Increasing the surface stability of the cutting tool through complex machining

Sergey Fedorov¹, Jamshid Sharipov² and Akbar Abrorov²

¹Federal State Budgetary Educational Institution of Higher Education "Moscow State Technological University" STANKIN "", Moscow, Russia
²Bukhara Engineering Technological Institute, Bukhara, Uzbekistan.

E-mail: sv.fedorov@icloud.com

Abstract. Nowadays, the application of multilayer coatings is widely used to increase the abrasion resistance of cutting tools. Before applying the multilayer coating, the selected cutting tool was purified in a bath with a disc cutting surface from quick-cutting steel and carried out the process of ion-nitriding or chemical-thermal treatment. In this case, nitrogen and argon ions diffuse over the surface of the disc cutter. Ion alloying using low-energy high-precision electron beams followed this process. The processing was carried out on a single-chamber two-system magnetron installation “RITM-SP-M”. Finishing was carried out by disc milling with Swiss Platit π311 ((TiCr)N-(TiAl)N-(CrAlSi)N+ion nitriding, (TiCr)N-(TiAl)N-(CrAlSi)N(nATCrO³)), (TiAl)N+ion nitriding + ion alloying (NbHf), (TiAl)N, (TiAl)N+ion nitriding, diamond-like coatings). Such multilayer coatings were tested at the Navoi mining and metallurgical plant “Navoi machine-building plant”. Machined disc cutters have been tested on 34XH1MA which is difficult to machine.

1. Introduction

Currently, mechanical engineering is developing rapidly. There is no industry that is not related to mechanical engineering. One of the practical works on the development of the industry is the signing of a memorandum of understanding (cooperation) between the “STANKIN” Moscow State Technological University and Bukhara Engineering-Technological Institute.

The development of technology requires constant improvement, the invention and use of new materials. These materials must always meet the required stability, quality and reliability of use. Despite the increasing application of tools made of hard alloys, cutting ceramics and super-hard materials, the number of quick-cutting steels used in the production of metalworking tools does not decrease at all [1,2]. It is possible to deposit a protective coating onto a predetermined area of the specimens surface subjected, for example, to severe wear conditions, or to restore locally damaged/worn-out surface [3,4].

To compare the results of the hardness measurement, inserts made of quick-cutting steelR6M5 (6% W, 5% Mo and 4% Cr) with the same coatings were also used. The research objective is the choice of optimum approaches to the control of adhesive bond strength and the micro-hardness measurement of multilayer composite wear-resistant coatings allowing highest accuracy and consistent result [5-8]. Ionic nitriding of high speed steel increases the microhardness of the surface layer structure and hardens free carbon atoms. The microstructure consideration in the machining process covers phase transformation, dynamic recrystallization, grain morphology and dislocation density. The material microstructure
evolution in the machining process is a combined effect from the thermal-mechanical interactions. For example, the phase transformation is dependent on the temperature history, grain growth is determined by the strain, strain rate and temperature effect [9-12]. Influences of the multilayer modulation period on the wear resistance and hardness characteristics of TiN/TiC-n and Ti(C,N) coatings, fabricated on hot work tool steel (H13) substrates by the PACVD, were investigated. The crystalline structure of coatings was determined by the field emission scanning electron microscopy (FE-SEM) [13,14]. To significantly increase their cutting properties, the development and application of a comprehensive surface treatment for carbide tools includes a preliminary surface treatment in combination with subsequent depositions of multi-layered nanoscale wear-resistant coating and is an effective method to solve this challenge. Despite sophisticated methods of plasma production, expensive microwave power supplies and other equipment used to fill vacuum chamber with homogeneous plasma, working nitrogen pressure in vacuum chambers of known facilities [15,16]. The scratch test is an instrumented complex technique for the assessment of both adhesive and cohesive properties and tribological characteristics of thin films [17,18]. The production of carbon and carbon-based thin films can be accomplished via several physical and chemical vapor deposition (CVD) methods such as magnetron sputtering, plasma jet CVD and plasma enhanced CVD (PECVD) [19-21]. The bonding layer is an epoxy resin layer much thinner than that of the coating layer. The substrate layer is a stainless steel layer, usually much thicker than that of the coating layer. The cutting tool will intensively wear because of heating, thus neutralizing many useful properties of the wear-resistant coating [22,23]. Due to the more complex phenomenology which accompanies the intermittent cutting process, in this study only coatings of HSS (quick-cutting steel) turning tools will be treated [24].

