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Coating tribology

AN INVESTIGATION ON THE WEAR PROPERTIES OF CARBON STEEL COATED WITH NANOPARTICLES USING ELECTRON BEAM TECHNIQUE

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ABSTRACT

Due to the rapid development of the nanotechnologies recently, it becomes possible to modify successfully the properties of metals and alloys by use of nano-sized particles. The introduction of metallic or nonmetallic nanopowders in the melted alloy leads to redistribution of the impurities and decrease of the grain size that finally results in a zone or layers characterised by new properties, e.g. higher robustness, microhardness and wear-resistivity.

In the present work we investigate the wear properties of carbon steel coated with nanoparticles, such as TiN and TiCN, using electron beam technique.

Keywords: nanopowders, electron beam, alloying, tribology, wear resistance, abrasion wear, coating.

AIMS AND BACKGROUND

One of the methods to extend the lifetime of contact friction connections and cutting or molding tools, etc. is based on the development of tribo materials and coatings with higher wear resistance. This is one of the most important issues of the modern material science. The development of efficient wear resistant coatings is a complicated task since the coatings has to combine higher hardness and toughness with low inner tensions, good adhesion to the insert and low coefficient of friction[1].

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The use of electron beam for surface treatment of metals and alloys is a promising field and is increasingly widely applied in practice[2,3]. It ensures improvement of the physic and mechanical characteristics and higher quality of articles made of cast iron, aluminum and aluminum alloys, as well as copper and titan alloys, etc.

The purpose of this work is to make a comparative study on the influence of nano modifiers TiN and TiCN on the wear resistance of electron-beam melted surface layer of samples of steel S235JR.

EXPERIMENTAL

The test samples used have dimensions 60×40×5 mm and are made of steel S235JR +AR according to DIN17100 (Rst 37-2; EN10025). The preliminary preparation of the samples consists in abrasive cleaning and degreasing in acetone and alcohol (Fig. 1).

Some surfaces are roughened using electron beam. The roughened longitudinal band is 20 mm wide (Fig. 2).

Fig. 1. Abrasively cleaned and degreased sample surface

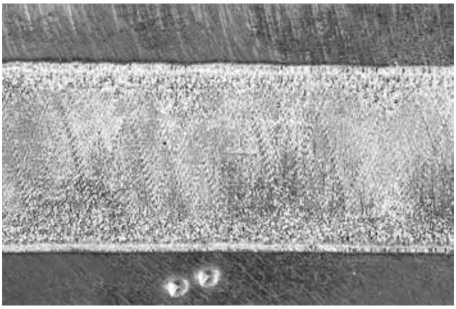


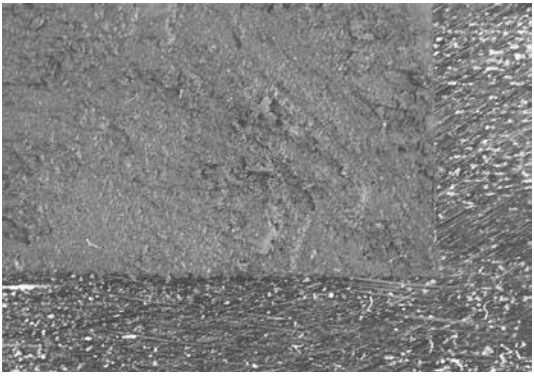
Fig. 2. Sample surface after roughening

The nanopowders of TiN and TiCN have particle size from 40 to 60 nm. They are additionally activated through treatment in planetary grinder and coated with Gr and Gr +Fe, respectively.

The following samples are examined:

- Reference sample No 0: without roughening, and without application of nano-containing coating (Fig. 1);
- Sample No 1: without roughening, and with TiN+Cr nano-containing coating (Fig. 3);
- Sample No 2: with roughening, and without nano-containing coating (Fig. 2);
- Sample No 3: with roughening, and with TiN+Cr nano-containing coating;
- Sample No 4: without roughening, and with $TiCN+Y_2O_3+Cr+Fe$ nano-containing coating.

