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NANOMODIFIER EFFECT ON STRUCTURE AND PROPERTIES CHANGES OF HEAT-TREATABLE STEEL

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The paper considers the effect of titanium carbide nanopowder (hereinafter referred to as the nanopowder material, NPM) on the structure and properties of medium-carbon heat-treatable steel containing vanadium, niobium, molybdenum and chromium. The titanium carbide nanopowder with dispersion of 80-90 nm in the amount of 0,08 % was introduced into steel before casting. After heat treatment, the prototypes were tested for hardness and wear resistance. The results show that in the experimental samples these properties are improved, which is associated with changes in the structure. The metallographic analysis of the structure (interstitial phases) was performed using ThixometPro software (Russia). In the analysis such parameters as the average size and the perimeter of interstitial phases, their shape and total relative occupied area were estimated. The results show that introducing the NPM leads to decreasing the size of interstitial phases and increasing the sphericity of the shape. Such structural changes increase hardness and wear resistance.

Keywords: alloy steel, titanium carbide nanopowder, hardness, wear resistance, interstitial phases

INTRODUCTION

After appropriate heat treatment, heat-treatable steels possess a whole range of properties that determine their widespread use. Recently, a significant number of works have appeared that deal with studying the structure and properties of steel after treatment with various modifiers [1-5].

In almost all the studies, it is noted that introducing a nanomodifier positively affects changes in the structure and therefore, the properties of steel. This effect is expressed in the grain grinding, reducing segregation, etc. Various substances are used as nanomodifiers: nitrides and oxides of refractory metals, particles of pure metals, clad particles of various oxides.

This work studied the effect of titanium carbide nanopowder on the structure and properties of the heat-treatable steel 30H3MF additionally alloyed with niobium. The choice of titanium carbide as a modifier is caused by the following. On the one hand, titanium carbide, unlike many other recommended nanomodifiers (for example, YtO_2, clad particles of Cr, etc.) is quite affordable both in price and in prevalence. On the other hand, titanium carbide having the melting point of 3 140 °C does not melt in the steel melt and plays the role of additional crystallization centers, i.e. it contributes to the grain grinding. In addition, the presence of solid titanium carbide in the structure ensures the presence of the MeC solid phase that always plays the role of a hardener.

Thus, introducing titanium carbide in the composition of the heat-treatable steel should provide increasing its properties, such as hardness and wear resistance.

EXPERIMENTAL PART

To verify this assumption, the following experiments were carried out. As the object of research, steel 30H3MF was additionally alloyed with niobium. In previous studies [6], it was shown that introducing niobium into the composition of this steel makes it possible to increase its strength and wear resistance by about 20–25 % and to use it as a wear-resistant material for parts operating under conditions of abrasive wear and impact loads.

Titanium carbide was introduced in the form of a nanopowder in the amount of 0,08 % with dispersion of 80-90 nm. To achieve the specified dispersion, titanium carbide grade F 500 (TU 6-09-492-75) was ground in a RetschEmax nanomill with the following grinding parameters: the size of grinding balls was 15 mm; the rotation speed was 1 200 rpm. After grinding, the fractional analysis of the obtained titanium carbide powder was carried out on a FSX-6K photosedimentometer. The dispersion of the given fraction was at least 80 %.

Steel of the required composition (Table 1) was smelted in a UIP-25 induction furnace with a modernized cooling system in an inert CMC crucible.

The melting was poured into alundum crucibles fixed in the ground. The titanium nanopowder was introduced into the crucible before casting. After complete cooling, the samples were subjected to heat treatment in the following mode: annealing at the tempera-

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Table 1 **Chemical composition of steel under study / wt. %**

Element	Experimental steel
C	0,32
Si	0,6
Mn	1,7
Ni	0,55
S	0,025
P	0,025
Cr	2,3
Mo	0,28
V+Nb	0,13

ture of 650 °C; quenching at the temperature of 920 °C followed by cooling in oil; tempering at the temperature of 500 °C, cooling in water.

After heat treatment according to the indicated modes, the samples were tested for hardness and wear resistance. Hardness was determined on a Willson-VH1150 hardness tester, wear resistance on a TABERABRASER 352G wear testing device. S-35 tungsten carbide disks were used as abrasive disks. The test results are shown in Table 2.

