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Influence of Complex Treatment on the Cutting Ability of Solid-Molding Plates

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ABSTRACT: One of the promising areas of tool hardening from high-speed steels is the creation of layered structures on their surface, providing a gradient distribution of physicochemical properties between the wear-resistant coating and the base material.

KEY WORDS: surface layer, heat-resistant, nickel alloy, high-speed steel, coating, nano-composite coating, ion-plasma treatment,

I.INTRODUCTION

Every year in the modern automated machine-building industry, the introduction of innovative technologies that allow to significantly increase the productivity of machining plays an increasingly important role.

The cutting tool is one of the bottlenecks in technological systems of automated production. Research and production experience shows that the largest share of failures of metalworking technological systems is associated with failures of cutting tools — catastrophic wear and tear. Due to the fact that the failure of the tool usually occurs much earlier than the wear of parts and components of the process equipment (machines, devices, etc.), it is because of the tool that the preventive system as a whole will fail. When processing such alloys, due to the characteristics of their physic mechanical properties and, of course, cutting conditions, a significant amount of heat is released, the temperature level in the zone of contact between the tool and the workpiece sharply increases, which contributes to the activation of adhesive and diffusion processes and intensifies the wear of working surfaces of tools . As a result, the use of hard alloys as a tool material is not always possible, and the use of traditional high-speed tools is justified only at low cutting speeds [1]. The use of modern high-speed steels with better heat resistance, obtained by powder metallurgy, partially solves the problem of intensification of processing, however, the introduction of new structural materials with increased heat resistance inevitably places additional demands on the tool material.

Today, a tool made of high-speed steels with various versions of wear-resistant coatings based on nitrides of refractory metals obtained by the method of physical deposition of a substance is widely used. These coatings have high microhardness, low friction coefficient and inertness with respect to the material being processed [2]. However, the practice of operating a high-speed tool with a coating shows that the effectiveness of such a tool is not the same at different technological operations of cutting. The successful implementation of wear-resistant coatings is hampered by the fact that, due to the large difference in physical and mechanical properties between the substrate and the coating, an intensive destruction of the working surfaces of the tool is often observed during plastic deformation of the substrate under high load. This disadvantage can be dealt with by forming a kind of transition layer, which can be obtained, for example, with the help of chemical-heat treatment that precedes the process of applying a wear-resistant coating, in particular, ion nitriding is widely used [3]. This process is called the combined ion-plasma treatment. Its use has made it possible to raise the durability of a high-speed tool several times as compared with a tool with a PVD coating [4].

Nevertheless, it should be noted that the iron nitrides formed during ion nitriding are not thermostable and, in order to prevent their thermochemical dissociation, it is necessary to limit the temperature when applying a wear-resistant coating. It is possible to increase the thermal stability of the surface layer of the tool directly adjacent to the coating due to the additional surface alloying of nitrated high-speed steel.

The process is based on the task of reliable integration into the surface layer of the instrument of synthesized nitride compounds between metals of IV-V groups and nitrogen introduced into steel during preliminary chemical-thermal treatment. The metal is applied as a coating, for example using magnetron sputtering. Then an exothermic chemical

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reaction is initiated, carried out in the thermal explosion mode, by pulsed heating of the surface of the product [5]. In this case, it is possible to use a rather large spectrum of substances chemically active at high temperature as reagents [6]. At the same time, other substances can be used as fillers or diluents, including those participating in the synthesis, as by-products of the reaction. Here, it is not so much the chemical nature of the reagents, as the magnitude of the thermal effect of the reaction, the conditions of heat transfer and the kinetics of phase and structural transformations.

In this article, we consider some compositions that are interesting from our point of view, modified surface layers with the use of which it is realistic to obtain in this way to increase tool life from relatively low-alloyed high-speed steel P6M5 (M2) of average heat resistance, in our case, with longitudinal turning of heat-resistant nickel alloy (NiCr20TiAl).

HSS cutting tool.

In a cutting tool for turning operations are used indexable cutting inserts (insert) a special design with various embodiments of the combined surface ion-plasma treatment (Fig.1).

Fig.1. Strengthened cutting plates from steel R6M5 (M2).

The plates were made of high-speed steel R6M5 (M2) and subjected to standard heat treatment in salt baths.

