

Increasing of the carbide cutting tool life by developing the multilayer coatings

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Abstract. The paper presents the results of studying the structural parameters and mechanical properties of multi-element coatings based on-TiZrN, TiZrAlN, TiZrCrN, and TiNbAlN. The phase composition, the structural parameters, and the mechanical properties of such coatings are shown to depend on the design of cathode evaporators and the machine layout at the moment of application. Compared to TiN coating, multi-element coatings have higher residual compressive stress, smaller CSR, higher microdeformations of the crystal lattice, better mechanical properties, yet weaker adhesion to the tool base. Based on studying their structural parameters and mechanical properties, we have designed double-layer coatings. Use of such multi-layer coatings prolongs the tool life of carbide plates compared to TiN coating.

1 Introduction

Multi-layer coatings are increasingly used to improve the efficiency of cutters [1-4]. The efficiency of such coatings depends on the mechanical properties of individual layers with specific functions [5, 6]. The mechanical properties of coatings depend on their deposition. Changing the layout of the machine and the design of cathodes has a significant impact on the mechanical properties of coatings [7-13]. Therefore, by changing the deposition conditions, we can adjust the properties of multi-layer coatings.

This research is to improve the efficiency of carbide tools by adjusting the layer-specific composition of multi-layer coatings.

2 Methodology of Experiment

Durable coatings were applied to MK8 carbide plates using a Bulat-6 machine. The chemical composition of such coatings was identified by quantitative X-ray analysis on a MAP-4 machine with ZAF adjustments being factored in. The parameters of the coating structure (lattice spacing a , half-width of the X-ray diffractive line β_{111}) and the residual compressive stresses σ_0 were studied by means of a ДРОН-3М diffractometer; relative microdeformations of the crystal lattice $\Delta a/a$ and the coherent scattering regions (CSR) D were calculated as in [14]. Microhardness H_M , first-kind elasticity modulus E , fracture toughness K_{ICII} were determined as in [15]. The adhesion strength was evaluated on the bases of the stratification coefficient calculated using a TK-2M hardness tester as in [1]. The efficiency of MK8 carbide plates was evaluated based on

the tool life when turning workpieces made of 38XГН steel.

3 Methodology of Experiment

The multi-layer coating architecture has been selected based on their application in continuous turning as recommended in [2, 6, 16]. According to those papers, the upper layer should create favorable interaction of machined and tool materials at the front surface of the cutter to lower equivalent stresses and stabilize the shape of the cutting wedge. At the same time, in order to contain the fracturing processes, it is desirable that this layer has high mechanical properties as well as high level of its own residual compressive stress that contribute to the generation of higher normal compressive stresses during the cutting. As shown in [2, 4], multi-element coatings, i.e. three-element coatings based on modified titanium nitride, are the best when it comes to meeting such requirements. Beside the above requirements, coatings should have strong adhesion to the tool base; single-element coatings are adhesion-stronger than their multi-element counterparts [1, 2].

Based on the above, we studied TiN, TiZrN, TiZrAlN, TiZrCrN and TiNbAlN which were then used as layers in multi-layer coatings. TiZrN coatings were applied by two cathodes of titanium and zirconium located opposite to each other; TiZrAlN was applied by the same cathodes plus a cathode made of a titanium-aluminum alloy. TiNbAlN was applied by two titanium cathodes plus a titanium-niobium-aluminum cathode; TiZrCrN was applied by composite cathodes: two titanium cathodes with zirconium inserts and one titanium cathode with a chromium insert. Table 1 presents the chemical composition of the coatings.

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Table 1. Chemical composition of coatings.

Coating	Elements in the coating at. %				
	Ti	Zr	Cr	Nb	Al
TiZrN	57.2	42.8	-	-	-
TiZrAlN	57.5	39.75	-	-	2.8
TiNbAlN	83.4	-	-	14.5	2.1
TiZrCrN	75.4	13.4	11.2	-	-

TiZrN and TiZrAlN are biphasic coatings. TiZrN diffraction pattern is shown in Figure 1a. As shown there, there are two diffraction peaks that are identified as TiN (111) and ZrN (111), both having a cubic crystal lattice. At an angle of $2\theta=35.2$ grad. between them, there is a diffraction peak identifiable as solid TiZrN solution (111). According [6, 15], such coatings have a multi-layer structure where the multi-layers of separate phases and the solid solution alternate to improve the mechanical properties. TiNbAlN and TiZrCrN are uniphasic coatings. The diffraction patterns of these coatings (see Figure 1b) only show one high-intensity diffraction peak identifiable as TiN (111). Being uniphasic proves the homogeneity of such coatings and lack of multi-layer structure.

