IMPROVING PROPERTIES OF CAST PARTS OF AGRICULTURAL MACHINERY BY THE NANOMODIFICATION METHOD

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Abstract. The technology of obtaining and treating steel for agricultural machinery consists in smelting steel of the specified composition, modifying the steel with titanium carbide nanopowder in an amount of 0.06-0.08% with dispersion of 80-100 nm and subsequent heat treatment consisting of the following stages: annealing at 640 ºC, quenching in oil at 920-930 ºC and tempering in water at 500-550 ºC. As a result of using the developed technology, the properties of parts increase: hardness by 12-14%; tensile strength by 13-15%; wear resistance by 15-18%. The grain class and segregation decrease, the properties of carbon steels approach in hardness and wear resistance to those of heat treated steels with carbide hardening. It has been experimentally proven that the treatment of alloyed steel with titanium carbide nanopowder significantly changes the nature of the interstitial phase (carbides): the average size of carbide inclusions decreases by 36%, the shape factor (the tendency to form a spherical shape) increases by 34%, which favorably affects the properties.

Keywords: nanomodifiers, steels, titanium carbide, hardness, wear resistance, carbide inclusions.

Introduction

A significant amount of agricultural machinery parts is made of low- and medium-alloyed steels, the service life of such parts is very limited, the frequency of changing per season is 3 or more times. Accordingly, the use of materials with higher performance properties will extend the life of these parts.

Studies [1-3] provide data on the positive effect of metal nanoparticles, refractory carbides and oxides on properties, such as wear resistance, hardness, toughness and corrosion resistance. It is shown in [1] that modification of shipbuilding steel with magnesium nanoparticles increases the dispersion of ferrite, which improves the properties of steel as a whole. The results obtained in [2] showed that microalloying with yttrium nanoparticles promotes the formation of a fine structure and improves its properties. In [3], the effect of titanium carbide nanoparticles on the properties of carbon steel was studied. It has been shown that in comparison with cast carbon steel without TiC nanoparticles, a decrease in grain size and an improvement in mechanical properties are observed.

In previous works [4; 5] an experimental steel was investigated, the composition of which is given in Table 1. For comparison, 30H3MF steel was used, as is often used for the manufacture of cast parts. It has been shown that microalloying with vanadium and niobium leads to the formation of carbides of the MeC type, which have increased resistance and hardness, thereby increasing wear resistance.

Table 1

Chemical composition of the test steel

Element, %	C	Si	Mn	Ni	S	P	Cr	Mo	B	V + Nb
Test steel	0.32	0.6	1.7	0.55	0.025	0.025	2.3	0.28	-	0.13

Carbides of the MeC type, in contrast to the carbides of the cementite type, do not dissolve when heating, remain in the matrix after quenching, thereby providing hardness and strength. In addition, carbides of this type have, as a rule, high dispersion and a more rounded shape, in contrast to acicular carbides of the cementite type. This shape of the carbide phase provides a lower stress level and therefore higher toughness.

The classical heat treatment of steel 30H3MF is quenching from 870 ºC in oil, followed by tempering at 620 ºC in water [6]. In [4], it was noted that due to additional alloying, the heat treatment mode was corrected: quenching from 890 ºC in oil, followed by tempering in the range of 500-550 ºC, cooling in cold water. In connection with the additional modification of the experimental steel, the heat treatment mode was adjusted. The information analysis in this area has shown [7-11] that to increase the structure homogenization, increasing the hardening temperature and preliminary treatment of the structure can improve the final properties of steel.

Pre-annealing of castings made of this steel at the temperature of 640-660 ºC allows homogenizing the structure, eliminating possible casting defects, and reducing the level of chemical segregation.

Increasing the hardening temperature to 900-930 ºC ensures the dissolution of both cementite and $Me_{23}C_7$ carbides that form chromium.

In order to study the effect on the structure and properties of the tested steel another NPM was introduced.

