On the influence of Ti-Al intermetallic coating architecture on mechanical properties and wear resistance of end mills

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Abstract. Thin-film wear-resistant coatings are widely used to increase life and efficiency of metal cutting tools. This paper shows the results of a study on the influence of architecture (number, sequence and thickness of layers) of wear-resistant coatings on physical, mechanical and operational properties of end mills. Coatings consisting of alternating Ti-Al/Ti-Al-N layers of equal thickness demonstrated the best physical and mechanical properties. Durability of coated tools when processing materials from chromium-vanadium steel increased twice as compared to uncoated tools.

1. Introduction

One of the main ways to improve the efficiency of metal cutting tools is to increase their life through the use of thin-film wear-resistant coatings consisting, for example, of various refractory compounds: TiN, TiCN, TiAIN, ZrN, ZrCN, ZrHfN, CrN [1]. Increased life is commonly assessed by increased hardness of the surface layer. However, when parts and tools interact, tool wear also depends on elasticity and resistance to deformation of their surface layers. Therefore, materials with optimum hardness and increased tribological properties (low friction factor, minimum run-in duration, minimum heat release in friction, minimum wear of exposed surfaces) should be referred to wear-resistant coatings. Physical, mechanical and operational properties of wear-resistant coatings greatly depend on their chemical and phase composition as well as on architecture (sequences of alternating layers, layer thickness ratio, etc.). Besides, the use of modern wear-resistant coatings should ensure maximum adhesion to the base material.

Surface properties of tool materials can be directionally modified with high efficiency by application of functional coatings to working surfaces of the cutting tools from vacuum-arc discharge plasma. Recently, Ti-Al intermetallic coatings have become of great interest [2, 3]. The issue yet is to identify optimal parameters of wear-resistant coatings (phase composition, architecture) and the technology of their application to improve operational properties of cutting tools [1].

Therefore, this paper aims to study the influence of architecture (number, sequence and thickness of layers) of wear-resistant coatings on physical, mechanical and operational properties of end mills.

2. Experimental methods

Coatings were applied on a modernized facility NNV-6.6-I1 [3]. The developed technology for the application of intermetallic coatings is described in detail in [3]. Four types of coatings were chosen to study the influence of coating architecture on physical, mechanical and operational properties of end mills. Schematic coating architectures are shown in figure 1.

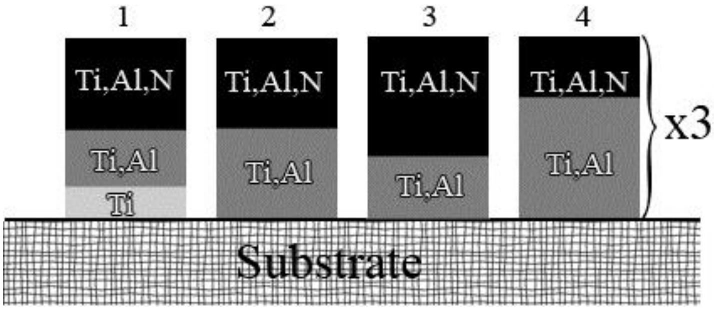

Figure 1. Schematic architectures of Ti-Al intermetallic coatings.

The thickness of coatings was determined from well parameters. Wells were made with the CSM Calotest. A scratch-tester (CSM Instruments) was used to measure adhesive strength and scratch resistance, as well as to clarify the mechanism of coating destruction. Scratches were applied on the coating surface under a continuously increasing load with a diamond spherical indenter of the Rockwell C type with a curvature radius of 200 μm. The microstructure and chemical composition of the sample surfaces were examined by scanning electron microscopy (SEM).

Parts from chromium-vanadium steel were treated on a milling machine in the tool shop of the Ufa Aggregate Production Association. Tests were performed on end mills made from P6M5 high speed tool steel with and without Ti-Al intermetallic coatings applied with different technologies. The mills were treated on a machine vertical console and milling 6T12 at a spindle rotation speed of 100 rpm and feed rate of 20 mm/m.