As it can see from the data in Table 2, hardness and wear resistance of steel treated with NPM (No. 2) are higher than those of the reference sample (No. 1). Given that the composition of steel in both samples is the same, a similar difference in properties can only be explained by changes in the structure.

For this purpose, there was carried out the metallographic analysis using the ThixometPro software.

Table 2 **Results of testing for hardness and wear resistance**

No.	Sample	HB	Wear resistance, $\times 10^4$/ g
1	Experimental steel (without treating with NPM), annealing, hardening 920 °C oil + tempering 500 °C water	430	322
2	Experimental steel (treated with NPM), annealing, hardening 920 °C oil + tempering 500 °C water	452	380

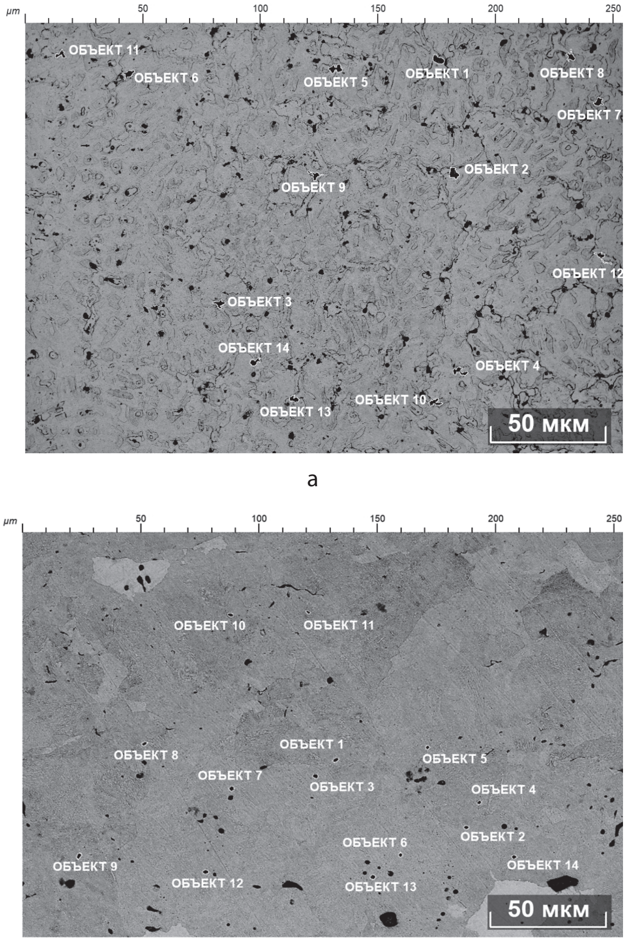
The program automatically selects the objects according to the specified characteristics and carried out a quantitative analysis according to the required parameters. The analysis was carried out in 10 fields of view.

In each field of view, 14 objects were selected as the object of research: interstitial phases identified as carbides (Figure 1). Identification of the phase nature was performed using MRSA.

An example of the data analysis is shown in Figure 2.

The phase anisotropy was defined as the ratio of perpendicular maximum diameters. In this case, anisotropy was understood to be an isometric shape of the object under study. Accordingly, in this case, the closer the anisotropy index to unity, the more isometrically the shape of the object under study is developed.

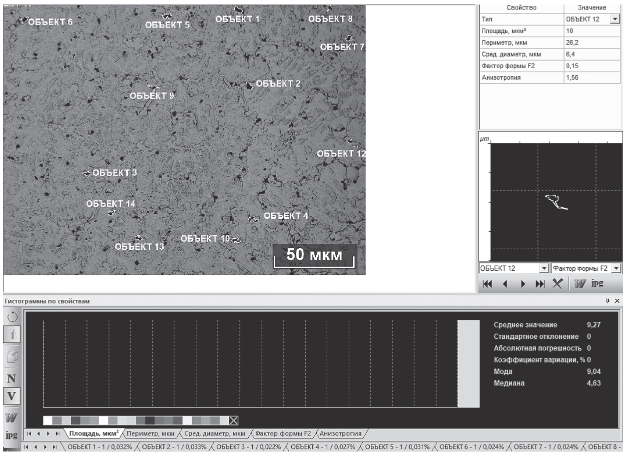
The shape factor was calculated by the formula:



a

b

Figure 1 Objects for the metallographic analysis using the ThixometPro software: *a* – sample No. 1; *b* – sample No. 2



