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Investigation of a coatings based on intermetallics of Ti-Al system alloyed with chromium by vacuum-arc plasma

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Abstract. In the work, the influence of technological parameters on the chemical composition of coatings alloyed with Cr was studied. The mechanical properties of alloyed coatings based on intermetallics of the Ti-Al system depending on the percentage contents of Cr are studied. For to determine the coefficients of friction and wear resistance were carried out Tribological tests by the Nanovea Tribometr equipment. Based on the results of the studies, the pilot lot of the slotting tool was processed and production tests were carried out. The results of the production tests showed an increase in tool life of 10 times compared to the original tool without coating.

1. Introduction

Cutting properties of the instrument are determined by a complex of factors. That are depend on the chemical composition, structure and crystal-chemical structure of the tool material and determine the most important operational properties of the tool - microhardness, heat resistance, thermal conductivity, strength, toughness [1]. To increasing the life of tools with coated that working at shock loads is paid particular attention. The directions for improving the life-cycle of cutting tools with coating are the development and improvement of the multilayer coating design, the improvement of coating technology and the development of new coating compositions [2, 3]. So, multilayer coatings are characterized by a smooth transition of physical, mechanical and thermal properties of layers from the tool base to the upper boundary layer of coatings. Recently, coatings based on intermetallics of the Ti-Al system are of great interest, due to their high physical and mechanical properties [4, 5]. Therefore, in this paper is proposed to apply composite multilayer coatings based on intermetallics of the Ti-Al system alloyed with chromium to improve the performance properties of the grooving tools working at shock loads.

2. Experimental methods

The object of research are powder instrumental materials and vacuum ion-plasma deposition technologies for composite coatings.

The choice of the brand of high-speed steel depends on the type of tool, the chemical composition and other characteristics of the material being processed. The choice is also influenced by factors, the required productivity of machining, the use of coolant and others. High-speed steels are used for the processing of stainless, heat-resistant steels and alloys.

The scheme of the experiment for depositing high-alloy coatings is shown in figure 1. The first stage (figure 1a) – a coating is formed on the surface of the sample based on intermetallics with simultaneous deposition from two single-component cathodes of titanium and aluminum and a potential on the substrate of ~150-200 V.

In the second stage, (figure 1b), the sources of the metallic plasma with titanium and aluminum cathodes are turned off and the source with the cathode from the alloying element is turned on, while a high voltage (~ 800-1000 V) is supplied on the substrate by a high-current glow discharge source. At the second stage occurs the partial etching and doping of the intermetallic layer. After the formation of the
doped layer, the intermetallic layer is re-applied. This cycle is repeated several times (depending on the thickness of the intermetallic and alloyed layers) to ensure coating thickness in the range of 3-5 μm.

Figure 1. Schematics of the coating equipment: 1 – Chamber; 2 - Table; 3 – Al cathode; 4 – Ti cathode; 5 – Sample, 6 – Cathode of alloying material.

Figure 2. Stages of formation of high-alloy coatings based on intermetallic compounds of the Ti-Al system.

During the experiment to apply high-alloy coatings, the thickness of the intermetallic layer varied from 0.5 to 3 μm, and the exposure time of the metal plasma source to the cathode from the alloying material was 10 to 30 minutes.

3. Results and discussion
Using a scanning electron microscope, there were investigated inclined sections to determine the distribution of the chemical composition in the coatings. The microstructure of the Cr-doped coatings is shown in figure 3, and the results of measuring the chemical composition of the coating at various points indicated in figure 3, is given in table 1. The change in the chemical composition by depth is shown in figure 3.
The percentage content of chemical elements in the depth coatings is given in table 1.

| Spectrum No. | N   | Al  | Ti  | Cr  | Fe  |
|-------------|-----|-----|-----|-----|-----|
| Spectrum 1  | 53.22 | 20.36 | 26.16 | 0.27 |
| Spectrum 2  | 36.85 | 18.89 | 33.04 | 5.19 | 0.61 |
| Spectrum 3  | 48.98 | 19.33 | 29.62 | 3.42 | 0.35 |
| Spectrum 4  | 34.23 | 9.31 | 22.42 | 2.13 | 0.39 |
| Spectrum 5  | 49.18 | 17.94 | 28.29 | 2.33 | 3.75 |
| Spectrum 6  | 50.28 | 18.02 | 27.33 | 1.89 | 3.32 |
| Spectrum 7  | 36.13 | 10.44 | 30.2 | 1.34 | 18.14 |
| Spectrum 8  | | | | 5.59 | 70.11 |

The results of analysis of the chemical composition of the coating from the surface and the depth showed that depending on the technological modes of coating application, it is possible to control the volume content in the coating of the alloying element and to obtain new coatings with increased mechanical properties. Analysis of the chemical composition by depth showed that the alloying element in the range from 1 to 5% is present in all layers of the coating, which is probably due to diffusion processes.

Researches of adhesion strength, scratch resistance and the elucidation of the mechanism for the destruction of coatings were carried out using a scratch-tester (CSM Instruments). The tests were carried out under the following conditions: the load on the indenter increased from 0.3 to 30 N, the speed of the indenter \( a \) was 2 mm/min, the length of the scratch was 5 mm, the load application rate was 11.88 N/min, the frequency of the signal resolution was 60 Hz, the power of the acoustic emission signal is 9 dB. As a result of the tests, the minimum (critical) LC loads were determined - the appearance of the first crack of alloyed edges.

The results of the researches of doped coatings based on intermetallic compounds of the Ti-Al system with Cr content in the ScratchTest CSM installation are presented on figure 4.

The results of tests showed that within the limits of installed loads and the length of the scratch, the coatings do not collapse and do not exfoliate.

The results of measuring the coefficient of friction during the test are shown in figure 5.

As can be seen from figure 5, the friction coefficients of samples made of tool steel EP657 with a coating based on Ti-Al intermetallics with different content of alloying elements differ from each other, and range from 0.2 to 0.6. The best results on wear resistance and low coefficient of friction showed samples coated with an alloyed Cr ~15%.

**Figure 3.** SEM image of the inclined section of a sample with a coating based on intermetallides of the Ti-Al system alloyed with Cr < 5%.

**Table 1.** Percentage of chemical elements in the coatings.
Figure 4. The results of recording the depth of penetration of the indenter when scratching the coating of high-alloyed coatings based on intermetallic compounds Ti-Al systems with a 4% Cr content.

Figure 5. Coefficients of friction of coated samples based on intermetallic compounds of the Ti-Al alloyed with Cr system.

Based on the results of the studies, the pilot lot of the slotting tool (figure 6a) was processed and production tests were carried out.
Figure 6. Slotting tool: a) with coating alloyed by chromium; b) without coatings; c) results of compared production tests.

The results of the production tests (figure 6c) showed an increase in tool life of 10 times compared to the original tool without coating.

4. Conclusion
1. The results of analysis of the chemical composition of the coating from the surface and the depth showed that depending on the technological modes of coating application, it is possible to control the volume content in the coating of the alloying element and to obtain new coatings with increased mechanical properties.
2. The best results on wear resistance and low coefficient of friction showed samples with a coating of Cr ~15% doped,
3. The results of the production tests (figure 1c) showed an increase in the tool life of 10 times compared to the original tool without coating.

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