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INFLUENCE OF A STRONG ELECTRON BEAM ON THE STRUCTURE OF PLASMA COATINGS

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The paper reports on the application of a high-current electron beam for the modification of ion-plasma multielement coatings obtained by simultaneous sputtering of various cathodes. The methods of raster electronic and atomic force microscopy, energy dispersion analysis, microhardness measurements and tribological measurements were used. Irradiation of the coating with an electron beam leads to a dispersion of the coating structure, an increase in the microhardness, and a decrease in the coefficient of friction. The surface energy also increases, which leads to an increase in wear resistance. The melting temperature of the coating is estimated and its magnification is shown after irradiation with electrons, which leads to an increase in its heat resistance. Thus, the use of a high-current electron beam for the modification of ion-plasma multielement coatings leads to a significant increase in all its operational characteristics.

Keywords: multi-element coatings; electron beam treatment; structure dispersion; hardness; friction coefficient

Introduction

During oil production the work resource and operational characteristics of deep bar pumps used in systems of oil production are defined by durability of their main working parties. These are the plunger and the cylinder. Its contacting surfaces formed the couple of friction are affected by abrasive, corrosion and cavitation impacts. Therefore, the problem of increase of operational reliability of the details is exclusively relevant. At present the vacuum technologies of thin-film strengthening coating formation on the surfaces of details friction couples are widely accepted [1-5]. However, in the most cases such coatings with a high hardness and durability also possess a high coefficient of dynamic friction in contact with a set of the applied materials.

Therefore, the multi-element high-entropy coatings [6-9] which have unique properties in some cases are of considerable interest. The great prospects have the ion-plasma multi-element coatings based on composition of 12Cr18Ni10Ti steel and Zr alloy, which possess improved operational characteristics [10].

At the same time, these coatings have the high level of the compressive stresses. One of ways for decrease of stress level, reduction of brittleness, deficiency and increase of wear resistance of the coatings is their treatment by an intense pulsed electron beam [11-14]. However, the application of pulsed electron beam for modification of ion-plasma coatings is studied insufficiently.

1. Materials and experimental procedure

The research objects were the coatings deposited by vacuum ion-plasma method (NNV6.6-I1 setup) on 45 steel specimens. The coatings were deposited by simultaneous evaporation of Zr cathode prepared by the method of induction melting and the cathode of the 12Cr18Ni10Ti stainless steel in the argon atmosphere at the working pressure of 0,7 Pa, arc current of 80 A, negative bias voltage of 200 V, duration of 10-40 min. After deposition the obtained coatings were irradiated by pulsed electron beam on SOLO installation developed in Institute of high current electronics SB

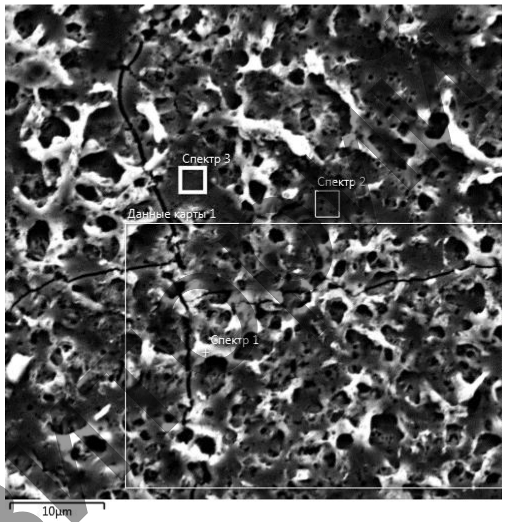
RAS (Russia, Tomsk) [11] by the technique which is described in detail in [12] at a beam energy density of 20 J/cm^2, pulse duration of 150 μs, and pulse repetition frequency of 0.3 Hz; the number of pulses was N = 5.

The electron microscopic research was carried out on the MIRA 3 scanning electron microscope (SEM) of TESCAN. The researches were carried out at the accelerating voltage of 20 kV and working distance about 15 mm. Four images of surface from four points were recorded at the magnification ×245, ×1060, ×4500 and ×14600. The energy dispersive analysis of x-rays (EDAX) in 4 points of a surface for each specimen was carried out too.

