Investigation of the mechanical properties of coatings with different architecture deposited from vacuum arc plasma

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Abstract. The physical and mechanical properties of coatings with different architectures are investigated. The results of measuring the thickness of the coating, microhardness, adhesive strength are presented.

1. Introduction
To improve the operational characteristics of the cutting tools, one of the most effective methods is the application of wear-resistant coatings. Although the first wear-resistant coatings were developed in the 70s, coatings of different composition and functionality were developed. An analysis of the systematized requirements of hardening coatings allows us to note that the developed single-layer (monolayer, single-component) coatings do not satisfy all the requirements for wear-resistant coatings for metal-cutting tools.

One of the ways to improve the operational characteristics of coatings is the transition to multicomponent coatings: (Ti, Al)N, (Ti, Zr)N, (Ti, Nb)N, (Ti, Hf)N, (Ti, Mo,)N and others among these systems for hardening metal-cutting tools, the most widespread are (Ti, Al)N coating [1, 2]. However, these coatings have a serious drawback – a tendency to brittle fracture, which limits the use of this tool for intermittent cutting operations [3]. One of the possible approaches to increase the resistance to destruction of the coating is the introduction of coatings with a multilayer structure [4, 5].

Among the existing principles of creating functional coatings for various purposes, the most promising is the concept of a multi-layer architecture of coatings, since such coatings are able to satisfy a range of often conflicting requirements. For example, when using this concept, it is possible to create a coating design consisting of separate layers of various functional purposes, providing the maximum reduction in the tool wear rate under various machining conditions [6].

The aim of the work is to study the effect of layer thickness on the physic-mechanical properties during the deposition of multilayer composite coatings based on the intermetallic compound Ti-Al N.

2. Methods of conducting experiments
The coating was carried out on the mills using the upgraded installation NNV-6.6-II. Microhardness was measured on a DuraScan instrument. Determination of the microhardness of the coatings was carried out according to the Vickers method. While measuring, the diamond tip in the form of a regular tetrahedral pyramid is pressed into the investigated area of the coating under the action of a load of P = 0.05 N applied for 10 s. After removal of the load, the diagonal d of the square print remaining on the surface of the coating is measured. The thickness of the applied coatings was determined from the results of measuring the diameter of the hole. The well was obtained using a CSM Calotest instrument. The adhesive strength of the coatings was investigated on a CSM SCRATCH TEST installation. A Rockwell indenter was used for scratching the coating, which uses a diamond tip with a tip radius of 200 µm and an angle of 120°. Move the indenter along the surface by 5 mm and simultaneously applying a force that smoothly increases in the range from 0.3 to 30 N. The analysis of the chemical composition of the coating was carried out on inclined thin sections using energy dispersive analysis on a scanning electron microscope model JSM-6490LV.
3. Experimental results

In this work, we investigated 4 types of architecture of coatings (figure 1). The structure of the coatings are presented on figure 1, 2. Due to the small thickness of layers in moduls (as presented on scheme of coatings figure 1), boundaries between is not visible on sample A (figure 2(a)). On samples B, C, D, when the thickness of the layers is more than 100 nm, the boundaries between Ti-Al (intermetallics layers) and Ti-Al-N are clearly visible (figures 2(b), 3(a), (b)).

![Figure 1. Scheme of coatings architecture.](image1)

![Figure 2. Structure of samples with a multilayer composite coating based on intermetallic compounds of the Ti-Al system: (a) – sample A; (b) – sample B.](image2)

![Figure 3. Structure of samples with a multilayer composite coating based on intermetallic compounds of the Ti-Al system: (a) – sample C; (b) – sample D.](image3)

Study of the coatings thickness showed, that:

- the thickness of each layer for sample A (the number of modules 30, the number of layers 60): $Z = 0.0377 \, \mu m$;
- the total thickness of the coating for sample A is: $Z_{\text{total}} = 2.262$ microns.
- thickness of each layer for sample B (number of modules 6, number of layers 12): $Z \approx 0.176 \, \mu m$;
- ...
the total thickness of the coating for the sample is: \( Z_{\text{total}} = 2.112 \) microns.