Wear resistant coating nATCRo[3] with microhardnessHV_{50} = 345 MPaapplied on the installation ofπ311 companyPlatit. This coating is a combination of an adhesion layer of (CrTi) N composition, a gradient (TiAl) N coating and a multilayer Nano composite coating. (nc-AlTiCrN/a-Si_3N_4). A two-phase nanostructured coating layer with an AlTiCrN grain size of up to 5 nm, at the boundaries of which the amorphous Si_3N_4 phase is located, inhibits the coagulation of the grains of the main phase, both during coating deposition and instrument operation. The interphase boundaries, which are a zone of intense energy dissipation, deflect the resulting cracks from the direction of propagation, partially or completely inhibit them [8].

II. SIGNIFICANCE OF THE SYSTEM

Part of the samples before applying the wear-resistant coating was subjected to the operation of doping the surface layer. The processing was carried out in the “RITM-SP” installation, which is a combination of the source of low-energy high-current electron beams (RHEB) “RITM”, and two magnetron sputtering systems on a single vacuum chamber. The installation allows the deposition of films on the surface of the desired product and the subsequent liquid-phase mixing of the film and substrate materials with an intense pulsed electron beam [9]. The generation of the NECS involves the emission of electrons, the formation of a beam in a plasma filled diode, and its transport in the plasma channel. The use of such a generation scheme makes it possible to obtain a beam of microsecond (about 5 μs) duration with a current density of up to 105 A / cm2 with an accelerating voltage of 15 to 30 kV. The area of one-time processing is about 50 cm2.

III. LITERATURE SURVEY

Applying a thin layer of nitride-forming elements to the surface of the tool (we used targets made of Zr and $Nb_{70}Hf_{22}Ti_8$ alloy) allows us to dye the unstable iron nitrides of nitrated high-speed steel as donors of atoms due to doping with exothermic reaction between the metal of the film and the electron beam. multiphase structure. The outer layer is enriched with refractory nitride phases of the MN type, which, due to the extremely high cooling rate, in the final product remain shallow and homogeneously distributed.

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The depth of the surface layer, in which it is possible to obtain a modified structure in steel, is from 2 to 10 microns depending on the alloying composition.

Micro alloying of pre-nitrated high speed steel with zirconium and niobium alloy

Figure 2a demonstrates the effect of a series of pulses from an HECS with an energy density of 4.5 J / cm^2 and a duration of 5 μs on the surface of a nitrated specimen of steel R6M5. The thermal effect of the electron beam is enough for the upper metal layer not only to melt, but also to actively evaporate, exposing the carbide component. The irradiation of NSEL causes dissociation of iron nitrides, especially the ε-phase, a large amount of residual austenite is formed on the surface (Fig. 3b).

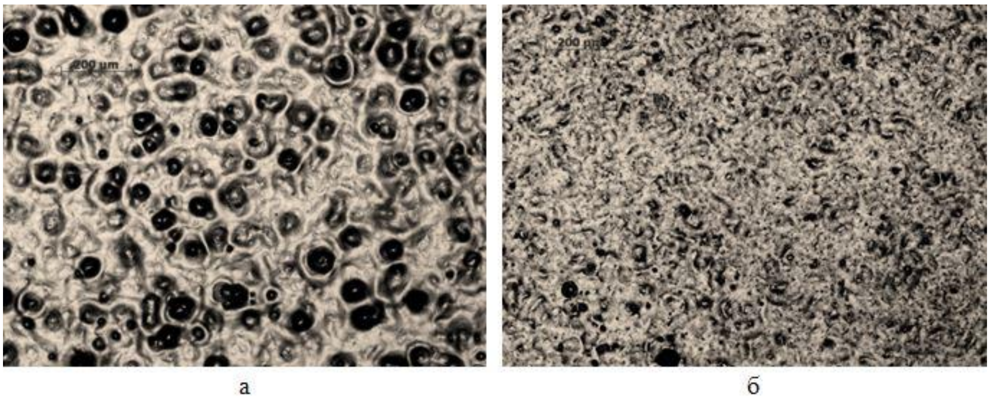


Fig.2 a) Structure of the surface of nitrided high-speed steel R6M5 after exposure to NESP, b) Same after electron-beam alloying with zirconium.