Materials and methods

Titanium carbide in an amount of 0.02-0.1% by weight and with different dispersion was introduced into the experimental steel. Previously, titanium carbide grade F 500 (TU 6-09-492-75) was ground in a Retsch Emax nanomill with such parameters: grinding balls size 15 mm; rotation frequency 1200 rpm. After grinding, the fractional analysis of the obtained titanium carbide powder was carried out on a FSKh-6K photo sedimentometer. Dispersion varied within 60-120 nm with the fraction content of at least 80%.

Experiments on treating experimental steel were carried out according to the developed modes. The pilot steel was melted in a UIP-25 furnace with a modernized cooling system. The melt was poured into alundum crucibles fixed in the ground. Previously, titanium carbide powder was placed in the crucible in specified amounts and dispersion. After complete cooling, the samples were subjected to heat treatment according to the following mode: annealing at the temperature of 650 ºC; quenching at the temperature of 920 ºC followed by cooling in oil; tempering at the temperature of 500 ºC, cooling in water.

Results and discussion

After heat treatment according to the indicated conditions the samples were tested for hardness and wear resistance. According to the data of Tables 2 and 3 graphs were built for assessing the optimal ranges of the NPM amount and dispersion (Fig. 1).

Table 2

TiC dispersion effect on the steel properties (the TiC amount 0. 06%)

Sample No.	Dispersion, nm	Properties	
		Hardness, HV	Wear resistance, x10^4, g
1/1	Not introduced	430	322
1/2	60	432	330
1/3	80	452	380
1/4	100	461	416
1/5	120	323	302

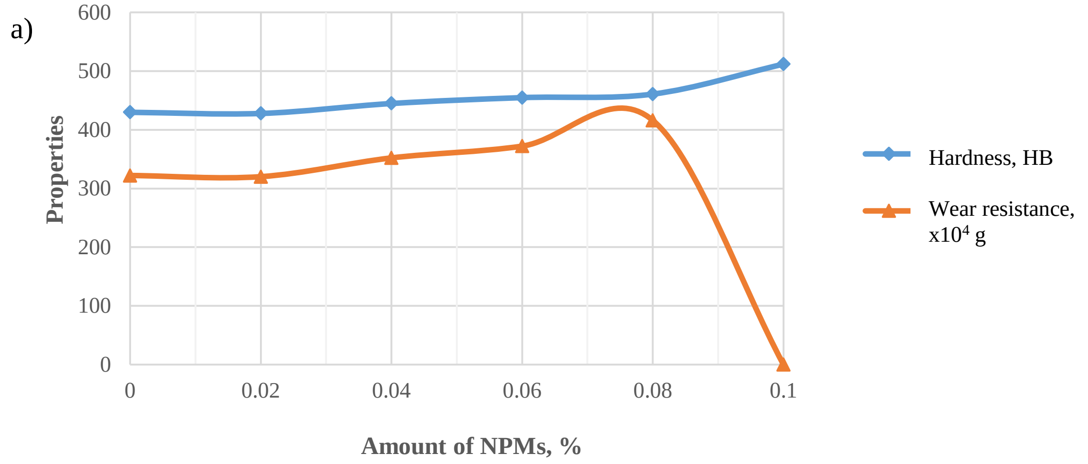
Table 3

TiC amount effect on the steel properties (dispersion 80 nm)

Sample No.	TiC amount, %	Properties	
		Hardness, HV	Wear resistance, x10^4, g
2/1	Not introduced	430	322
2/2	0.02	428	320
2/3	0.04	445	352
2/4	0.06	455	372
2/5	0.08	461	416
2/6	0.1	512	0, chips

Analysis of the graphs presented in Figure 1 shows that the most optimal dispersion interval is the particle size range of TiC particles 80-90 nm. With increasing the TiC particle size above 100 nm, the hardness and wear resistance of the samples decreases. This can be explained by the fact that for a given particle size TiC disrupts the homogeneity of the matrix, causing additional stresses around the particle. This phenomenon can be compared with the effect of coagulation of interstitial phases, when upon reaching the critical size, the hardening interstitial phase has an opposite effect rather than the hardening one [8-11].