In this article, some interesting compositions, which may be used to obtain modified surface layers by the method considered herein to increase the durability of tools made of relatively middle-alloyed quick-cutting steel with average heat resistance, during longitudinal turning of heat-resistant chrome alloy 34XH1MA, are discussed.

2. Materials and methods
R6M5 cutting tool is disc cutter from quick-cutting steel. For milling, the ion nitriding process was first carried out on disk-milling machine on APP-2 unit produced by “STANKIN”MSTU. Diffusion saturation of the steel surface with nitrogen is called nitriding [25]. Nitrogen combines with metals in steel to form nitrides. The surface of steel modified with metal nitrides has a number of special properties: the surface hardness remains stable at relatively high temperatures, durability, abrasion and corrosion resistance increases [26]. The hardness of the nitrogen-saturated surface is cemented and then far exceeds the hardness of the treated surface, and this hardness is maintained even at high operating temperatures (600-700 °C) [27].
APP-2 unit used two-stage vacuum arc gaseous medium. The treatment lasted 30 minutes at 500 °C; the advantage of this method over the traditional ones is that it forms a thick layer that resists corrosion with low energy consumption in a short time.

After treatment the disk mill, it was established that its hardness increased to HV 50 =120 MPa, and the strength of the atoms on the surface increased. Nitriding was carried out in the two-stage vacuum arc gaseous medium mode. For experiments with disk cutters on the effect of the composition of gas mixture on nature of the nitrided layer (figure 1), the nitrogen/argon ratios of the following proportions were chosen: 80/20.

The Fe-N diagram should be used to analyze the phases formed on the surface during nitriding. When the surface is saturated with nitrogen, the following phases are formed: solid solution of nitrogen in α-iron (α-phase); solid solution based on γ-modification of iron (γ-phase); solid solutions based on iron nitrides (FeN, Fe3N) (γ- and e-phases); Fe2N can also form at 480 °C when the nitrogen content is 11.35%.

The ion alloying process was carried out on a disc cutter with a diameter of Ø50mm using low-energy high-potential electron beams (NbHf). Before applying the wear-resistant coating, some of the work pieces were subjected to subsurface layer alloying. The treatment was conducted in a RITM-SP-M Unit, which makes up a combination of a source of low-energy high-current electron beams (LECHEB) "RITM" and two magnetron-spraying systems on a single vacuum chamber [28].

The device allows the spraying of various materials on given surface of the product, and then liquid-phase mixing of the coating (film) materials and marks using a beam of fast pulsed electrons. The main function of this device is to apply a coating on the surface of the work-piece and then stir the liquid phase under the action of an electron beam. Based on this technology, a composite was obtained with a gradient transition from the base of the carbide tool to the protective coating.

An alternative to the traditional methods of chemical heat treatment can be the creation of a doped surface layer of micron thickness with improved wear resistance on steel or hard-metal tools with the use of low-energy high-current electron beam (LEHCEB). The samples were covered by thin coat of Zr with thickness from 150 to 250 nm by means of magnetron to obtain crystals ZrN in the surface layer in case of quick-cutting steel and a coat of the NbHfTi alloy in the case of processing of the hard alloy to get a layer of wear-resistant non-stoichiometric carbides [29]. Nb, Hf in the coating bind free carbon, and the presence of other alloying elements provides resistance to residual thermal stresses. This increases the micro-deformation resistance of the cutting tool. Such processing, which is recommended before applying a wear-resistant coating, allows the cutting tool to influence the wear processes, which increases its rigidity resource [30].