After applying a thin film about 0.2 μm thick (in this case Zr) to the samples using a magnetron nebulizer and subsequent electron beam exposure, it is possible to initiate the exothermic chemical reactions of the formation of the nitride phase. Due to the formation on the surface of a refractory nitride film, metal evaporation is significantly reduced, and the structure becomes fine (Fig. 2b). The formation of the nitride phase is confirmed by x-ray diffraction data (Fig. 3c). It should be noted that in the latter case, the content of residual austenite in the subsurface layer is noticeably less.

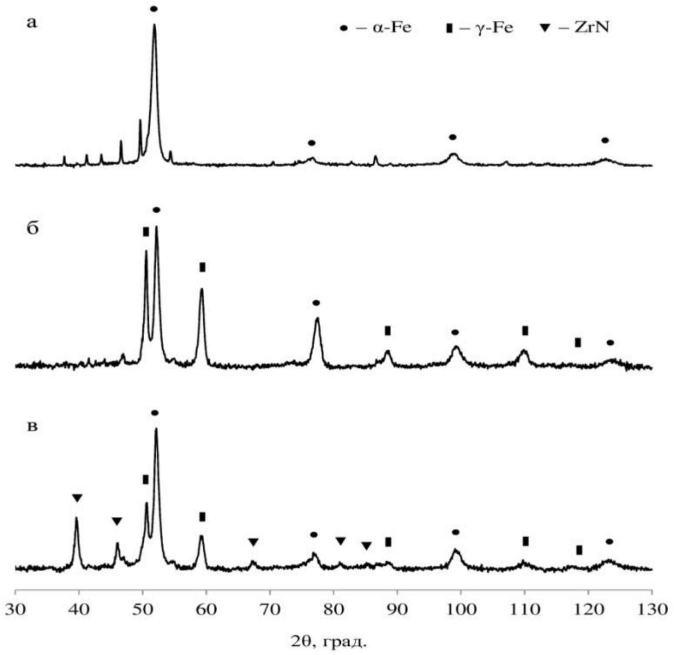
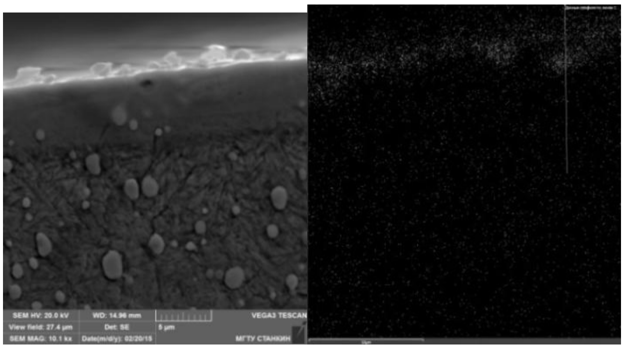


Fig.3. a) A diffractogram (CoCα) from the surface of a sample of nitrided steel R6M5, b) the same after exposure to NESP, c) the same after deposition of Zr film on the surface before irradiation.

At the same time, in our case, we are dealing with strain hardening caused by the passage of an elastic wave, which is generated by pulsed electron beam exposure. But due to the short duration of the process and the thermal inertia of the metal, the heating due to compression and internal friction is not likely to be a physical factor determining the behavior of the substance in such conditions. The main role in this case should be played by the mechanical activation of the physicochemical processes that occur quickly in the substance, which inevitably take place both in the liquid and in the solid phases. The appearance of the melt leads to a sharp increase in the interfacial surface and an increase in the rate of the reaction of formation of nitrides, due to the additional release of energy during the exothermic reaction.

Multiple initiation of the process practically does not change the original microstructure. In order to complete the transformation, as a rule, a series of five to six pulses is enough.

The distribution of zirconium near the surface is shown in Fig.4b. It can be seen from the figure that Zr is found in the surface layer with a thickness of about 2 μm. But the thickness of the zone of influence of the processing by a pulsed electron beam is 5-6 microns (Fig. 4a). The large energy density and short interaction time give reason to expect the formation of rapidly quenched layers with a more uniform and finely dispersed structure and an improvement in the performance characteristics of the surface layer due to secondary quenching with the formation of a martensite-carbide structure with high hardness. In addition, during the subsequent application of a wear-resistant coating, the tool is subjected to at least two hours of tempering at a temperature of about 450 ° C, which reduces the content of residual austenite in the modified layer and contributes to the removal of residual stresses.



a b

Fig.4. The surface layer of high-speed steel P6M5 modified by zirconium nitride. a) SEM image of pickled section, b) zirconium distribution map of section.

