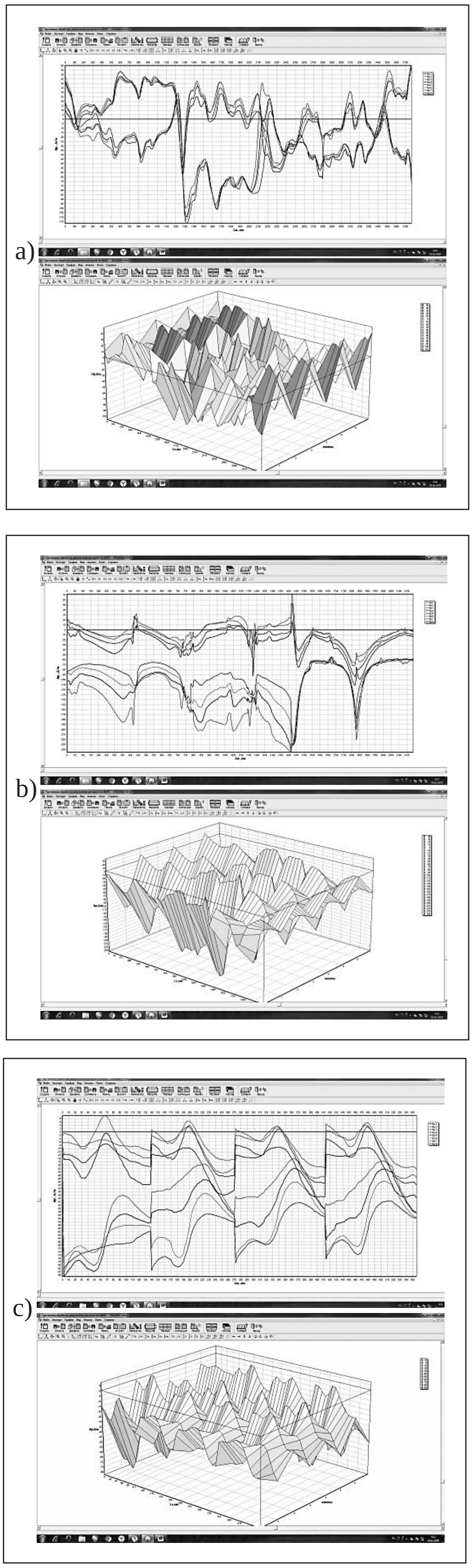

Figure 2 Cast iron magnetograms:
a) – sample No. 1;
b) – sample No. 2;
c) – sample No. 3

clusion, which affects the properties of the structure as a whole. Table 2 shows averaged data of the results obtained, as well as the values of hardness and wear resistance of the samples under study obtained earlier. It should be noted that quantitative metallographic studies were carried out in no less than 20 fields of view. It allows considering the results obtained as statistically significant.

Table 2 **Metallographic analysis results**

Sample No	1	2	3
Share of the area occupied by graphite / %;	7,17	8,48	5,75
Average diameter / μm	106,46	66,32	33,48
Average perimeter / μm	542,3	421	182,5
Average area of inclusions / μm^2	1 066,3	561,8	87,1
Shape factor	0,204	0,114	0,063
Anisotropy	0,58	1,368	0,606
Density / psc/mm^2	17 109	29 652	43 479

It is seen from the data in Table 2 that the quantitative indicators of the structures differ very significantly. In ChN2H cast iron the share of the area occupied by graphite inclusions is 7,17 %. If we compare this indicator with those in samples Nos. 2 and 3, the difference is 15,4 % and 19,8 %, respectively. However, the average area of graphite inclusions for sample No. 2 is almost 2 times smaller, and for sample No. 3 it is almost 12 times smaller. If we draw a parallel with such an indicator of the structure as the density of inclusions per 1 unit of area, the difference is 43 % for sample 2 and 60 % for sample 3. A quantitative analysis of the structure experimentally confirms preliminary visual observations:

- graphite inclusions in sample No. 1 are larger than in other samples, and their distribution density is rather low. The smallest in area inclusions are present in sample No. 3, and their distribution density is the highest;
- graphite inclusions in sample No. 3 have the simplest shape without convolutions and uneven edges. This fact is proved by the smallest value of the average perimeter.

From the point of view of strength and wear resistance, a structure with small, evenly distributed graphite inclusions should have better characteristics than a structure with large irregular graphite inclusions. It is obvious that the smaller the size of the inclusion, the simpler the shape and uniformity of distribution (density), the higher hardness and wear resistance of the structure [7-11].

However, there are some contradictions between the data, for example: the average area of graphite inclusions in the studied samples is not related to hardness, although at the first glance this relationship is obvious. Meanwhile, in sample No. 2, the area of inclusions and the average size of graphite are almost 2 times larger than in sample No. 3, however, hardness and wear resistance indicators in these samples are comparable. It can be assumed that the difference in the quantitative indicators of graphite inclusions is offset by the difference in the parameters of the metal base.

To exclude the presence of internal defects, magnetograms of the samples were taken, shown in Figure 2. For the analysis, we used a 12-channel fluxgate magnetometer TSC-3M-12 with a scanning device of the 1-8M type. It is based on the method of magnetometric diagnostics. At least 15 tests were carried out on each sample. Figure 2 shows the most typical magnetograms for each of the samples. The upper graphs represent the Hp field component distribution along the scan line; the lower graph is a three-dimensional graph of the intensity of changes in the field dH/dx over the controlled surface.

Comparison of magnetograms shows practically the same pattern of the Hp fields distribution in the samples. In sample No. 3, slightly larger deviations from the scanning axis are observed, which can indicate a large number of structural components in the object under study. In sample No. 3 the presence of a possible additional component in the form of TiC carbides is quite consistent with this change in the field strength.

CONCLUSION

Based on the studies carried out, it is possible to recommend introducing titanium carbide in the amount of 1 % with dispersion of 500 μm as a passive modifier. It facilitates grinding and simplifying the shape of graphite inclusions. Simplifying the shape of graphite inclusions leads to decreasing the level of internal stresses in the body of the ingot, which should also have a beneficial effect on such properties of alloys as hardness, ultimate strength and wear resistance, all other things being equal.

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