In case of a coated tool not subjected to microalloying, after exposure of the substrate, the friction conditions along the back surface are progressively similar to those, which are characteristic of an uncoated tool. In case of a tool subjected to a combined treatment, the modified layer continues to perform its protective functions even after the breach of the coating, which is reflected in the tool wear pattern. The combined treatment notably suppresses the formation of a worn crater on the front surface.

The finishing wear-resistant (TiCr)(N-(TiAl)N-(CrAlSi)N)+ion-nitriding, (TiCr)(N-(TiAl)N-(CrAlSi)N(nATCRo3), (TiAl)N + ion-nitriding+ ion-alloying(NbHf), (TiAl)N, (TiAl)N + ion-nitriding, diamond-like coating with a microhardness of V30=350 MPa was applied using a π311 unit manufactured by Platit. This coating represents a combination of the adhesion layer of (CrTi)N composition, (TiAl)N gradient coating and a multilayer nanocomposite (nc-AlTiCrN/a-Si3N4) coating. The two-phase layer of the coating with AlTiCrN grain size of up to 5 nm, at the boundary of which a Si3N4 amorphous phase is located, suppresses the coagulation of grains of the basic phase during both the coating deposition and the tool operation. The first step is similar to that for conventional powder metallurgy, where the precursors are weighed out in the appropriate amounts, and then mixed. For some technologies (II–III), cold pressing of the green mixture received [31-36].

Coatings based on nitrides and carbides of refractory metals applied to the working surfaces of tools or machine parts meet most of the specified requirements. Evaporation of many metals and alloys while maintaining the chemical composition of alloys, their formation with gaseous compounds, and flexible
adjustment of the phase composition and structure of condensates, high adhesion to the substrate provide coatings that significantly increase the performance of products under certain conditions [37,38].

3. Results and discussions
Most anticorrosive coatings have high hardness, high heat resistance, low coefficient of friction, corrosion resistance and the ability to maintain geometric shape during processing. This allows creating tools and parts that are more versatile, optimizing their geometry, significantly increasing productivity and reducing unit cost.

Table1. Wear by cutter diameter in processing.

| Name, and model of machine  | Processed material and hardness | Tool name                                      | Cutting mode | Tool life T, min |
|-----------------------------|--------------------------------|------------------------------------------------|--------------|-----------------|
| Milling machine FUS-32      | Billet steel 34XH1MA with a hardness of 375 HB (forged blank) | Cutting disc cutter No. 2 (diamond-like coating (DLC)) | 250 3.0 100 | 1. Before machining the part, the outer diameter of the cutter was Ø49.3 mm. |
|                             |                                | Cutting disc cutter No. 1 (coating (TiCr)N-(TiAl)N-(CrAlSi)N+ion-nitriding) | 250 3.0 100 | 2. Slot depth 3 mm by 170 mm length |
|                             |                                | Cutting disc cutter No. 3 (coating ((TiAl)N + ion-nitriding + ion- | 250 3.0 100 | 3. After processing, wear on the outer diameter was 0.15 mm. |

1. Slot depth 3 mm by 170 mm length
2. Slot depth 3 mm by 170 mm length
alloying (NbHf)

3. After processing, wear on the outer diameter was 0.1 mm.

| Cutting disc cutter No. 4 | 250 | 3.0 | 100 |
|---------------------------|-----|-----|-----|
| (coating (TiAl)N)         |     |     |     |

1. Before machining the part, the outer diameter of the cutter was Ø49.5 mm.

2. Slot depth 3 mm by 170 mm length

3. After processing, wear on the outer diameter was 0.4 mm.

| Cutting disc cutter No. 5 | 250 | 3.0 | 100 |
|---------------------------|-----|-----|-----|
| (coating (TiAl)N + ion-nitriding) | | | |

1. Before machining the part, the outer diameter of the cutter was Ø49.6 mm

2. Slot depth 3 mm by 170 mm length

3. After processing, wear on the outer diameter was 0.2 mm.

| Cutting disc cutter No. 5 | 250 | 3.0 | 100 |
|---------------------------|-----|-----|-----|
| (coating (TiCr)N- (TiAl)N- (CrAlSi)N (nATCrO³)) | | | |