A similar picture can be observed upon irradiation of a thin film of niobium-hafnium alloy deposited on the metal surface. On the diffractogram (Fig. 4) there appear reflections corresponding to the phase $Nb_4N_3(\gamma)$ (*tI16*, a = 0.4385 nm, c = 0.4320 nm) based on niobium. The nitride lattice periods agree well with reference data; apparently, other elements dissolved in nitride do not significantly affect its crystal structure.

Figure 5 shows the SEM image of a thin section from a sample of steel R6M5 after micro-alloying with a niobium-hafnium alloy, on which a wear-resistant coating was applied. In contrast to the case of doping with zirconium, niobium and hafnium are distributed over the entire depth of the electron beam-modified surface layer to a depth of 10 μm (Fig. 5b), which can be attributed to the fact that the mixing of metals in the melting zone in the case of niobium alloy occurs at a higher temperature It is in our case, apparently, will be limited by the evaporation temperature.

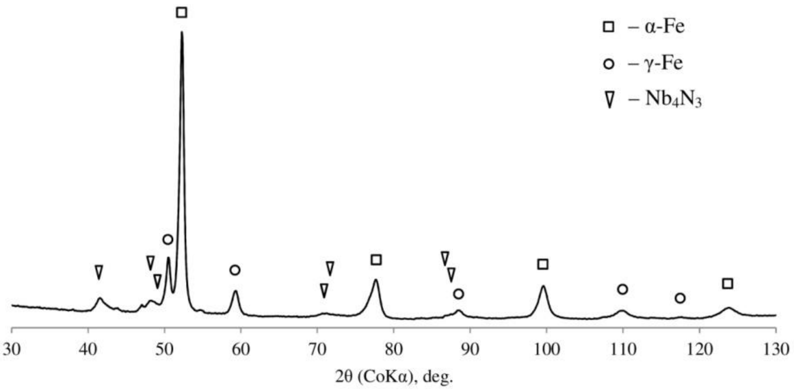


Fig.5 Diffraction pattern (CoCα) from the surface of the sample of nitrided steel R6M5 after coating the surface of the film of NbHfTi alloy before irradiation

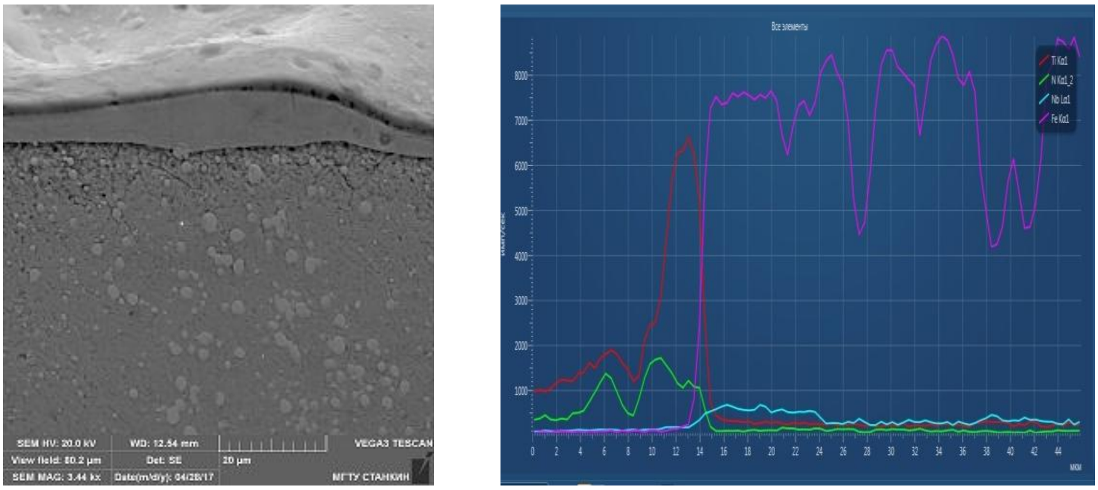


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Fig6 Sample of R6M5 steel after combined surface treatment: ion nitriding + microalloying of $Nb_{70}Hf_{22}Ti_8$ alloys + wear-resistant $nATCRo^3$ coating, a) SEM image, b) distribution of some chemical elements in the surface layer.