Fig. 3. Sample with coating containing nano -aterial TiN



The coating contains the respective nano modifier and binder ensuring good adhesion.

The surfaces of the samples of steel S235JR were treated with high speed scan electron beam with a Leybold Heraeus electron beam equipment (Fig. 4). The electron beam of 3 kW power was deflected with frequency 1–10 kHz and amplitude 2*b* = 14 mm perpendicular to the direction of sample movement with speed 0.5–5 cm s^{-1}.

The samples to be examined for wear resistance were shaped as quadrangle plates with dimensions 15×15×5 mm through water abrasive cutting to avoid the thermal influence.

The test is performed using a device for accelerated abrasive wear upon the kinematic scheme 'finger-disk' in the Center for Tribology at the TU – Sofia, FIE. The functional scheme of the device is shown in Fig. 5.

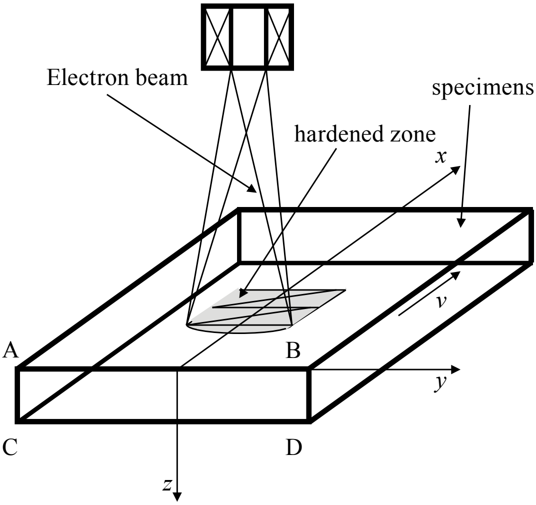


Fig. 4. Scheme of the process of electron beam treatment

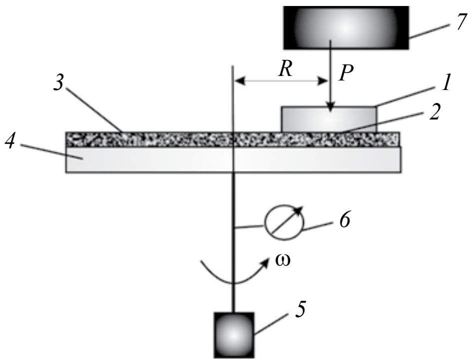


Fig. 5. Device for abrasive wear type ‘thumb-disk’

The sample *1* (body) with applied coating *2* contacts, the abrasive surface of the counter body *3*, which is modelled by impregnated corundum with certain characteristics (hardness 60% higher than the micro-hardness of the coating, and predetermined average size of the abrasive particles).

The counter body *3* is firmly attached to the bearing horizontal disk *4* and is replaced after each measurement. Thus the equal initial conditions for the contact interaction between the coating *2* and the abrasive surface *3* are ensured. The tip of the vacuum pump is arranged close to the path of friction in order to suck the particles scraped in the process of wear.

The bearing horizontal disk *4* rotates together with the abrasive surface *3* with a constant angular velocity ω = const around its own vertical axis. The angular velocity is imparted by the motor *5*, and the number of cycles, i.e. the path of friction, is counted with meter *6*. The sample 1 is appropriately attached to the loading head *7*, where the required normal loading P is exerted by lever system in the center of gravity of the sample *1*. The average speed of sliding during friction is set by varying the distance R between the axes of disk *4* and sample *1*.

The wear resistance of the coatings is determined according to the methodology developed by the authors[4,5]. It consists in measuring the mass wear of samples during a number of cycles and calculating the intensity of wear and the wear resistance for the friction path passed. The comparison upon the indicator ‘wear resistance’ is carried out at the same test conditions. The parameters of the testing are shown in Table 1.