Table 2 presents the results of studying the structural parameters of multi-element coatings compared to TiN.

Table 2. Structural parameters and mechanical properties.

Coating	TiN	TiZrN	TiZrAlN	TiNbAlN	TiZrCrN
a , nm	0.4335	0.4356	0.4344	0.4309	0.4279
β_{111} , deg	0.40	0.82	1.06	0.70	0.59
σ_o , MPa	-775	-1352	-1487	-1875	-1422
D , nm	26.0	11.63	8.90	13.70	16.56
$\Delta a/a \cdot 10^{-3}$	4.8	10.6	13.8	9.1	7.5
H_{μ} , GPa	24.2	36.0	39.8	37.6	36.8
E , GPa	315	385	424	402	405
K_{IC} , MPa·m ^{1/2}	8.24	8.73	12.32	11.73	10.35
K_O	0	0.08	0.61	0.13	1.57
H_{μ}^3/E^2 , GPa	0.143	0.315	0.351	0.329	0.304

It is found out that compared to TiN, multi-element coatings have a greater X-ray line half-width, greater residual compressive stresses, smaller CSR, and greater relative microdeformations of the crystal lattice. Comparing bi- and tri-element coatings shows that the latter have higher residual compressive stresses, whereas TiNbAlN has the greatest value of σ_o .

The half-width of the X-ray line depends on the design of cathodes and the layout of the machine used to apply the coating. β_{111} is at highest for TiZrAlN applied

with solid titanium and zirconium cathodes; such coatings have a multi-layer structure. The absence of thereof in TiZrCrN is what results in lower β_{111} . These data accord to what is described in [6, 16]. Multi-layer TiZrAlN coatings also have the smallest SCR D and the greatest value of $\Delta a/a$.

Multi-element coatings have higher mechanical properties compared to TiN, see Table 2. Their microhardness is 1.48-1.64 times higher, and the modulus of elasticity is 1.2-1.35 times higher depending on the composition. Tri-element coatings have higher microhardness, modulus of elasticity, and fracture toughness, but lower adhesion strength compared to bi-element coatings. TiZrCrN have the least adhesion strength, whereas its stratification coefficient is considerably higher than that of other three-element coatings. Multi-element coatings do not differ significantly in terms of resistance to plastic deformation (the ratio H_{μ}^3/E^2). These data are in line with what is described in [6, 16], which is due to the effect of various mechanisms strengthening the material upon their condensation.