Measurement of micro hardness on the transverse section shows the presence of a hardened zone up to 80 µm in depth (Fig. 6). At the same time, at a depth of up to 50 µm, the micro hardness of HV25 exceeds the micro hardness of the substrate by at least 15 MPa and is about 100 MPa. An increase in micro hardness can be attributed to the effect of residual tensile stresses generated during pulsed heating.

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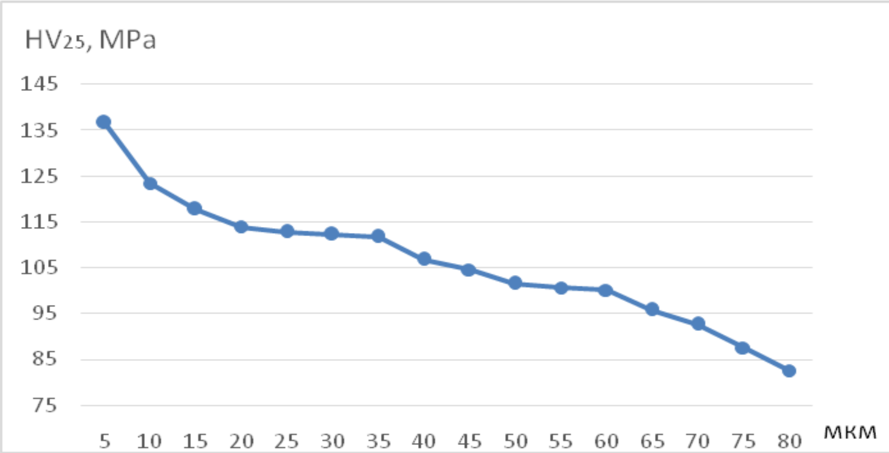


Fig.6. Change of micro hardness over the depth of the hardened zone on the transverse section with a sample of steel R6M5 after the combined treatment.

The effect of complex surface treatment on the cutting ability of the tool

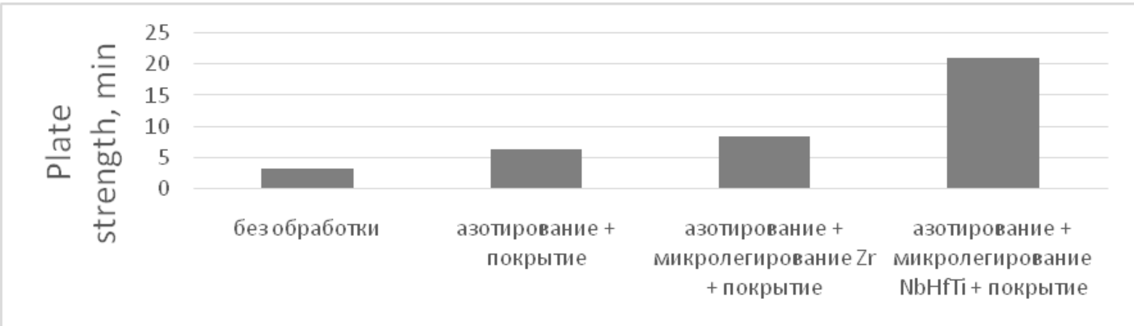
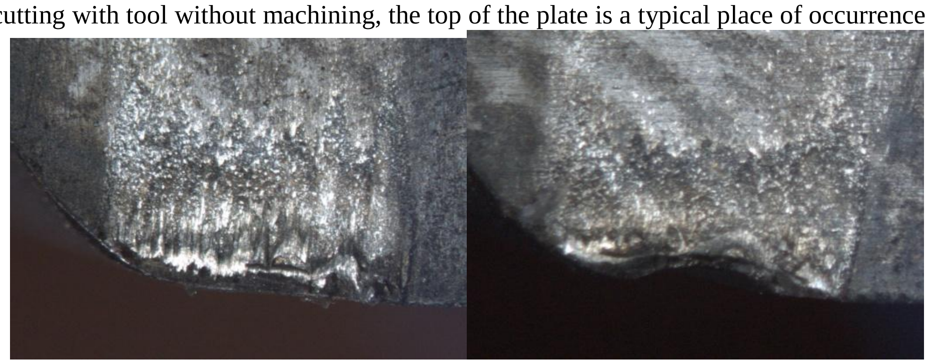


Fig.6 Durability of plates with a combined surface treatment (min).