1. Before machining the part, the outer diameter of the cutter was Ø50.7 mm

2. Slot depth 3 mm by 170 mm length

3. After processing, wear on the outer diameter was 0.2 mm.

| Cutting disc cutter No. 7 | 250 | 3.0 | 100 |
|---------------------------|-----|-----|-----|
| (uncoated)                |     |     |     |

1. Before machining the part, the outer diameter of the cutter was Ø49.5 mm
2. Slot depth 3 mm by 170 mm length

3. After processing, wear on the outer diameter was 0.5 mm.

Experimental tests of the processed cutting tool were carried out at the Navoi mining and metallurgical plant “Navoi machine building plant”. Differences in the diameters of the cutting tool (table 1) at the beginning and end of the test were determined (histogram).

![Histogram](image)

**Figure 2.** Cutter wear by weight.

This reduces the shear force by 20-25%. The presence of a coating on one of the working surfaces of the cutting tool reduces the wear of not only machining chrome alloy 34XH1MA of this material, but also of other surfaces. (TiCr)N-(TiAl)N-(CrAlSi)N+ion-nitriding, (TiCr)N-(TiAl)N-(CrAlSi)N(nATCRo³), (TiAl)N + ion-nitriding+ion-alloying (NbHf), (TiAl)N, (TiAl)N + ion-nitriding, diamond-like coating in instruments, there is a tendency to reduce the formation of tumors, as a result of which, after processing, a much higher level of surface cleanliness is achieved [39,40].
before and after treatment (coating (TiCr) N-(TiAl)N-(CrAlSi)N + ion-nitriding)

before and after treatment (diamond-like coating (DLC))

before and after treatment (((TiAl)N ion-coating + ion-nitriding + ion-alloying (NbHf))

before and after treatment (((TiAl)N coating)

before and after treatment (((TiAl)N ion-coating + ion-nitriding)

before and after treatment (coating (TiCr)N-(TiAl)N-(CrAlSi)N (nATCRo3))

before and after processing (with no coating)

**Figure 3.** Appearance of disc cutters under a microscope before and after treatment.
It can be seen from the figure, disc cutters with complex machining have higher wear resistance than cutters without coolant coating, high load and quick-cutting machining (figure 3).

Corrosion resistance of titanium nitride coatings is well manifested in conditions of rapid friction, erosion and corrosion of machine parts. (TiCr) N- (TiAl) N- (CrAlSi) N + ion-nitriding, (TiCr) N- (TiAl) N- (CrAlSi) N (nATCR0), (TiAl N + ion-nitriding + ion-alloying (NbHf), (TiAl) N, (TiAl) N + ion-nitriding+ diamond-like coating. Various parts applied in enterprises of food, light and other industries in the national economy are made of titanium alloys and are successfully used to increase the erosion and corrosion resistance of compressor blades of aircraft gas turbine engines.

4. Conclusions

Surface modification by ion-nitrogen, electron-beam alloying in a two-stage vacuum arc discharge, including the durability of disc mills made of high-speed steel R6M5 and (TiCr) N- (TiAl) N- (CrAlSi) N + ion-nitriding, (TiCr) N- (TiAl) N- (CrAlSi) N (nATCR0), (TiAl) N + ion-nitriding + ion-alloying (NbHf), (TiAl) N, (TiAl) N + ion-nitriding, diamond-like coating during treatment by 34XH1MA material, the complex value of the anticorrosive coating increased by four times compared to the initial value after the complex processing, and the cutters reinforced with the anticorrosive coating by the ion nitriding method increased by 2 times compared to the normal value.

Increase in the durability of disc cutters with combined processing is ensured by obtaining on their surface a hardened zone with a depth of 80 microns.

