The influence of architectural coatings based on intermetallics, carbides, oxides and nitrides of the Ti-Al system on their physico-mechanical properties

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Abstract. The results of the study of the thickness influence of the layers are considered, as well as the architecture of composite coatings of the physico-mechanical properties of coatings based on the Ti-Al intermetallic system. The results of the thickness influence of the layers on the coatings properties are discussed. It has been established that in coatings of the Ti-Al system (N, O, C) under decrease in the thickness of the applied layers, an increase in the microhardness occurs due to a decrease in grain sizes, the growth of which is blocked by the application of a new coating layer.

1. Introduction
Today, a large number of scientific works are being carried out aimed at the development and research of new types of coatings, which in their operational properties would be superior to existing ones.

Among the existing principles of the creating coatings for various purposes, the concept of a multilayer composite architecture has become widespread, because these coatings are able to satisfy a range of conflicting requirements. Coatings of this architecture consists of the layers of various functional purposes. The coating can be divided into three sublayers differing in purpose: adhesive, intermediate and wear resistant. Different functional requirements are formed for each layer [1–5]:

- adhesion sublayer must have the maximum crystal-chemical similarity towards to the base material and provide strong adhesion between them [6];
- intermediate sublayer must execute various functions to reduce friction, increase the resistance to the high temperature corrosion, decrease the temperature of the substrate, increase the intensity of the diffusion between the tool and the material being processed [7];
- wear resistant sublayer must have the maximum physical and chemical passivity to the material being processed and increase the resistance to wear of the tool pads [8].

One of the ways to improve the performance of coatings is the transition to the multicomponent coatings: (Ti,Al)N, (Ti,Zr)N, (Ti,Nb)N, (Ti,Hf)N, (Ti,Mo,)N and other. Among these systems for hardening metal-cutting tools, the most widespread are coatings of the (Ti,Al)N system [9].

2. Methods of conducting experiments
The coating was carried out on a modernized installation NNV-6.6-I1 (figure 1). A multilayer structure with different layer thicknesses was obtained as a result of multiple passage of the samples near the plasma source during rotation of the carousel mechanism. Microhardness was determined on a Vickers DuraScan instrument. During the 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 sec. After removing the load, the diagonal of the square print remaining on the surface of the coating was measured. The thickness of the applied coatings was determined from the results of measuring the diameter of the hole, obtained using a CSM Calotest instrument. The phase composition was researched with a Rigaku X-ray diffractometer.

![3D model of NNV-6.6-I1.](image)

**Figure 1.** 3D model of NNV-6.6-I1.

### 3. Experimental results and discussion

The results (figures 2 and 3) show the measurement of the microhardness of the coatings with various amounts of the applied layers and during deposition in various environments. 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.

![Microhardness of the coatings during deposition in the environment: a) nitrogen; b) oxygen.](image)

**Figure 2.** Microhardness of the coatings during deposition in the environment: a) nitrogen; b) oxygen.
Figure 3. Microhardness of the coatings during deposition in the acetylene.

Such a change of the microhardness can be explained by the fact that, with a decrease in the number of layers, grains of this coating do not coagulate. It is also known [7] that at the nanometer thickness of the layers, the probability of dislocation formation decreases. For different types of compounds there is no universal pattern. For each type of compound, there is a limit to the thickness of the layers, where the microhardness increases, with a further decrease in the thickness of the layers, the microhardness decreases [8, 9].

The (figures 4 and 5) shows the results of the research of the phase composition of the coatings during the deposition of nitrogen in the environment with the different layers thickness.

It was established that with the number of layers 120 pieces – the thickness of one layer is 41 nm, and with 360 pieces – 13 nm. From the diffractograms (figures 4 and 5) it can be seen that the coating mainly consists of the phases TiAl, Ti, Al, TiN, Ti₃Al. With increasing distance from the axis of the table, the amount of the Ti phase decreases, and the content of TiAl and TiN increases. This fact is explained by the fact that with increasing distance from the axis of the table the thickness of the applied layer of titanium and aluminium decreases, while all aluminium reacts with titanium to form an intermetallic compound, and the remaining free titanium forms – TiN. When comparing the X-ray diffraction patterns of the coatings with a layer thickness of 41 nm and 13 nm (figures 4 and 5), the peak broadening and the decrease in the intensity of the TiN phase are found, which indicates a decrease in the average grain size. Microstructure of the composite coatings presented in figure 6.

According to the results of sclerometric tests of composite coatings with different architecture, it was established that under load of 30 N the destruction of the coating was not detected as the maximum penetration depth of the indentor was 7.7 μm and the thickness of the applied coating was 8–8.5 μm.

Table 1 shows the results of sclerometric tests of composite coatings.

Figure 7 shows the results of tests of the coating for adhesive strength. All of them proposed types of composite coatings have high adhesive strength. In the scratch test when the maximum load (30 N) was reached by optical microscopy, no detachments and cracking of the coatings were detected. This indicates high adhesion of the applied coating to the substrate.
Figure 4. Diffractogram of the samples with the number of layers 120 pcs. Location of samples from the axis of the table: a) center; b) $R = 80$ mm; c) $R = 150$ mm; d) $R = 220$ mm.

Figure 5. Diffractogram of the samples with the number of layers 360 pcs. Location of samples from the axis of the table: a) center; b) $R = 80$ mm; c) $R = 150$ mm; d) $R = 220$ mm.

Figure 6. Structure of the composite coatings.
Figure 7. Results of the sclerometric tests of the composite coatings: a) Ti-Al-O/-C/-N; b) Ti-Al-O/-N/-C.

Table 1. Results of sclerometric tests.

| Coating       | Maximum depth, $h_{\text{max}}$ (μm) | Load of the destruction $L_c$ (N) | Elastic recovery ratio $W_e$ (%) |
|---------------|--------------------------------------|----------------------------------|----------------------------------|
| Ti-Al-O/-C/-N | 5.5                                  | -                                | 54.5                             |
| Ti-Al-O/-N/-C | 6.5                                  | -                                | 58.4                             |
| Ti-Al-N/-O/-C | 7.7                                  | -                                | 51.8                             |
| Ti-Al-C/-O/-N | 6.5                                  | -                                | 26.1                             |

4. Conclusion

According to the results, it was found that in coatings of the Ti-Al system (N, O, C) with a decrease in the thickness of the applied layers, an increase in the microhardness occurs due to a decrease in grain sizes, the growth of which is blocked by the application of a new coating layer. An X-ray structural analysis made it possible to establish that a decrease in the thickness of the layers leads to a decrease in the average grain size. However, this pattern works for different types of compounds in different ways and to obtain accurate results they must be considered separately.

From the calculations of the coefficient of elastic recovery it can be seen that for the first three composite coatings of elastic recovery after removal of the load is $W_e = 53\%$, and for the coating with the architecture of Ti-Al-C / Ti-Al-O / Ti-Al-N $W_e = 26.1\%$. This is due to the fact that the upper layers of the coating are formed by carbides and oxides of Ti and Al, the elastic coefficient of which is small due to their high hardness and brittleness.

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