Composite nanostructured wear-resistant coatings for high-speed cutting processing

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Abstract. The wear resistance of coatings, chip formation conditions, microstructure and chip shrinkage, the angle of the conventional shear plane were studied. The data on the characteristics of the surface structure and the adhesion of such coatings, etc., were studied and analyzed. It is shown that the main reason for high wear resistance of these coatings during high-speed processing is the formation of thin protective oxide films on the surface of a tool made from aluminum oxide with a complex amorphous-crystalline structure. Such protective films significantly improve the friction and wear characteristics of coated tools: the adhesion of the tool surface to the workpiece decreases and the thermal intensity of the cutting zone decreases due to the intense heat removal into the chips.

1. Introduction
Increasing the wear resistance of the cutting tool can now be achieved through the use of coatings made of titanium and aluminum nitrides (Ti, Al) N. These coatings are characterized by unique combinations of properties: high hardness at elevated temperatures in the contact zone together with thermal and chemical stability and low thermal conductivity. An important advantage (TiAl) N coatings is their tendency to oxidation and to the formation of relatively stable surface oxide films [1–6]. Further increase in wear resistance (TiAl) N coatings during cutting can be obtained by adjusting the grinding of the grain to the nanoscale level (grain size less than 100 nm). This can be done by doping (TiAl) N coatings onto the tool material with advanced advanced methods (for example, magnetic arc filtration (MAF), etc.) [3, 5, 6].

Obviously, a study of the mechanism of tribo-oxidation coating during cutting will most fully utilize the reserves to increase the wear resistance of such coatings. It can be assumed that the actual task in this case is the formation in the cutting zone of a thermodynamically stable and constant aluminum oxide film with high tribological properties [3, 5–8].

The purpose of this work is to study the friction and wear processes of cutting tools with multilayer composite coatings and to determine the influence of nanocrystalline structure in MAF coatings on these processes under high-speed processing conditions.

2. Experimental research
Various coatings were investigated, including: conventional monolayer, multilayer and nanostructured (improved).

Improved coatings were applied by filtration with a magnetic arc on an installation of the type NNV 6.6 - 11. These installations for the physical deposition of coatings (FOP) have up to three removable targets, the so-called modules. The temperature regime on the surface of the sample during
coating was monitored with an optical pyrometer. The substrate was heated to the coating deposition temperature by means of argon ions during their deposition at a bias voltage of the substrate at 1 kV. When the desired substrate temperature was reached, the amount of bias voltage was lowered, and nitrogen was applied to the chamber for coating (TiAl) N.

Such a scheme makes it possible to influence the physicochemical and plasmochemical processes when applying heat-resistant coatings by increasing the ionization rate of both metals and chemically active gases. The effectiveness of MDF technology to prevent coating during the "droplet" phase is well known. But there is another advantage of MDF, which is important for the application of hard coatings. Due to the high rate of plasma ionization in the coating chamber chamber and the relatively low coating speed, the temperature at the beginning of the crystallization of MAF coatings is also low.

The coating conditions are close to the heating of the nanoscale, when the kinetic energy of the bombarding ions is transferred to very small regions of actively growing thin layers of coating, which then quickly move it deep into the substrate material. Thus, the cooling rate during a sufficiently nonequilibrium MDF precipitation process is high. Ion bombardment with low energy of growing films can limit the growth of grains and promote the formation of nanocrystalline layers. So nanocrystalline structures of wear-resistant coatings on the cutting tool are formed (especially for high-speed processing applications).

In the paper, an experimental method was used to estimate the tribotechnical parameters ($\tau_{nn}$, $p_{nn}$, $\tau_{nn}/p_{nn}$) [4]. This method is based on the physical model (figure 1), which in the first approximation reflects the real conditions of friction and wear on the local contact. According to this model, the spherical indenter 2 (simulating a single roughness of the contact spot of rubbing solids), squeezed by two plane-parallel samples 1 (with high accuracy and cleanliness of the contacting surfaces) rotates under load around its own axis. The force F expended on the rotation of the indenter and applied to the cable 3 laid in the groove of the disc 4 is mainly related to the shear strength $\tau_{nn}$ of the adhesive bonds.

