Investigation of physico-mechanical properties of composite coatings based on intermetallics of the Ti-Al system synthesized in the environment of various reaction gases (O, C, N)

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Abstract. The requirements for metal-cutting tools are increases. One of the most promising ways to solve the problem is the creation of new wear-resistant composite coatings for metal cutting tools. The physical and mechanical properties of coatings based on intermetallides of the Ti-Al system synthesized in the environment of oxygen by vacuum arc plasma are studied in this work. Microhardness, wear resistance, coefficient of friction, adhesion strength, scratch test of coating were studied on the obtained samples. Influence of the deposition conditions on the content of intermetallic compounds in the coating was established by X-ray diffraction methods. The results of investigations showed that the main physico-mechanical properties of coatings based on intermetallides of Ti-Al system synthesized in the environment of oxygen were increase compared to the coatings synthesized in the environment of argon or nitrogen.

1. Introduction

In the aircraft engine industry, the characteristics of the engine are constantly increased due to the stricter requirements imposed on the construction materials. To solve the tasks set, there are created new materials with improved physical and mechanical properties. In this regard, the requirements for metal cutting tools are increased, as the durability of existing tools does not provide the necessary durability. One of the most promising ways to solve these problems is the creation of new wear-resistant protective coatings for metal cutting tools. Currently, the great deal of attention is attracted to coatings based on intermetallics of the Ti-Al systems. TiAl systems with the different phase compositions are considered as promising materials for high-temperature structural ones due to their unique properties, for example: high melting point, high resistance to oxidation, increased physico-mechanical properties [1, 2]. In researches [3-5] it is pointed out that the formation of intermetallic compounds is quite promising, since intermetallides have a high hardness and, importantly, are a good barrier to diffusion processes, which should improve the efficiency of the cutting tool with coatings. In researches [6, 7] considered the kinetics of oxidation of intermetallic materials at different temperatures. At high temperature oxidation, the coating forms Al2O3 + TiO2 compounds on the inner layer and the outer layer consists of TiO2, which has good adhesion to the coating, which further improves the resistance to oxidation. In work [8] considered the process of TiAlC deposition on the silicon substrate by means of a magnetron. In research [9], the coatings were prepared by deposition from two targets of titanium and one from aluminum at different ratios of the reaction gases Ar and C2H2. The results of researches show that there are formed
Ti$_3$AlC and TiC compounds. The percentage of phase content depends on the ratio of C$_2$H$_2$ in the mixture with Ar. As the content of C increases, the size of the crystallites of the Ti$_3$AlC phase remains practically unchanged, but the size of the TiC phase crystallites decreases with increasing C content. Also, an increase of the C content forms a layer with a high content of graphite, which, as discussed earlier, reduces the hardness of the coating [9,10]. From the analysis of works devoted to this subject, it can be seen that in most of the works the emphasis is on establishing the regularities or the dependence of mechanical properties on the stoichiometric composition. However, the effect of the content of intermetallic phases in the coating of atmospheric (C, N) products is not investigated, and there are practically no operations associated with deposition of coatings in the O environment from vacuum-arc discharge plasma. The aim of this work is to study the physical and mechanical properties of coatings based on intermetallic compounds of the Ti-Al system synthesized in the environment of various reaction gases (O, C, N).

2. Methods of conducting the experiment

The coating was carried out on the facility NNV-6.6-I1. To study the physico-mechanical properties of coatings based on Ti-Al intermetallics synthesized in the environment of various reaction gases (O$_2$, C, N), in the chamber were installed 4 samples, the scheme is shown in figure 1. The first sample was placed in the center, the second was placed at the distance of 8 cm, the third – at the distance of 15 cm, the fourth – at the distance of 22 cm. In the first experiment, the rotation speed of the table was 1 rpm. Thus, coatings were deposited with the number of layers of 120 pieces.

![Figure 1. Scheme of the experiment.](image-url)

The microhardness was measured on the EMCO-Test DuraScan 50. The coefficient of friction and wear resistance were measured on a Nanovea tribometer. The thickness of the coating was measured on a CSM CALOTEST instrument. The phase composition was determined on a Shimadzu XRD-6000 X-ray diffractometer.