A similar effect is exerted by the introduction of TiC in the amount greater than 0.08%. With the amount of TiC in the specified amount, the sample hardness continues growing, but when tested for wear, the surface is chipped. This circumstance is associated with increasing the fraction of solid inclusions incoherent with the matrix, which leads to additional structural tension. Under the impact of dynamic loads, which are all abrasive loads, individual structural components, in this case TiC, crumble.



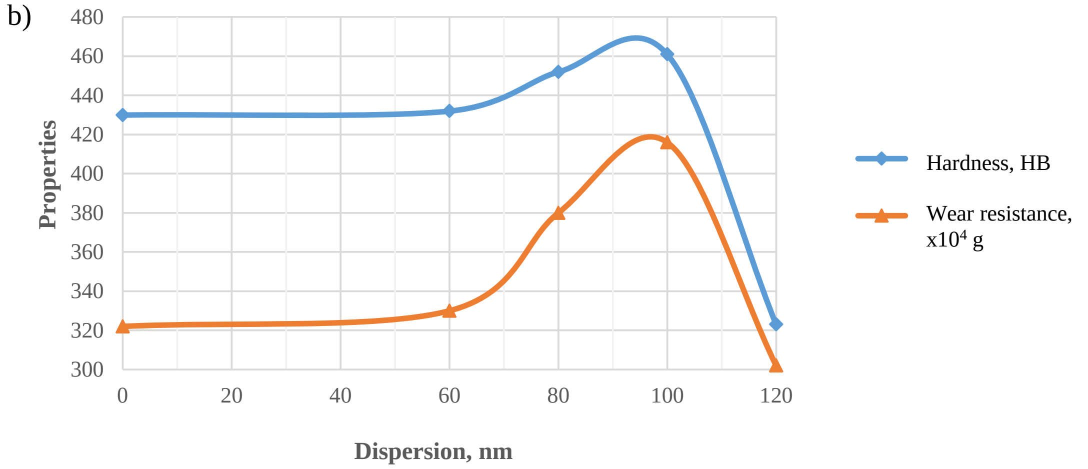


Fig. 1. **Dependence of hardness and wear resistance on the amount (a) and dispersion (b) of the introduced TiC**

Thus, the tests performed make it possible to recommend the following treatment mode for TiC: the introduction of titanium carbide with dispersion of 80-100 nm in the amount of 0.06-0.08%. The obtained experimental data show that samples 2/4 (1/3) are promising for further research, i.e. the sample modified with titanium carbide with dispersion of 80 nm in the amount of 0.06%. In this sample, as well as in the reference samples (Table 4), ultimate strength and impact strength were determined.

Table 4

Results of testing for mechanical properties of experimental samples

No	Sample	HV	Ultimate strength, MPa	Wear resistance, x10^4, g	KCU, kJ·m^{-2}
1/0	Steel 30H3MF (comparison sample)	326	972	243	912
1/1	Experimental steel (without, TiC annealing, quenching at 920 ºC oil + tempering at 500 ºC water	430	1317	322	832
1/3	Experimental steel (TiC treated, annealing, quenching at 920 ºC oil + tempering at 500 ºC water	452	1356	380	802

It is seen from Table 4 that sample No. 1/3 treated with TiC, in all respects surpasses the reference sample and sample No. 1/2 represented by the same alloy composition, but without subsequent modification with TiC.

In addition to testing prototypes for mechanical properties, metallographic tests were also carried out. Sections were prepared from the steel prototypes for structural analysis. Fig. 2 shows the microstructures and MRSA data of the studied samples. MRSA was performed to determine the nature of the interstitial phases. There are given selected, most typical spectra.