References

[1] Grigoriev S N, Melnik Yu A, Metel A S and Volosova M A 2017 Focused beams of fast neutral atoms in glow discharge plasma editors-pick J. Appl. Phys. 121 223-302
[2] Grigoriev S N and Tarasova T V 2016 Possibilities of the technology of additive production for making complex-shape parts and depositing functional coatings from metallic powders Metal Sci Heat Treatment 57 579-84
[3] Hachkevych O R, Drobenko B D, Vankevych P I and Yakovlev M Yu 2017 Optimization of the high-temperature induction treatment modes for nonlinear electroconductive bodies Strength Mater. 49 (2017) 429-435
[4] Smurov I, Doubenskaia M, Grigoriev S and Nazarov A 2012 Optical Monitoring in Laser Cladding of Ti6Al4V J. Thermal Spray Technol 21 1357-62
[5] Fedorov S V, Okunkova A A, Peretyagain N Y and Peretyagain P Y 2017 Electroconductive graphene-hydroxyapatite PVD targets for magnetron sputtering J. Adhes. Sci. Technol. 1-15
[6] Atlati S, Moufki A, Nouari M and Haddad B 2017 Interaction between the local tribological conditions at the tool-chip interface and the thermomechanical process in the primary shear zone when dry machining the aluminum alloy AA2024-T351 Tribol. Int. 105 326-33
[7] Chowdhury M S I, Chowdhury S, Yamamoto K, Beake B D, Bose B, Elfizy A, Cavelli D, Dosbaeva G, Aramesh M, Fox-Rabinovich G S and Veldhuis S C 2017 Wearbehaviour of coated carbide tools during machining of Ti6Al4V aerospace alloy associated with strong built up edge formation Surf. Coat. Technol. 313 319-27
[8] Pan Zh, Feng Y and Liang S Y 2017 Material microstructure affected machining: a review Manuf. Rev. 4
[9] Azadi M, Rouaghanem A S and Ahangaran S 2016 Mechanical Behavior of TiN/TiC-n Multilayer Coatings and Ti(C, N) Multicomponent Coatings Produced by PACVD Strength Mater. 8 279-89
[10] Kuzin V V, Fedorov M Yu and Volosova M A 2017 Nitride ceramic surface layer stressed state transformation with a change in TiC-coating thickness. Stress distributed force load version Refract. Ind. Ceram. 57 551-6
[11] Grigoriev S N 2016 Study of cutting properties and wear pattern of carbide tools with comprehensive chemical-thermal treatment and nano-structured/gradient wear-resistantcoatings Mech. & Ind. 17 702
[12] Grigoriev S N, Metel A S, Volosova M A and Melnik Y A 2015 Surface hardening by means of plasma immersion ion implantation and nitriding in glow discharge with electro-static confinement of electrons Mech. & Ind. 16 711

[13] Tomastik J and Ctvrtlik R 2013 Nanoscratch test a tool for evaluation of cohesive and adhesive properties of thin films and coatings EPJ Web Conf. 48 00027

[14] Quazi M M, Ishak M, Arslan A, Nasir Bashir M and Ali I 2017 Scratch adhesion and wear failure characteristics of PVD multilayer CrTi/CrTiN thin film ceramic coating deposited on AA7075-T6 aerospace alloy J. Adhes. Sci. Technol. 0

[15] Trompeta A F A, Koumoulos E P, Kartsonakis I A and Charitidis C A 2017 Advanced characterization of by-product carbon film obtained by thermal chemical vapor deposition during CNT manufacturing Manuf. Rev. 4 7

[16] Berlin E V, Koval N N and Seidman L A 2012 Plasma thermo-chemical surface treatment of steel parts (Moscow: Technosphera)

[17] Ivanov Yu F, Teresov A D, Petrikova E A, Krysina O V et al. 2017 Surface Alloying of SUS 321 Chromium-Nickel Steel by an Electron-Plasma Process Russ. Phys. J. 60 515-21

[18] Li Y, Han Z and Chen Y 2017 Research on Ultrasonic Testing Methods for Adhesion Quality of Ceramic Coatings MATEC Web Conf. 114 02001

[19] Volosova M A, Grigoriev S N and Ostrikov E A 2016 Use of laser ablation for formation of discontinuous (discrete) wear- resistant coatings formed on solid carbide cutting tool by electron beam alloying and vacuum-arc deposition Mech. & Ind. 17 720

