PROCEEDINGS OF THE INTERNATIONAL CONFERENCE
NANOMATERIALS: APPLICATIONS AND PROPERTIES
Vol. **3** No 1, 01FNC08(2pp) (2014)

High Entropy Alloys Based on Nitrides of Refractory Metals – a New Solution for Protective Coatings on the Instruments Working at High Temperatures

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(Received 12 August 2014; published online 29 August 2014)

The coatings based on (Ti-Al-Zr-Nb-Y)N and (Ti-Zr-Hf-V-Nb-Ta)N were obtained by means of vacuum-arc deposition from the cathodes based on Ti+Al+Zr+Nb+Yand Ti+Zr+Hf+V+Nb+Tasystems in the atmosphere of nitrogen. Their physical and mechanical properties, as well as tribotechnical characteristics have been studied. The coatings are characterized by a columnar structure and their hardness reaches 51.02GPa. The adhesion strength of the coatings has also been studied, the coefficient of friction of the system "coating – Al_2O_3" is 1.1.The results of tribological tests at high temperature showed that at 460 °C coatings had greater wear resistance, lower coefficient of friction compared to similar tests of coatings at 20 °C.These coatings are perspective as protective coatings for friction pairs and cutting tools.

Keywords: High entropy alloys, Coatings, Vacuum-arc deposition, Nanocomposite coatings.

PACS numbers: 68.55. – a, 68.35.Np

1. INTRODUCTION

Destruction of instruments or machine parts starts from their surface, which is subjected to severe mechanical, thermal and chemical impact. Thus, an actual problem of modern materials science is improvement of characteristics of products working in harsh environments. One of the methods of solving this problem is creating protective coatings on the surfaces of such details. Coatings, which increase performance of the product in conditions of friction at high temperatures are of particular interest. To solve this technological problem, we have proposed a method for creating coatings based on high-entropy alloys of refractory metals on the working surfaces of machine parts. Using HEAs stabilizes unstable phase of a solid solution and prevents formation of intermetallic compounds, which have a negative effect on mechanical properties of the coating.

In this paper we have deposited and studied the properties of the following coatings: coating based on Ti, Al, Zr, Nb, Y and .Ti, Zr, Hf, V, Nb, Ta.

2. EXPERIMENTAL PART

Vacuum-arc deposition method was selected, the coatings were deposited in the atmosphere of reaction gas – nitrogen - at different technological deposition parameters (partial pressure of nitrogen and bias potential applied to the substrate). The target of pre-polished steel 12X18H10T, 70 mm in diameter was selected as the substrate.

The coatings were deposited at arc current $I = 110$ A, bias potential $U = -150$ V and different pressures of nitrogen – from 0.3 Pa to 0.7 Pa

The deposited cathode wasobtained by means of vacuum-arc melting method. The composition of the sprayed cathode (in wt. %) is presented in the Table 1.

The obtained coatings had thickness about 7 nm. The surface coating is characterized by a large share of dropping component that explains the selected method of applying them. Drop fraction is also present in most thicker coating.

Table 1 – Composition of the cathode

	Ti	Zr	Nb	Al	Y
Ti-Al-Zr-Nb-Y	6.12	36.99	24.50	6.12	19.32

The study of mechanical properties of coatings occupy an important role tribological tests. Comparative results for coatings of the tribological tests are shown in the table below:

Table 2 – Results of tribological tests of the coatings (Critical loads L_{C1}, L_{C2}, L_{C3}, L_{C4})

Critical loads, N	(Ti-Al-Zr-Nb-Y)N	(Ti-Zr-Hf-V-Nb-Ta)N	TiN
L_{C1} – first chevron cracks	19.89	11.8	21.31
L_{C2} – multiple chevron cracks	27.62	20.93	30.91
L_{C3} – cracking process	36.43	30.35	40.28
L_{C4} – wear of the coating, reaching the substrate	66.24	66.77	48.84

Table 3 – Results of tribological tests of the coatings

	(TiZrHfVNbTa)N	(TiZrHfVNbTa)N
Friction coefficient, μ	1.06	0.82
Wear factor, coating, mm³/N·m	$3.36 \cdot 10^{-5}$	$2.23 \cdot 10^{-5}$
Wear factor, counterbody, mm³/N·m	$2.97 \cdot 10^{-6}$	$7.36 \cdot 10^{-6}$
Testing temperature	T = 20 °C	T = 460 °C