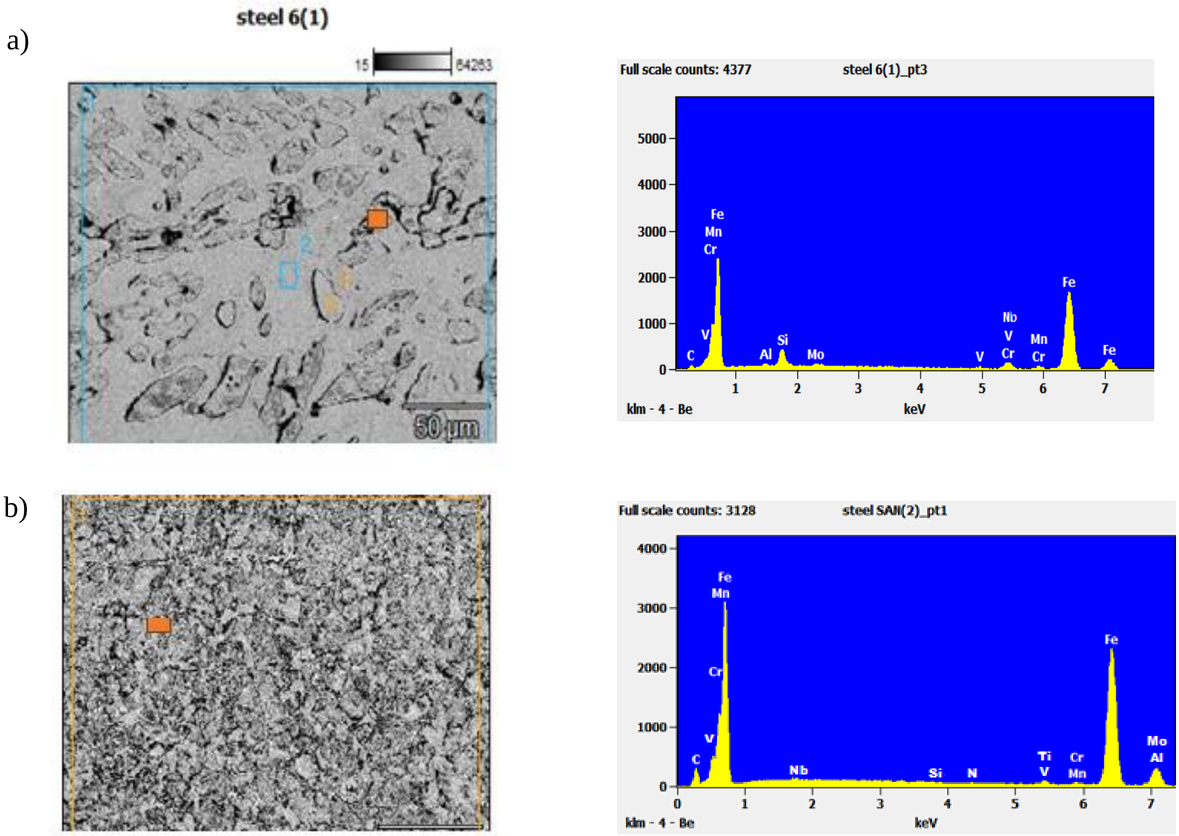


Fig. 2. **Structure and composition of the test samples (magnification 5000):**
a – sample No. 1/2; (the data of 2019); b – sample No. 1/3

The MRSA data show that such elements as C, V, Nb, Ni are present in the interstitial phases. Taking into account the chemical composition of steel, the phases under study can be identified as carbides.

The quantitative analysis of the microstructure of the prototypes was carried out using the Thixomet Pro software. The program automatically selects the objects according to the specified characteristics and carries out the quantitative analysis according to the required parameters.

The shape factor characterizes the shape of the inclusion, it does not characterize isometry, but the tendency towards the development of a spherical shape of the inclusion. In other words, the higher the values of the shape factor in this case, the closer to the sphere the shape of this inclusion. In this case, inclusions were understood as carbides; the nature of the inclusion was determined by MRSA (Fig. 3).

Fig. 3 and the data of Table 5 show that the microstructure of steel modified with titanium carbide nanopowder is characterized by smaller carbides: this is evidenced by a smaller average diameter and perimeter of the phase under study. With the equal number of objects under study, they occupy a smaller area, both in absolute and in relative terms.