Table 1. Parameters of wear resistance testing

No	Parameters	
1	loading	$P = 4.53$ N
2	nominal contact surface	$A_a = 225\times10^{-6}$ m^2
3	nominal contact pressure	$p_a = 2$ N/cm2
4	sliding speed	$V = 80.2$ cm/s
5	abrasive surface	impregnated corundum P 320

RESULTS AND DISCUSSION

The dependencies of the mass wear on the time of friction for samples No 1 to 4 are presented graphically in Fig. 6.

The diagrams of the wear resistance of each sample at different friction times are presented in Figs 7–9. The wear resistance I is not a constant. Under the same

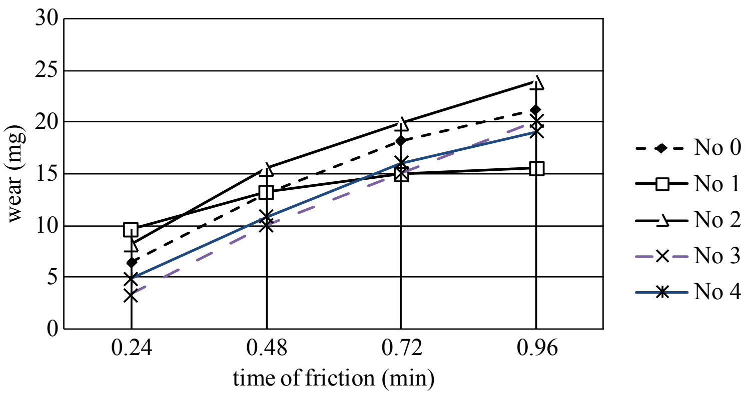


Fig. 6. Dependencies of the mass wear on the time of friction

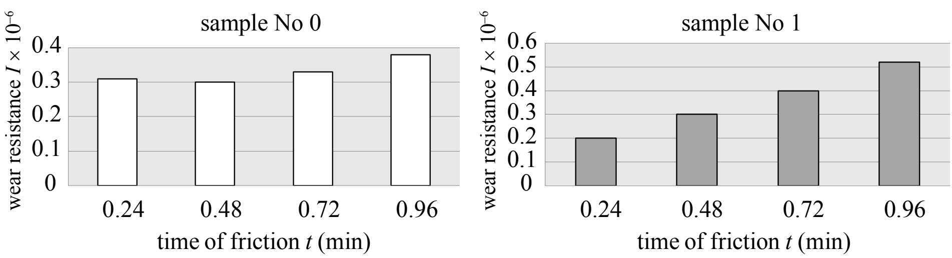


Fig. 7. Dependence of wear resistance I on time of friction t of samples No 0 and No 1

test conditions, it varies following different laws for the different samples. For the reference sample No 0, the wear resistance varies smoothly and changes from 0.3 to 0.38×10^6 for a 4 times longer path, i.e. friction time, while for the rest samples this change is up to twice (sample No 1). For other coatings there, either decrease of the wear resistance occurs (sample No 3), or a minimum followed by a further increase are observed (sample No 4).

The variable wear resistance evidences for the instability of the wear process. This correlates with the presence of non-linear areas in the dependence of the mass wear on time (Fig. 6). At this stage of the study we can talk about two reasons: on the one hand, presence of a transient mode during abrasion of coatings, and on the other, inhomogeneous distribution of the components with different mechanical properties over the debt of the coating.