[20] Diciuc V and Kazek-Kesik A 2017 The structure and formation of functional hard coatings: a short review MATEC Web Conf. 112 04008

[21] Urinov, N., Saidova, M., Aborov, A., & Kalandarov, N. (2020). Technology of ionic-plasmic nitriding of teeths of disc saw of the knot of saw cylinder. IOP Conference Series: Materials Science and Engineering, 734(1). https://doi.org/10.1088/1757-899X/734/1/012073

[22] Aborov, A., Kuvoncheva, M., Rajabov, O., Mukhammadov, M., & Jumaev, S. (2020). Method of thermal treatment of saw disk teeths of fiber-processing machines by laser quenching. IOP Conference Series: Materials Science and Engineering, 862, 032034. https://doi.org/10.1088/1757-899X/862/3/032034

[23] Sharipov Zhamsid, Saidov Sunnat and Fedorov Sergey 2020 Improving the surface stability of the teeth of disk cutters by complex processing Inj. Resh. 5(15)

[24] Fedorov S V, Aleshin S V et al. 2017 Comprehensive surface treatment of quick-cutting steel tool Mechanics & Industry Accepted 19 2-6

[25] Grigoriev S N and Fedorov S V 2015 Tool material surface alloying by wide-aperture low-energy high-current electron beam treatment before wear-resistant coating Mech. & Ind. 16 708

[26] Grigor’ev S N, Fedorov S V, Pavlov M D et al. 2013 Complex surface modification of carbide tool by Nb+Hf+Ti alloying followed by hard-facing (Ti + Al)N J. Fric. Wear 34 14-8

[27] Levashov E A, Mukasyan A S, Rogachev A S and Shtansky D V 2017 Self-propagating high-temperature synthesis of advanced materials and coatings Int. Mater. Rev. 62 203-39

[28] Rogachev A S, Vadchenko S G, Baras F, Politano O, Rouvimov S, et al. 2016 Combustion in reactive multilayer Ni/Al nanofoils: experiments and molecular dynamic simulation Combust. Flame 166 158-69

[29] Cui X and Guo J 2017 Effects of cutting parameters on tool tool temperatures in intermittent cutting with the formation of serrated chip considered Appl. Thermal Eng. 110 1220-9

[30] Mu J, Wang J, Zhao Z, Zhu Z and Wang Ya 2017 Regulating kinetics of deformation-induced phase transformation in amorphous alloy composite via tuning nano-scale compositional heterogeneity in crystalline phase Intermetallics 93 72-6

[31] Gavrin V N, Kozlova Yu P, Veretenkin E P, Logachev A V, Logacheva A I, et al. 2016 Reactor target from metal chromium for “pure” high-intensive artificial neutrino source Phys. Part. Nucl. Lett. 13 267-73

[32] Grigoriev S N, Metel A S and Fedorov S V 2012 Modification of the structure and properties of
quick-cutting steel by combined vacuum-plasma treatment \textit{Metal Sci. Heat Treat.} \textbf{54} 8-12

[33] Grigoriev S N 2016 Study of cutting properties and wear pattern of carbide tools with comprehensive chemical-thermal treatment and nano-structured/gradient wear-resistant coatings \textit{Mech. \& Ind.} \textbf{17} 702

[34] Kuzin V V, Fedorov M Yu and Volosova M A 2017 Nitride ceramic surface layer stressed state transformation with a change in TiC-coating thickness. Stress version heat flow \textit{Refract. Ind. Ceram.} \textbf{58} 82-8

[35] Fedorov S V, Pavlov M D and Okunkova A A 2013 Effect of structural and phase transformations in alloyed subsurface layer of hard-alloy tools on their wear resistance during cutting of high-temperature alloys \textit{J. Fric. Wear} \textbf{34} 190-8

[36] Fedorov Sergey, Sharipov Jamshid, Odinaev Rustam, Sayliev Ismat, Saidov Sunnat and Mukhammadov Mukhsin 2020 Improving the Surface Stability of the Teeth of Disk Cutters by Complex Processing \textit{IJARSET} \textbf{7(5)} 13654-7