Ti-Al system coatings synthesized in reaction gases

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Abstract. The results of the study of reaction gases influence on microhardness and adhesion properties of coatings based on the Ti-Al intermetallic system. The results of different reaction gases influence on the coatings properties are discussed. The tests result of the samples with a single-layer coating based on Ti-Al intermetallic deposited in the reaction gas environment showed that the coating deposited in the nitrogen environment has the highest elastic recovery coefficient and has approximately the same fracture onset load compared to coatings deposited in the oxygen and acetylene environments.

1. Introduction
In modern technology the proportion of newly developed special materials with special properties is increasing: high hardness, strength, corrosion resistance, heat resistance, etc. The mechanical processing of such materials by existing metal cutting tools is fraught with great difficulties [1]. High temperatures in the cutting zone cause rapid wear or tool breakage. To solve this problem various solutions are used from the development of new materials for the cutting tool to special hardening methods. One of which is the application of wear-resistant coatings [2].

Among the existing principles for creating functional coatings for various purposes the most promising is a concept of a multi-layer architecture of coatings since such coatings are able to satisfy the gamut of often conflicting requirements. For example, using this concept it is possible to create a coating structure consisting of separate layers of various functional purposes providing the maximum reduction in the wear rate of the tool under various processing conditions [3].

Currently, Ti-Al-based intermetallic-based coatings are attracting much attention, and Ti-Al systems with various phase compositions are considered promising materials for high-temperature structural materials due to their unique properties like high melting point, high oxidation resistance, increased physical-mechanical properties [4, 5]. In [6–8] it is indicated that the formation of intermetallic compounds is quite promising since intermetallic compounds have high hardness, and, importantly, is a good barrier to diffusion processes which should increase the efficiency of cutting tools with coatings. In [9, 10] the kinetics of oxidation of intermetallic materials at different temperatures is considered. During high temperature oxidation AlO3 + TiO2 compounds are formed on the coating on the inner layer and the outer layer consists of TiO2 which has good adhesion to the coating, which further improves oxidation resistance. In [11] the process of deposition of TiAlC on a silicon substrate using a magnetron was considered. In the work, coatings were obtained by precipitation from two targets of titanium and one aluminum at different ratios of the reaction gas Ar and C2H2. The results of the study showed that Ti3AlC and TiC compounds are formed. The percentage of phase content depends on the ratio of C2H2 in the mixture with Ar. As the C content increases, the size of the crystallites of the Ti3AlC phase remains almost unchanged, but the crystallite...
size of the TiC phase decreases with an increasing the C content. Also, an increase in the C content forms a layer with a high content of graphite which, as discussed earlier, reduces the hardness of the coating [12, 13].

2. Methods of conducting experiments
Coating was carried out on the modernized installation of NHV-6.6-I1. Determination of microhardness was carried out on The DuraScan instrument by the Vickers method. When measuring the diamond tip in the form of a regular tetrahedral pyramid is pressed into the test area of the coating under the action of a load P=0.05 N applied for 10 seconds. After removing the load, the diagonals d of the square imprint remaining on the coating surface were measured. Sclerometric studies were carried out on the CSM SCRATCH TEST unit. Rockwell indenter was used for scratching, which seems like a diamond tip with a radius at the top of 200mkm and an angle of 120°. The indenter is moved along the surface by 5mm with simultaneous application of force which is gradually increased in the range from 0.3 to 30 N.

3. Experimental results and discussion
The figure 1, 2 shows the results of measuring the microhardness of coatings in different count of layers and deposition in different environments.

![Figure 1](image1.png)
![Figure 2](image2.png)

Figure 1. Microhardness of the coatings during deposition in the environment: (a) – nitrogen; (b) – oxygen.

Figure 2. Microhardness of the coatings during deposition in the acetylene.
The total coating thickness was 5 µm for all samples, and the thickness of the applied layers was changed by increasing them. With the number of layers 120, the thickness of one layer was 41 nm, 360 – 13 nm, 840 – 6 nm, 1680 – 3 nm.

This changing in microhardness can be explained by the fact that with a decrease in the number of layers the grains of the coating do not have time to coagulate. It is also known that the nanometer thickness of the layers reduces the probability of dislocation formation. For different types of compounds there is no universal pattern, everyone has its own. For each type of compound there is a limit to the thickness of the layers to which the microhardness increases. As the thickness of the layers decreases further, the microhardness decreases. There are the results of scratch tests in figures 3 and 4.

![Figure 3](image1.png)

**Figure 3.** Results of scratch tests of the coating synthesized in the following environments: (a) – nitrogen; (b) – oxygen. Rd – residual depth, Pd – penetration depth.

![Figure 4](image2.png)

**Figure 4.** The results of scratch tests of the coating synthesized in acetylene environment. Rd – residual depth, Pd – penetration depth.
Table 1. Results of scratch tests.

| Coating system | The maximum depth of penetration \(h_{\text{max}}, \text{mkm}\) | The destruction beginning load \(L_c, \text{N}\) | Coefficient of elastic recovery \(\text{We, } \%\) |
|----------------|-------------------------------------------------|--------------------------------|---------------------------------|
| Ti-Al-N        | 17,3                                            | 21,5                            | 72,2                            |
| Ti-Al-O        | 15,8                                            | 21                              | 58                              |
| Ti-Al-C        | 21,4                                            | 25                              | 66,8                            |

The tests result of the samples with a single-layer coating based on Ti-Al intermetallic deposited in the reaction gas environment showed that the coating deposited in the nitrogen environment has the highest elastic recovery coefficient and has approximately the same fracture onset load compared to coatings deposited in the oxygen and acetylene environments. Meanwhile, the coatings deposited in oxygen and acetylene environments have a smaller coefficient of elastic recovery. This is because oxides and carbides have high hardness and are brittle, while nitrides are less hard but more flexible.

4. Conclusion

Thus, the studies showed the possibility of forming coatings (or layers in the coating) with various physical and mechanical properties. So, for example, during deposition of coatings in a nitrogen environment, more elastic layers are obtained than in oxygen and acetylene. Also, when the reaction gas changes, the mechanical characteristics also change, because other chemical compounds are formed in the coating. The results will be useful in the construction of multilayer coatings consisting of alternating layers with different functional layers.

References

[1] Anikin V N and Blinkov I V 2009 Application of powder materials and functional coatings 1 44
[2] Blinkov I V and Volkhonsky A O 2012 STIN 5 18
[3] Tabakov V P and Sizov S V 2017 Bulletin of MSTU "Stankin" 4 6
[4] Vereshchak A A and Vereshchak A S 2014 Technologies, materials, transport and logistics 2 109
[5] Vereshchak A S 1993 The performance of the cutting tool with wear-resistant coatings (Moscow: Mashinostroyeniye Publ.) 336
[6] Vetter J, Burgmer W, Dederichs H and Perry A 1994 Material Science Forum 163–165 527
[7] Moll E and Bergmann E 2004 Surface and Coating Technology 37 483
[8] Holleck H 2007 Surface and Coatings Technology 43–44 245
[9] Tabakov V P 1998 The performance of a cutting tool with wear-resistant coatings based on complex nitrides and titanium carbonitrides (Ulyanovsk: UISTU) 270
[10] Karabi Das, Pritha Choudhury 2002 Journal of Phase Equilibria 23 256
[11] Chaliyawala H A, Gupta G, Kumar P, Srinivas G, Siju and Barshilia H C 2015 Surface and Coatings Technology 38 397
[12] Zhang S, Bui L X and Fu Y 2004 Thin Solid Films 467 261–6