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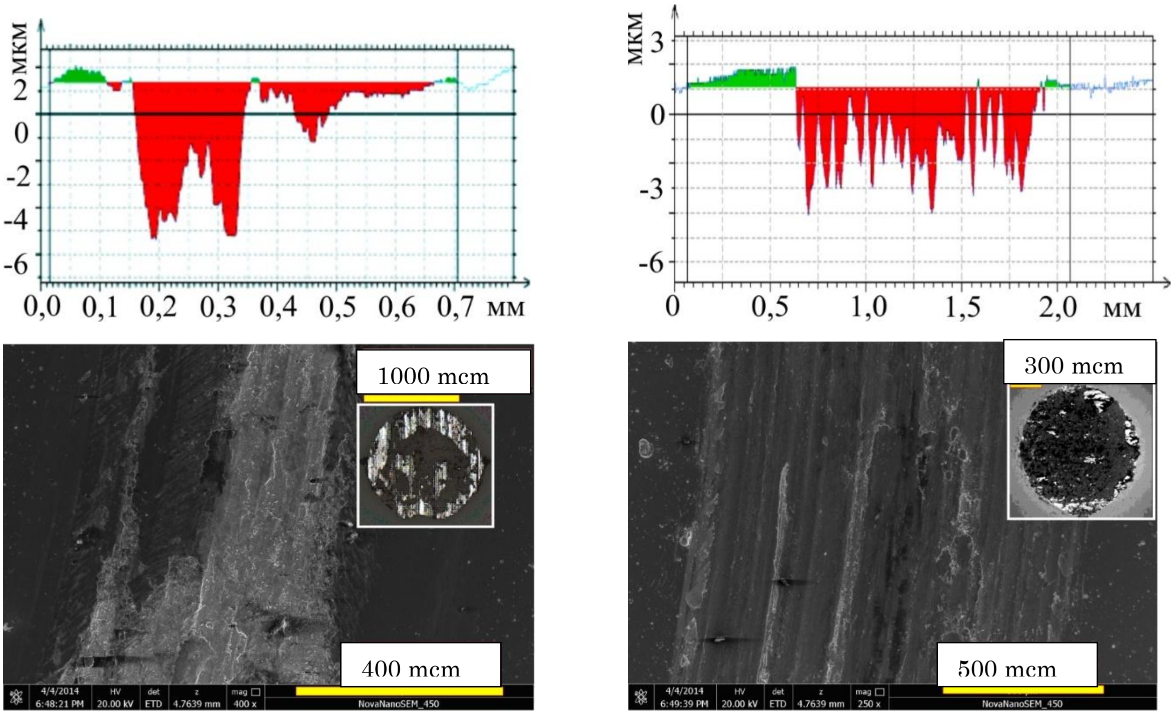
The most important parameters are critical load L_{C1}, which corresponds to the appearance of the first chevron cracks in the coating, and L_{C4} - load corresponding full abrasion coating. According to the results of the test load L_{C1}tribological coatings based on nitrides of HEA somewhat lower than that for coatings based on TiN, however, complete degradation of the coating occurs at a significantly higher load.

Tribological properties of the coatings at high temperatureshave also been studied. The test results are shown in Table 3.

Redistribution of elements within the coatings during friction also took place.

Electron microscopy image of a friction track, it profilogram and profile after the test rider for different temperatures are shown in Fig. 1.

Electron microscopic image of a friction track, it profilogram and profile after the test rider for different temperatures are shown in Fig. 2.



A B

Fig. 1 – Profilograms of friction and wear tracks of the coatings after tribological tests.

Redistribution of elements within the coatings during friction also took place.

3. CONCLUSIONS

Coatings were prepared on basis of (Ti-Al-Zr-Nb-Y)N and (Ti-Zr-Hf-V-Nb-Ta)N. The hardness of the coatings was 51.02 GPa for the coatings (Ti-Zr-Hf-V - Nb-Ta)N at a pressure of $3\cdot10^{-3}$Torr and36.36 GPa for $7\cdot10^{-4}$Torr.

The results of tribological tests at high temperature showed that at 460 °C coatings had greater wear resistance, lower coefficient of friction compared to similar tests of coatings at 20 °C. Formation of a new structural and phase state also takes place on the surfaces of the coatings..

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