The introduction phases in samples No. 1/2 and No. 1/3 are characterized by a fairly high degree of isometricity: the deviation from 1 is about 0.36, but in sample No. 1/3 the interstitial phase is characterized by a more spherical shape, judging by the shape factor. Thus, the structure in sample No. 1/3 is characterized by a shallower and more rounded interstitial phase with the same nature of the matrix. Microstructures with the selected interstitial phase are shown in Fig. 3.

Table 5

Results of the quantitative metallographic analysis

Sample No.	Sample characteristic	Average value of the object area, μm^2	Share of the inclusion area, %	Average value of the object perimeter, µm	Average value of the diameter, µm	Average value of the shape factor
1/2	Experimental steel (without NPM treatment)	9.27	2.84	14.4	4.04	0.425
1/3	Experimental steel (NPM treated)	4.42	1.17	8.58	2.61	0.64

The presence of such a structure should provide high strength properties with good impact strength. Microstructures characterized by finer and more rounded interstitial phases (Fig. 3) are characterized by higher hardness and wear resistance. The exceptions are objects 13, 14, which have significant deviations from the average. These objects are characterized by their large size, low isometricity and shape factor. Obviously, in the absence of these objects, the average values of the 1/3 sample would be even higher. The comparison of microstructures shows that despite the large total area of solid interstitial phases (2.84% and 1.17%), the sample 1/2 hardness is lower than that of the specimen 1/3. This contradiction can be easily explained, if we pay attention to the shape of the inclusions. In sample No. 1/2, the carbide phase has an elongated shape (the degree of sphericity is 0.425). This phase acts as a stress concentrator, which determines relatively low hardness and wear resistance.

a) b)

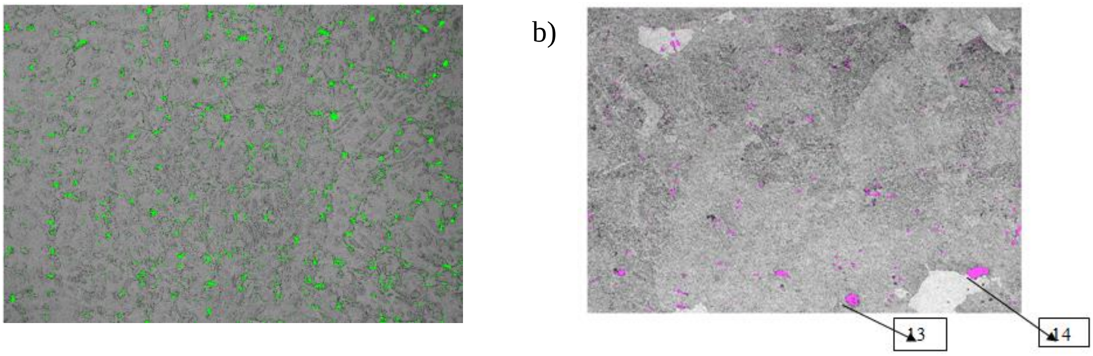


Fig. 3. **Microstructure of samples with the pointed omterstitital phase:**
a – sample 1/2; b – sample 1/3

In the structure of sample No. 1/3, the proportion 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 carbides of the cementite type usually crystallize into an elongated shape and carbides of the MeC type into a round shape [12-15].

Conclusions

The results obtained show that steel 30H3MF additionally alloyed with vanadium and niobium in the amount of 0.15-0.2% and modified with TiC nanopowder in an amount of 0.06-0.08% with dispersion of 80-100 nm and subjected to heat treatment that consists of annealing at 640 ºC, quenching in oil 920 ºC and tempering in water 500 ºC can be used as a material with good hardness and wear resistance.

Thus, based on the results of studying the properties of the laboratory samples, the following process adjustment can be proposed. The technology was proposed for producing steel based on 30H3MF with an increased content of vanadium and niobium and the further step, which consists in TiC treating of experimental steel and subsequent heat treatment. The modes of TiC treatment and heat treatment are indicated above.

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