3. Results and discussion

The thickness of the coatings on the samples positioned perpendicular to the flow was 2.2–2.5 μm, and on the samples positioned parallel to the flow was 3.5–3.8 μm. The surface microstructure of beveled cuts on samples with different coatings is shown in figure 2.

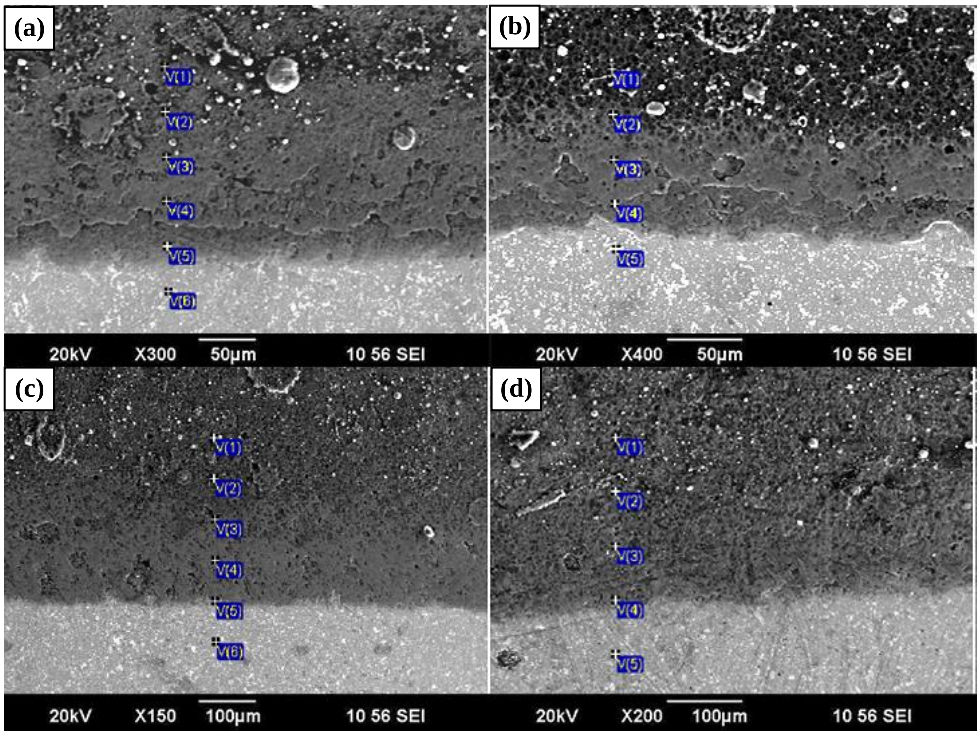

Figure 2. SEM images of beveled cuts on P6M5 steel samples with different coatings: **(a)** – 1; **(b)** – 2; **(c)** – 3; **(d)** – 4. V(1–6) – measuring points for the chemical composition of the coatings.

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Boundaries between the solid nitride layers (Ti-Al-N) and the softer intermetallic layers (Ti-Al) are clearly visible in the microstructure of the coated sample in figure 2(a). Similar situation is observed in the microstructure of the sample in figure 2(b). In the sample in figure 2(c) nitride layers are twice thicker than the softer intermetallic layers and the microstructure demonstrates a continuous surface with sparse pores of small size, almost no obvious boundary between the layers is observed. The microstructure of the 4-th group of samples differs from the previous one to a small extent, since this technology differs only in the ratio of the thicknesses of the layers.

Chemical composition of the sample surfaces measured at different depth (table 1) testifies to the difference in the architecture of coatings obtained using different technologies.

Table 1. Chemical composition of coatings.