the thickness of each layer for sample C (gradient coating, the number of modules 8, the number of layers 16): \( Z_1 = 0.041 \) microns; \( Z_2 = 0.045 \) microns; \( Z_3 = 0.082 \) \( \mu m \); \( Z_4 = 0.086 \) \( \mu m \); \( Z_5 = 0.123 \) microns; \( Z_6 = 0.118 \) microns; \( Z_7 = 0.164 \) \( \mu m \); \( Z_8 = 0.169 \) \( \mu m \); \( Z_9 = 0.205 \) \( \mu m \); \( Z_{10} = 0.199 \) \( \mu m \); \( Z_{11} = 0.246 \) microns; \( Z_{12} = 0.246 \) microns; \( Z_{13} = 0.287 \) \( \mu m \); \( Z_{14} = 0.171 \) \( \mu m \); \( Z_{15} = 0.328 \) microns; \( Z_{16} = 0.331 \) \( \mu m \);

– the total thickness of the coating for sample C is: \( Z_{\text{total}} = 3.157 \) \( \mu m \).

– the thickness of each layer for sample D (the number of modules 4, the number of layers 8): \( Z_1 = 0.479 \) \( \mu m \); the total thickness of the coating for sample D is: \( Z = 3.835 \) \( \mu m \)

Measurement of microhardness showed that sample A is \( HV_{0.050} = 604 \), sample B is \( HV_{0.050} = 1200 \), sample C is \( HV_{0.050} = 1573 \), sample D is \( HV_{0.050} = 2285 \).

The scratch tests results of samples with a composite coating based on intermetallic compounds of the Ti-Al system presented on figure 4 and 5.

![Figure 4](image.png)

(a) (b)

Figure 4. The results of scratch tests of samples with a composite coating based on intermetallic compounds of the Ti-Al system: (a) – sample A; (b) – sample B.

![Figure 5](image.png)

(a) (b)

Figure 5. The results of scratch tests of samples with a composite coating based on intermetallic compounds of the Ti-Al system: (a) – sample C; (b) – sample D.

Results of registration maximal depth of penetration, critical loads and calculation of elastic restoration coefficient, Stresses acting on the indenter presented in table 1.

The test results of samples with a multilayer composite coating based on intermetallic compounds of the Ti-Al system showed that the indenter has the greatest penetration depth of sample A is 13 microns and the smallest sample is D. And the elastic recovery coefficient of sample D is larger than that of sample A.

From the obtained results obviously, that an increase in the number of layers and a decrease in their thickness leads to the fact that there is no area of elastic-plastic deformation in the coating. When
reducing the number of layers and increasing their thickness leads to the fact that the coating contains an area of elastic-plastic deformation.

Table 1. Measurement results of adhesion strength.

| Sample | Max depth $h_{max}$, μm | Critical loads, $L_c$, N | Elastic restoration coefficient, $K$, % | Stresses acting on the indenter, $\sigma_{ind}$, MPa |
|--------|--------------------------|--------------------------|----------------------------------------|----------------------------------------|
| A      | 13                       | 29.59                    | 53                                     | 1900                                   |
| B      | 12                       | 24.69                    | 22                                     | 1744                                   |
| C      | 7                        | 19.5                     | 47                                     | 2256                                   |
| D      | 8                        | 19.825                   | 70                                     | 6115                                   |

In samples B and C, measurements of the depth of deformation and measurements after elastic recovery are almost the same. Consequently, there is no area of elastic-plastic deformation. Analysis of the test results showed that in samples B and C, the adhesion strength between the layers is satisfactory (the destruction of individual layers of the coating near the scratch is noticeable), while the coating does not move away from the substrate (does not peel off).

Analysis of the results showed that the destruction of the coating exfoliation does not occur.

4. Conclusion

Thus, as a result of measuring the microhardness of the coatings showed that the sample: A $HV_{0.050} = 604$; In $HV_{0.050} = 1200$; With $HV_{0.050} = 1573$; D $HV_{0.050} = 2285$. The results of scratch tests showed that composite coatings based on the Ti-Al intermetallic compound under loads up to 30N do not destroy the coating. The coating with the largest number of layers lacks the elastic-plastic deformation region, and the coating with the smallest number of layers after measuring the depth of deformation and measuring the depth of scratching after elastic recovery showed the presence of an area of elastic-plastic deformation.

References

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