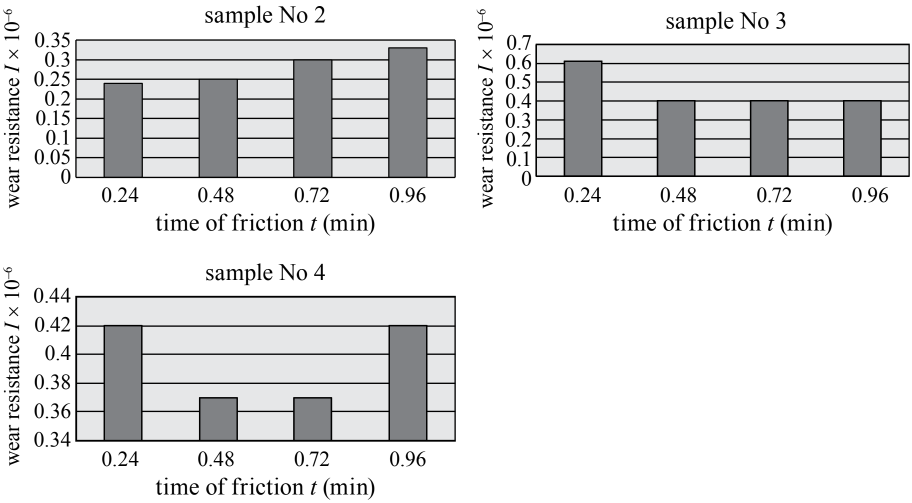


Fig. 8. Dependence of wear resistance I on time of friction t for samples No 2, No 3 and No 4

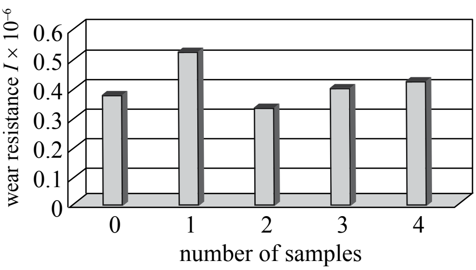


Fig. 9. Wear resistance of all samples at the same path of friction L = const = 90.4 m (N=200 cl = const)

The comparison between the coatings based on the 'wear resistance' criterion is made for the same path of friction L = const = 90.4 m (Fig. 9).

The highest wear resistance is observed in sample No 1, without roughening and with coating containing nano sized TiN + Cr particles, and we can maintain that this is due to the presence of nano particles. That assertion is confirmed by the fact that the wear resistance of sample No 2 (with roughening and coating containing no nanosized particles) is the lowest.

Samples No 3 and No 4 have wear resistance similar to that of the reference sample No 0.

Table 2 gives the values of the relative wear resistance $E_{i,e}$. The diagram is presented in Fig. 10.

Table 2. Relative abrasive wear resistance $E_{i,e}$

Relative abrasion wear resistance			
$E_{1.0}$	$E_{2.0}$	$E_{3.0}$	$E_{4.0}$
1.36	0.86	1.05	1.10

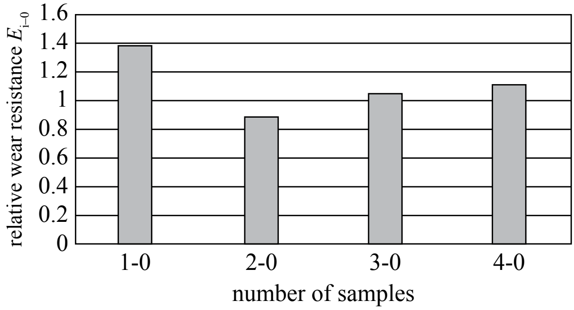


Fig. 10. Diagram of the relative wear resistance E_{i-0} for friction path L = const = 90.4m (N = 200 cl = const)

CONCLUSIONS

Experiments are performed for surface alloying of low carbon steel by use of nanopowders of two compounds, TiN and TiCN. The results indicate that the application of such type nanoparticles for surface alloying affects the mechanical and the tribological properties of the considered samples. The wear resistance of the treated samples is also higher compared to that of the reference sample.

A comparative study of samples on the 'wear' criterion on the method of expedited wear of a surface with attached abrasive is carried out.

Experimental results for all samples are obtained for the variation of the wear resistance depending on time.

The maximum wear resistance is observed in the coating layered on a roughened surface and containing nano sized particles of TiN + Cr. In this case, the wear resistance is 36% higher than that of the reference sample without coating.

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