Свойство	Значение
Тип	ОБЪЕКТ 12
Площадь, мкм²	10
Периметр, мкм	26,2
Сред. диаметр, мкм	6,4
Фактор формы F2	0,15
Анизотропия	1,56

ОБЪЕКТ 12 ▾ Фактор формы F2 ▾

Среднее значение	9,27
Стандартное отклонение	0
Абсолютная погрешность	0
Коэффициент вариации, %	0
Мода	9,04
Медиана	4,63

ОБЪЕКТ 1 - 1 / 0,032% ОБЪЕКТ 2 - 1 / 0,033% ОБЪЕКТ 3 - 1 / 0,022% ОБЪЕКТ 4 - 1 / 0,027% ОБЪЕКТ 5 - 1 / 0,031% ОБЪЕКТ 6 - 1 / 0,024% ОБЪЕКТ 7 - 1 / 0,024% ОБЪЕКТ 8 -

Figure 2 An example of the metallographic analysis using ThixometPro

$$F = \frac{4A}{\pi D_{\max}^{2}},$$

where A is the inclusion area;

D is the inclusion diameter.

The shape factor also characterizes the shape of inclusion, but unlike anisotropy, it characterizes not isometry but a tendency to develop a spherical shape of inclusion.

In other words, the higher the value of the shape factor in this case, the closer the shape of this inclusion to the sphere. It is known that the spherical shape of the interstitial phases contributes to a lower level of structural stresses, which favorably affects the increase in both strength properties and impact strength [7].

Thus, it is obvious that the shape, size, anisotropy, the amount of the carbide phase will have a direct and decisive effect on the properties of the structure. Table 3 presents the averaged research results.

Table 3 **Results of the quantitative metallographic analysis**

Sample No.	Sample characteristic	Average value of the objects area/ μm^2	Inclusion area fraction/ %	Average value of the object perimeter/ μm	Average value of the diameter/ μm	Average value of the shape factor	Anisotropy
1/2	Experimental steel (without treating with NPM)	9,27	2,84	14,4	4,04	0,425	1,365
1/3	Experimental steel (treated with NPM)	4,42	1,17	8,58	2,61	0,64	0,639

DISCUSSING OF RESULTS

It can see from Figures 1,2 and the data in Table 3 that the microstructure of steel additionally modified by the NPM, is characterized by smaller carbides: this is evidenced by a smaller average diameter and perimeter of the phase under study. With an equal number of studied objects, the latter occupy a smaller area, both in absolute and in relative terms. The interstitial phases in samples No. 1 and No. 2 are characterized by a rather high degree of isometricity: the deviation from 1 is about 0,36, but in sample No. 2 the interstitial phase is characterized by a more spherical shape, judging by the shape factor. Thus, the structure of sample No. 2 is characterized by a finer and more rounded interstitial phase with the same matrix character.

The presence of such a structure should provide high strength properties. The data in Table 2 correlate well with the data in Table 3. Microstructures characterized by finer and more rounded interstitial phases have higher hardness and wear resistance. The comparison of microstructures shows that, despite a large total area of solid interstitial phases (2,84 % and 1,17 %), hardness of sample No. 1 is lower than that of sample No. 2. This contradiction is easily explained if we pay attention to the shape of the inclusions. In sample No. 1, the carbide phase has an elongated shape (the degree of sphericity is 0,425). Such a phase acts as a stress concentrator, which leads to relatively low hardness and wear resistance.

In the structure of sample No. 2, the fraction of the carbide phase over the area is almost 2 times smaller, but the degree of sphericity is 0,64. It should be noted that the shape of the resulting carbide phase indirectly confirms the nature of the carbide phase. It is known that cementite type carbides usually crystallize in the elongated shape, MeC type carbides do in the round shape [7].

CONCLUSION

Thus, the studies carried out allow concluding that the titanium carbide nanopowder has a favorable effect on hardness and wear resistance of heat-treatable steel. The titanium carbide nanopowder, first of all, affects the structural change: the carbide phase becomes smaller, acquires a more rounded shape, which helps to reduce the level of internal stresses, which affects increasing hardness and wear resistance.

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