IV. METHODOLOGY

Studies on the wear of plates made of steel R6M5 have shown that electron beam doping in combination with the operation of applying a wear-resistant coating can have a significant impact on the process of tool wear. The resistance tests were carried out on the operation of turning a high-temperature alloy ($NiCr_{20}TiAl$) at a cutting speed v = 10 m / min, feeding s = 0.115 mm / rev, cutting depth t = 1 mm. As a failure criterion, the value of wear on the back surface of 0.3 mm was chosen. The test results are shown in Fig.6.

When cutting with tool without machining, the top of the plate is a typical place of occurrence of wear (Fig. 7).



а б

Fig.7. Wear plate of steel R6M5 when turning alloy (heat-resistant steel, v = 10m / min, s = 0.115 mm / rev, t = 1mm, a) after 1 min., B) after 3 min of cutting.

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It is known that a gradual increase in temperature in the zone of direct contact leads to catastrophic wear on the back surface, which over time reaches values at which irreversible processes begin in high-speed steel. Slow backing wear on the tool with a combined treatment, which is ion nitriding to a depth of about 40 microns and the subsequent application of a wear-resistant coating, can be explained by the fact that the surface layer created under the coating has increased hardness combined with higher heat resistance and better resists micro plastic deformations (fig.8). The dimensional stability of the cutting wedge increases, which reduces the level of internal stresses in the wear-resistant coating. This, apparently, and slows down the processes of softening at the rear surface.

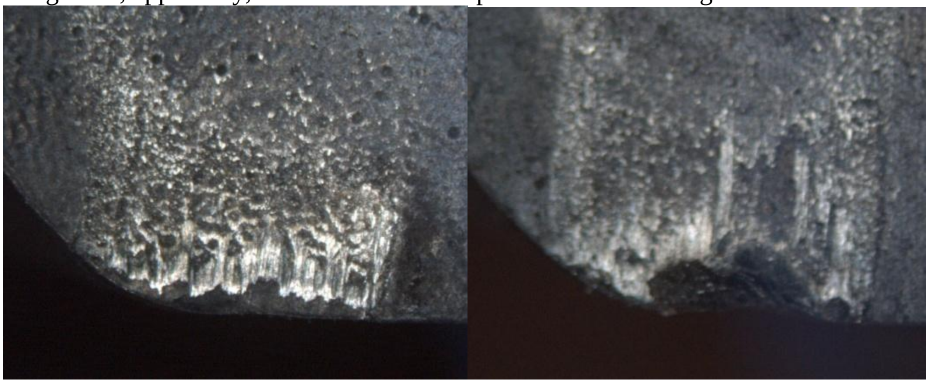

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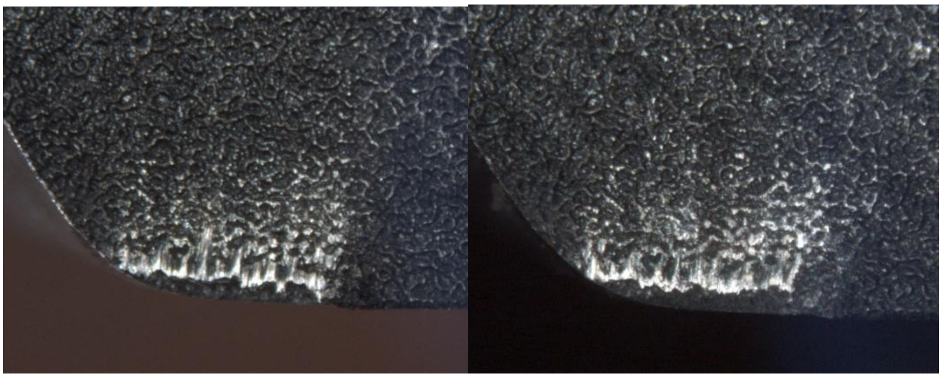
Fig.8. Wear plate of steel R6M5 (nitriding + coating) when turning alloy heat-resistant steel, v = 10m/min, s = 0.115 nn/rev, t=1mm, a) after 3 min., b) aftere 6 min cutting.