![Figure 1. Frictional contact model.](image)

To use this method, special equipment was developed and created [3], which makes it possible to produce an electric contact heating (via bus bars 5, insulated from the body with gaskets 6, figure 1), in order to use this method, and to provide a characteristic temperature distribution for the tribococontact in the near-surface layer. Tare methods have also been developed for controlling the temperature of the contact, as well as obtaining the dependence of the value of $\tau_{nn}$ on the normal stresses $p_{nn}$ at different contact temperatures.

Indenters are made of tool material (TT8K6) without coating and with coatings (TiN, (TiCr) N, (TiAl) N, (AlTi) N, (TiAlCr) N, (AlTiCr) N with different percentages of each of the coating elements
up to 15 μm). Samples of the counterbody (processed material) were made of steel 40X (HB 280–290). The studies were carried out using a 5% water-based emulsion and without coolant.

Full-scale tests of the cutting tool were made during milling and turning. The milling was carried out on the vertical milling machine HECKERT with end mills (d = 12 mm, z = 4) and tool milling cutters (d = 90 mm, z = 1) with interchangeable tetrahedral carbide plates TT8K6. The investigation was carried out under different milling conditions (n = 500–900 rev/min, S = 60-100 mm / min, t = 1–3 mm, b = 4–10 mm); longitudinal turning was performed at V = 150–450 m / min, S = 0.11 mm / rev, t = 0.5 mm. The coatings for the tools were applied by various companies (Balzers, Caromant, Carbide, Rimet) using factory technologies. The turning of the blanks was carried out on the lathe-cutting machine 16K20 with non-re-sharpening carbide plates TT8K6 γ = 0° α = 10°; φ = φ1 = 45°; r = 0.5 mm) with all the above coatings.

In actual experiments, during milling and turning, tool wear on the back surface, cutting temperature, cutting forces and roughness of the treated surface were investigated. Some of the results obtained are shown in figures 2–6.

Figure 2. The effect of temperature on the characteristics of the adhesive interaction of the pair steel 40X - indenter TT8K6 + coating ((TiCr) N, (TiAl) N, (AlTi) N).
3. Conclusions

1. Tribotechnical characteristics of wear-resistant coatings, investigated with the aid of an adhesiometer in full-scale tests, correlate with the wear resistance of the tool and this indicates the possibility of using inexpensive and labor-intensive tribotechnical studies for a qualitative rapid assessment of the wear resistance of coatings (figure 2);

2. The use of wear-resistant coatings ((TiAl) N, (AlTi) N) leads to a decrease in the intensity and magnitude of run-in and normal wear and tear, and increases the wear resistance of the cutters and the
period of their durability by an average of 2 to 2.5 times reduces the level of temperature-force loading of the cutting zone (figures 4, 5) and the roughness of the machined part surface (figure 6).

3. Two major improvements in the characteristics of the coating surfaces can be attributed to the magnetic filtering method. The first improvement is due to the complete or partial filtration of the "droplet" phase. As a result, a surface with a lower roughness is formed, which affects the adhesion (adhesion) of the material being processed to the tool surface. The second improvement is associated with a decrease in the frictional forces and wear of the filtered coatings.

4. The main advantage of MDF coatings for use in high-speed processing is a significant grinding of grains (TiAl) N coatings, which leads to the formation of a surface layer of the nanoscale (grain size about 60–80 nm). It is shown that the main cause of high wear resistance of filtered coatings under high-speed processing is the formation of thin protective oxide films on the surface of the cutting tool (as a result of self-organization phenomenon).

5. The formation of alumina films on the surface of the tool significantly changes the heat fluxes and the heat removal into the chips. The chip formation conditions (chip shrinkage ratio and the angle of the conventional shear plane), as well as the coefficient of friction along the front surface of the cutting tool, measured during the cutting, also show a significant improvement in the tribotechnical parameters for instruments with filtered coatings.

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