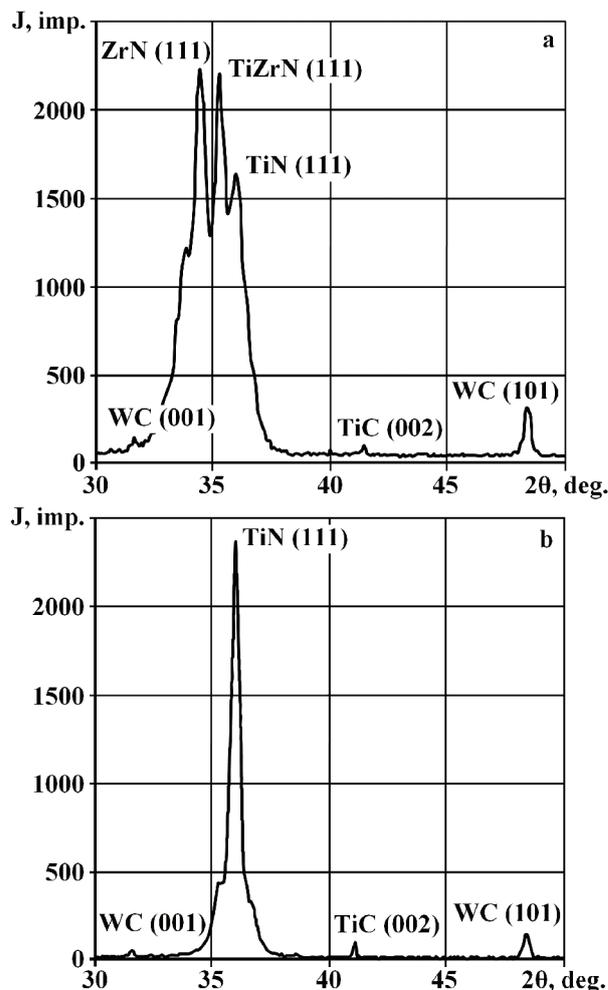


Fig. 1. Fragments of TiZrN (a) and TiNbAlN (b) diffraction patterns

Analyzing the results of studies, we note that TiZrN coatings have the greatest adhesion strength, whereas TiNbAlN and TiZrAlN boast the best combination of

mechanical properties and residual stresses to generate higher normal compressive stress during cutting.

Based on these data and the principle of how multi-layer coatings are formed for continuous cutting, we have developed double-layer coatings where the lower level is TiZrN and the upper level is TiNbAlN, TiZrAlN, TiZrCrN. The efficiency thereof was tested by turning 38XГH steel workpieces. Figure 2 presents the results.

It has been found out that use of our bi-layer coatings prolongs the tool life of carbide plates 1.8-2.8 times compared to TiN (the exact value depends on the cutting parameters and the material machined). In such terms, the most efficient coating is the double-layer with a TiNbAlN upper layer, the least efficient is that with TiZrCrN upper layer. TiZrN-TiZrCrN being less efficient is due to the lower adhesion strength of the lower layer as well as due to lower mechanical properties and residual compressive stresses characteristic of coatings made by composite cathodes [1, 2].

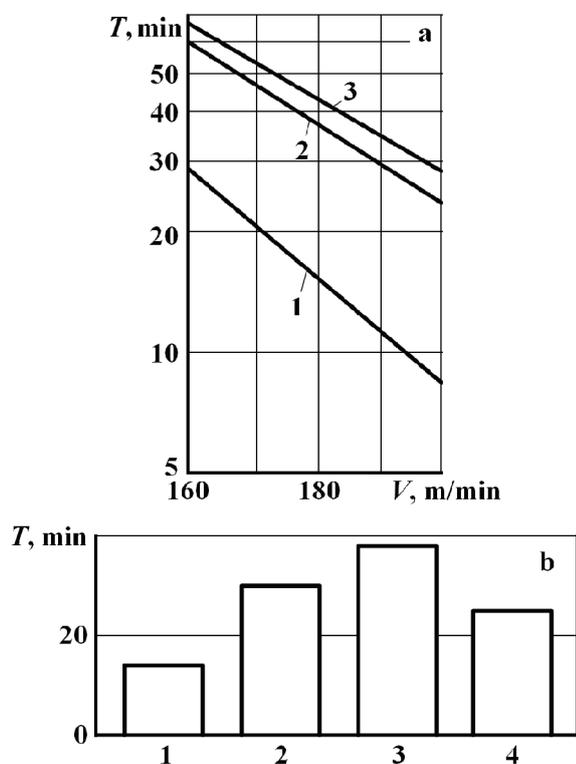


Fig. 2. The dependence of the tool life from the cutting speed (a) and the MK8 plate tool life diagram (b) when turning 38XГH steel workpieces: a - $S=0.15$ mm/rot., $t=0.5$ mm; b - $V=140$ m/min, $S=0.3$ mm/rot., $t=0.5$ mm; 1 - TiN, 2 - TiZrN-TiZrAlN, 3 - TiZrN-TiNbAlN, 4 - TiZrN-TiZrCrN

4 Conclusion

Multi-layer coatings improve the tool life of carbide tools compared to single-layer coatings. The most efficient are the coatings where the upper layer gives a favorable combination of mechanical properties and residual compressive stresses while the lower layer immediately adjacent to the tool has sufficient adhesion strength.

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