Measuring point	1				2				3				4			
	N	Al	Ti	Fe	N	Al	Ti	Fe	N	Al	Ti	Fe	N	Al	Ti	Fe
1	11	18	68	0	14	21	63	0	17	25	56	0	10	25	62	0
2	9	15	73	0	17	20	60	1	10	34	55	0	8	25	67	1
3	11	11	76	1	17	21	60	1	12	27	59	1	10	20	70	2
4	7	19	72	2	16	14	65	5	19	23	56	2	15	15	55	13
5	15	16	47	15	0	0	0	85	16	15	32	32	0	0	0	85
6	0	0	0	89	–	–	–	–	0	0	0	85	–	–	–	–

The results of scratch tests are given in table 2. They show that the strength of adhesion of the coatings to the base material is high for all samples. However, physical and mechanical properties of the coatings differ to a great extent.

Table 2. Maximum indentation depth (h_{max}), critical load (L_c) and calculated coefficient of recovery (W_e).

Technology		Maximum indentation depth h_{max}, μm	Critical load L_c, H	Coefficient of elastic recovery W_e, %
1	Perp.	8	20	92
	Par.	7	15	76
2	Perp.	5	23	95
	Par.	4	21	92
3	Perp.	8.5	18	50
	Par.	7	20	60
4	Perp.	8.5	18	72
	Par.	8.5	15	50

Increased mechanical properties are observed in the samples processed by the second technology: the maximum elastic recovery W_e up to 95 % at the minimum indentation depth h_{max} = 5 μm and the maximum critical load L_c = 23H. Six milling cutters coated with Al-Ti intermetallics with different alternating layers were tested in the tool shop of the Ufa Aggregate Production Association. Images of the instruments during operation and after testing are shown in figure 3. Test results showed that the greatest increase in wear resistance of end mills was observed in the tool prepared by the second technology (figure 3(c)). The tool's durability was 90 min, which is twice the life of the uncoated tool and 1.5 times longer in comparison with technologies 1 and 3.

4. Conclusion

The experiments have shown that the architecture of multilayer coatings affects physical and mechanical properties. The highest increase in physical and mechanical properties was observed in the coating consisting of alternating Ti-Al/Ti-Al-N layers of equal thickness. Operation tests were the greatest for the mills with the coatings of the second architecture. Durability of the tools when processing materials from chromium-vanadium steel increased twice as compared to uncoated tools and by 1.2–1.5 times in comparison with coatings with a different architecture.

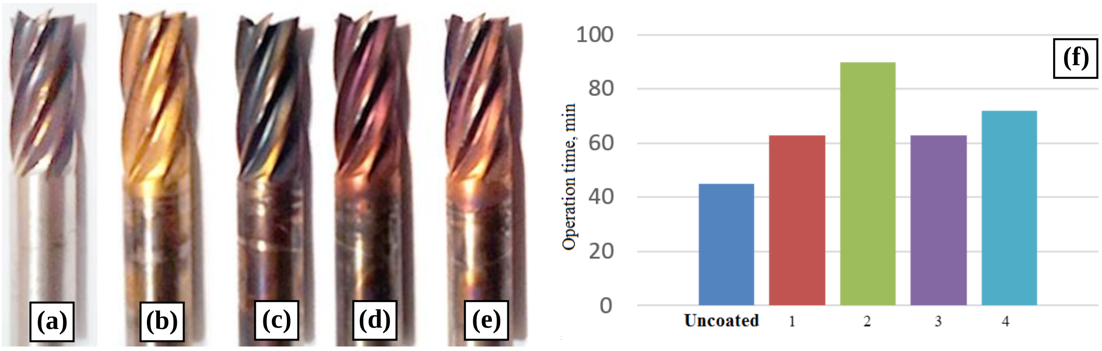

Figure 3. Instruments after operation tests: **(a)** – uncoated; **(b)**, **(c)**, **(d)**, **(e)** – with coatings of different architecture (1–4); **(f)** – test results.

References

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