For tools with a wear-resistant coating and pretreatment, which includes ion nitriding and surface doping, there is a noticeable blocking of the development of wear at the top, which significantly slows down the onset of the stage of catastrophic wear (Fig. 9). This can be attributed to the fact that the near-surface modified layer possesses chemical passivity and reduces the adhesive interaction with the material being processed. Nitrides Zr, Ti, Nb and Hf form stable and durable oxides. As a result, the characteristics of contact processes change, which significantly reduces the power of the source of heat release near the cutting tool wedge.

V. EXPERIMENTAL RESULTS

For a coated tool without micro-doping, after the base is exposed, the friction conditions on the back surface are more and more close to those characteristic of an uncoated tool. In a tool with complex processing, even after a coating breakthrough, the modified layer continues to perform its protective functions, which is reflected in the pattern of tool wear. Comprehensive processing significantly inhibits the formation of wear holes on the front surface.

It should be noted that the micro-alloying of steel with a niobium-hafnium alloy gave a much greater effect than the micro-alloying with zirconium. This confirms that the hardening of steel in our case is achieved to a greater extent due to the alloying of the surface layer, in particular, with niobium and hafnium nitrides, and not only due to the pulsed surface electron-beam hardening of high-speed steel.



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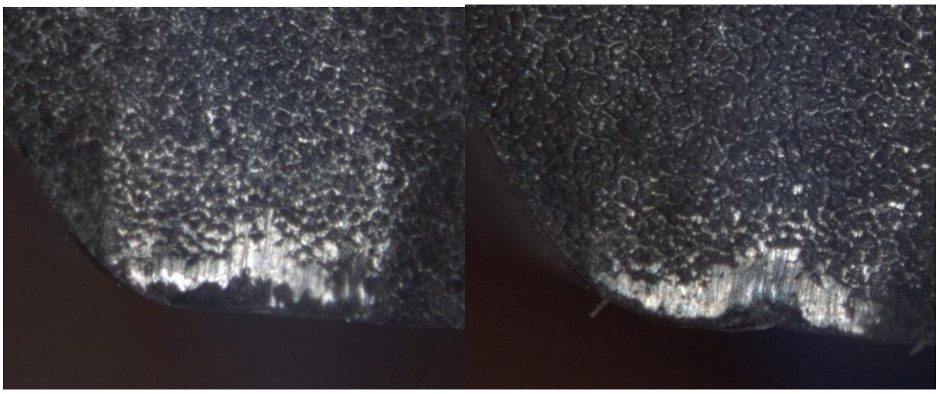

vg

Fig.9. Wear plate of steel R6M5 (nitriding + micro alloying alloy $Nb_{70}Hf_{22}Ti_8$ + coating) when turning alloy heat-resistant steel, v = 10m/min, s = 0.115 mm/revб, t=1mm, a) after 6 min., b) after 10 min. v) after 15 min. g) after 21 minof cutting.

It should be noted that the tool processing time for surface doping is about 15 minutes without taking into account the vacuum time of the working chamber. This determines the low cost of the process and allows you to ensure a full load of industrial machines for applying wear-resistant coatings of medium size with a working cycle of 4 to 5 hours using a single unit for surface doping.

VI. CONCLUSION AND FUTURE WORK

The experimental results obtained indicate that it is possible to obtain layers modified with surface alloying on the surface of a tool made of high-speed steel. Such layers were obtained by initiating exothermic chemical reactions between the pre-nitrated base and the thin film deposited on it. At the same time, the formation of new phase components was detected in the reaction products.

The formation of the structure in the surface layer of the material is largely due to the pulsed nature of the impact in the microsecond range. Here, the main factors of the surface doping process are the electron beam energy, which depends on the accelerating voltage and the thickness of the thin metal film deposited on the object's surface. The dependence of the thickness of the modified layer on the accelerating voltage has a pronounced extreme character. Radiation with insufficient energy in the beam is unable to initiate the process, and its excess leads to the evaporation of most of the film. Processing should be carried out in such a way that the coating thickness is approximately half the electron penetration depth into the substrate material, that is, in our case, about 200 nm.

Microalloying finds its application. In particular, such treatment, recommended before applying a wear-resistant coating, allows you to influence the wear processes of not only high-speed, but also carbide cutting tools, which can significantly increase its service life. [10].

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