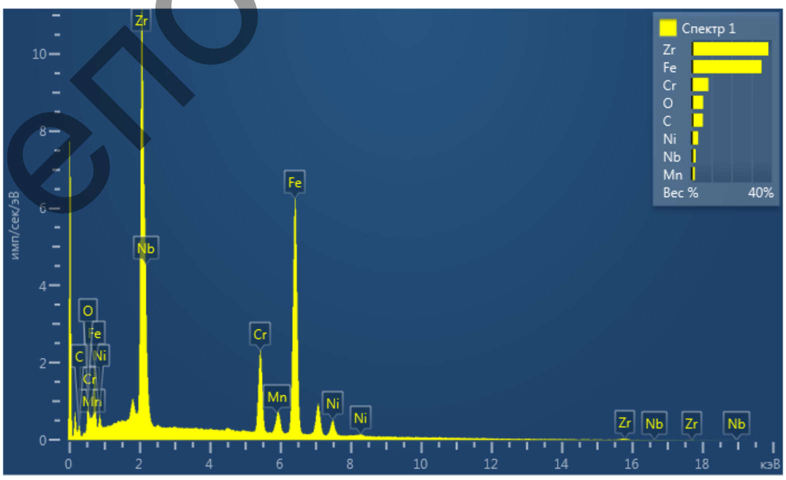
The microstructure was investigated by the EPIKVANT optical microscope. The NT-206 atomicforce microscope (AFM) was used for research of specimens in nanoscale. The coating microhardness was measured on the HVS-1000A microhardness tester. The tribological investigations were carried out on the installation described in [15].

2. Results of experiments

The SEM-image of the multi-element (Zr+12Cr18Ni10Ti steel) coating deposited during 40 min (a) and the results of EDAX element analysis (b-c) before specimen irradiation by pulsed electron beam are presented in the Fig. 1.



a)



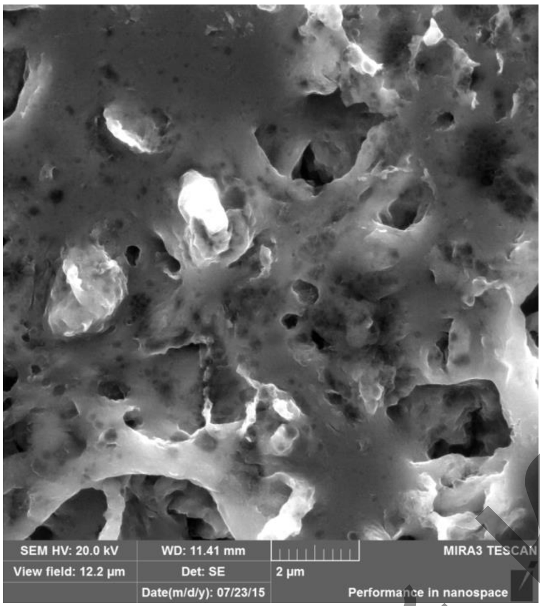
b)

Element	wt.%
C	5.63
O	5.78
Cr	8.41
Mn	1.66
Fe	34.88
Ni	3.25
Zr	38.29
Nb	2.10
Sum	100.00

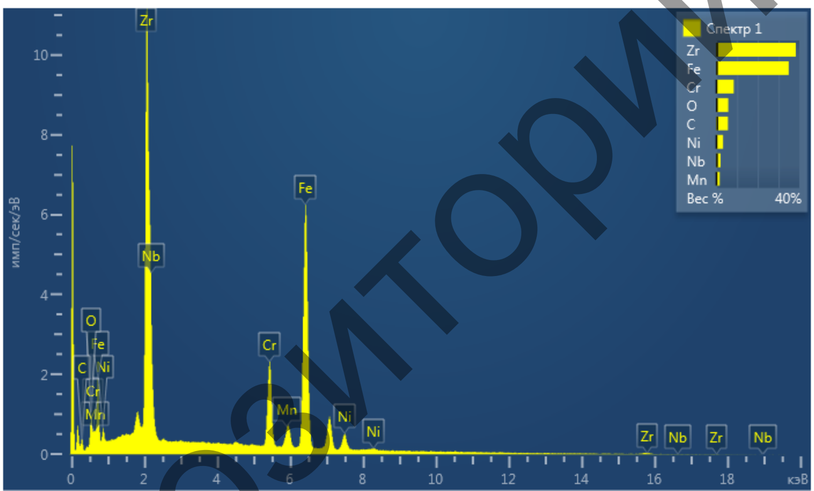
c)

Fig. 1. SEM-image (a), EDAX spectrum (b) and element concentration (c) of the multi-element coating before electron beam treatment

These results after electron beam treatment are shown in Fig. 2. The AFM-image of surface before electron-beam irradiation is shown in Fig. 3.