3. Results

The measurements showed that the thickness of the coatings is 4.5-5.5 μm. Analysis of the phase composition of the coating deposited in a nitrogen environment showed that when the distance from the table axis increases, the TiN phase content increases. At the deposition of oxygen deposited in the environment with increasing distance from the axis of the table, the phases TiO$_2$ and Al$_2$O$_3$ decrease. The
coating of the precipitated acetylene environment with an increase in the distance from the table axis increases the TiC phase content.

The measurements of the microhardness of the samples after deposition of composite coatings of the Ti-Al system deposited in the environment of various reaction gases (O, C, N) showed (figure 2) that the coatings precipitated in the environment of acetylene 1800-2300 HV have the greatest microhardness, in the environment of oxygen 1000-1400 HV, the coating of the microhardness deposited in the environment of nitrogen is 1500-1700 HV. In all coatings the microhardness increases with increasing distance from the table axis, this is explained by the increase in the coatings of solid phases.

![Figure 2. Microhardness variation chart.](image)

In figure 3, the graph of the change in wear resistance is shown. From the data obtained, it can be seen that the lowest weight loss is the coating of acetylene precipitated in the environment. In all coatings with increasing distance from the axis of the table, the wear resistance increases. In coatings deposited in nitrogen and acetylene, this is attributed to the increase in the solid phases of TiN and TiC, and the coating of oxygen-depleted in the oxygen environment by a decrease in the phases of Al₂O₃ and the increase in TiO₂.

![Figure 3. Wear resistance change chart.](image)
Figure 4 shows the graphs of the variation of the friction coefficients of the samples after deposition of composite coatings of the Ti-Al system deposited in the environment of various reaction gases (O, C, N). In all samples, the coefficient of friction is in the range 0.6-0.8.

![Figure 4](image1.png)

**Figure 4.** Coefficient of friction of composite coatings of the Ti-Al system deposited in the reaction gas environment: a) N; b) O; c) C.

To confirm the results of the studies, production tests were carried out of conical end mills with obtained coating (figure 5).

The obtained data confirm that the synthesis of coatings based on Ti-Al intermetallics in the oxygen environment increases the wear-resistance properties of coatings. The production tests showed at 12 times increase in the tool life of the tool without coating, thus the developed coatings can be recommended for hardening of metal-cutting tools.

![Figure 5](image2.png)

**Figure 5.** Conical end mills with obtained coatings based on intermetallics of the Ti-Al system synthesized in the oxygen environment by vacuum arc plasma.
4. Conclusion

From the data obtained, it can be concluded that the microhardness, wear resistance of composite coatings based on intermetallic compounds of the Ti-Al system deposited in the environment of various reaction gases improves with increasing distance from the axis of the table. This is due to the fact that with increasing distance from the axis under the plasma stream table residence time samples is reduced thereby decreasing thickness applied layers, wherein by reducing thickness applied layers of substantially all of the aluminum is in the coating reacts with titanium to form intermetallic phases at the same increases the content of pure titanium in the coating, which forms solid phases of nitrides and titanium carbides. And in the coating deposited in the environment of oxygen due to the reduction of aluminum oxide and the increase in titanium oxide. The production tests showed at 12 times increase in the tool life of the tool without coating. thus the developed coatings can be recommended for hardening of metal-cutting tools.

References

[1] Lipsitt H A. 1985 Mater. Res. Soc. Symp. Proc. 39 351
[2] Kim Y-W 1992 Acta metall. mater. 40 1121
[3] Smetkina A A, Muratova K R and Shaipova R F 2013 PNRPU Mechanics Bulletin 3 74
[4] Verhoturov A D 1983 Electrophysical and electrochemical methods of processing 1 3
[5] Kireev R M 2008 Bulletin of the Ufa State Aviation Technical University 10 96
[6] Wang F, Lou H and Wu W 1995 Oxidation of Metals 43 395
[7] Das K, Choudhury P and Das S 2002 Journal of Phase Equilibria 23 6
[8] Chaliyawala H A, Gupta G, Kumar P, Srinivas G, Siju and Barshilia H C 2015. Surface & Coatings Technology 42
[9] Zhang S, Bui X-L and Fu Y 2004 Thin Solid Films 467 261
[10] Gulbinski W, Mathur S, Shen H, Suszko T, Gilewicz A and Warcholinski B 2005 Appl. Surf. Sci. 239 302