a)



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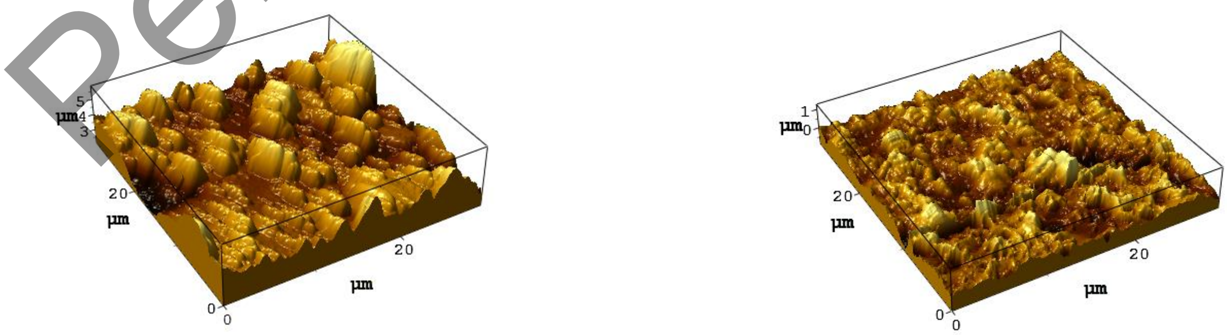

a) b)

Fig. 3. AFM images of the multi-element coating before (a) and after (b) electron beam irradiation

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The results of coatings microhardness investigations are shown in Table 1. The Table 2 presents the friction coefficients of specimens before and after electron-beam irradiation.

Table 1. Microhardness of (Zr+18Ni10Ti steel) coatings

Treatment mode	Microhardness, MPa			
Deposition duration	10 min	20 min	30 min	40 min
before electron beam treatment	373.2	390.4	411.3	420.9
after electron beam treatment	461.2	483.5	506.2	537.4

Table 2. Friction coefficient of (Zr+12Cr18Ni10Ti steel) coatings before and after electron beam irradiation

Treatment mode	Friction coefficient
before electron beam treatment	0.537
after electron beam treatment	0.221

3. Discussion

Based on the given results of researches it is clear that the nature of structural and phase transformations and depth of the modified layer significantly changes owing to the high density of the energy emitted at pulsed electron beam treatment.

Figures 1 and 2 show that the irradiation of the multi-element coating by pulsed electron beam leads to dispersion of coating structure. Especially it is visible accurately in Fig. 3. As well as in case of [12], the feature of thin structure of the coating treated by the pulsed electron beam is the formation of grains with accurately expressed substructure of various types. It is a cellular substructure with low-angle subborders and with considerable corners of a disorientation of the subgrains (low-angle) borders type. The substructural microvolums are identified as the fragments. Thus, it is possible to consider that the electron beam treatment promotes directly the structure fragmentation and the roughness reduction in the surface layers.

That leads to increase of coating microhardness (Table1) and to considerable (more than 3 times) decrease of friction coefficient (Table 2). The changes are caused by the increase of the actual area of friction couples contact and consequently, by the speed of its volume wear.

During electron beam treatment of the multi-elements coatings and their cooling there is a decrease of stress state which is a source of reproduction of dislocations in the bulk of the formed coating. The increase of the coating microhardness is also a consequence of dislocation hardening of coating material.

The change of microhardness along a specimen surface has a quasiperiodic character that testifies its wave nature. The similar situation is observed also for other coatings [16]. That is explained by the processes of self-organization during coating formation.

The surface energy of the studied coatings measured by a technique presented in [17] is equal to σ = 1,674 J/m^2 before irradiation and σ = 1,986 J/m^2 after irradiation.

As work on coating destruction is equal to following: $A = \sigma \cdot S$, where S – the area of the coating, σ – surface energy. The above results show the increase of the wear resistance of specimen with multi-element coating after irradiation by an electron beam.

Thus, the reduction of a roughness and the change of a structural state owing to the irradiation annealing causing decrease of deficiency and residual stresses is the main reason of the increase of multi-element wear resistance.

Conclusion

It is revealed that pulsed electron beam treatment of the multi-element ion-plasma coatings leads to the dispersion of its structure, to the increase of the microhardness and to the decrease of their friction coefficient.

The obtained results of operational characteristics of the coatings show the expediency of their use for hardening of surface layers of the pumps which are used in systems of oil production and refining.

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