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Structure and properties of PVD and CVD coated Al_2O_3+TiC mixed oxide tool ceramics for dry on high speed cutting processes

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Abstract: The paper presents investigation results of structure and properties of the coatings deposited with the PVD and CVD techniques on cutting inserts made from the Al_2O_3+TiC oxide tool ceramic. The investigation includes the metallographic analysis on the transmission and scanning electron microscope, chemical composition analysis as well as the analysis of the mechanical and functional properties of the material.

Keywords: Oxide ceramics; Al_2O_3; TiC; Multi-layer coatings; Multi-component coatings; Gradient coatings

1. INTRODUCTION

An interest is growing in the last years in particular in the ceramic and ceramic-carbide cutting materials used mostly for machining of cast iron and steel at high cutting speeds. The Al_2O_3 based oxide tool materials feature the biggest and dynamically growing group of materials among the ceramic tool materials [1-10].

The resistance of the Al_2O_3 based materials to chemical wear, their stability and abrasion wear resistance in the neutral and oxidising atmospheres, and also at high temperature is, however, connected with their high brittleness, low strength (mostly for bending), and the low thermal shock resistance, which feature the significant limitations in using the corundum ceramics for cutting tools. Partial improvement of the disadvantageous properties of the pure Al_2O_3 and Al_2O_3+ZrO_2 ceramics is possible thanks to introducing the TiC additive to the sinter [1-10].

Employment of the surface treatment technology for tools made from tool materials, with the PVD and CVD methods, to obtain the high wear resistant coatings makes it possible to improve the properties of these materials in the dry-cutting conditions, by – among others – decreasing their friction coefficient, micro-hardness increase, improvement of the tribological contact conditions in the cutting tool-machined workpiece zone, and also to improve protection against the adhesion and diffusion wear [1-23].

The goal of this paper has been investigation of structure and properties of the Al_2O_3 based Al_2O_3+TiC type based oxide tool ceramics coated with the anti-wear mono- and multilayers of the TiN, TiAIN, TiN+TiAlSiN+TiN, TiN+multiAiAlSiN+TiN and TiN+TiAlSiN+AlSiTiN types in the cathode arc evaporation CAE-PVD and with the multilayers of the TiCN+TiN and TiN+Al_2O_3 types obtained in the chemical deposition from the gas phase CVD process.

2. EXPERIMENTAL PROCEDURE

The investigations were carried out on the multi-point inserts made from the Al_2O_3+TiC oxide ceramics uncoated, coated in the PVD and CVD processes with thin coatings. The inserts made from Al_2O_3+TiC were mono-, multilayer and gradient coated in the PVD process – Cathodic Arc Evaporation (CAE) and CVD process. Specifications of the investigated materials are presented in Table 1.

Table 1.
Specifications of the PVD and CVD coatings put down on the Al_2O_3+TiC oxide ceramics.

Material type	Composition	Coating thickness, μm	Process type
Al_2O_3+TiC oxide ceramics	TiN	1.2	PVD
	TiN+TiAlSiN+TiN	1.8	PVD
	TiN+multiTiAlSiN+TiN	1.5	PVD
	TiN+TiAlSiN+AlSiTiN	2.0	PVD
	TiAlN	2.2	PVD
	TiCN+TiN	1.1	CVD
	Al_2O_3+TiN	5.8	CVD

Examinations of coatings' thicknesses were made using the "kalotest" method, observations of the investigated coatings' structures were carried out on the transverse fractures on the scanning electron microscope (SEM) Philips XL-3. The X-ray qualitative and quantitative microanalysis and surface distribution analysis of elements in the investigated coatings were made using the EDS X-ray energy dispersive radiation spectrometer, featuring the standard equipment of the scanning microscope. The diffraction examinations and examinations of thin foils were made on the JEOL JEM 3010CX transmission electron microscope at the accelerating voltage of 300 kV. The measurements of textures and phase composition were made with the diffractometric Schulz X-ray reflection method on the Bruker D8 Advance diffractometer equipped with Euler disk. The internal macro-stresses of the investigated PVD and CVD coatings were measured on the BRUKER D8 Advance X-ray diffractometer, the macro-stress values were calculated using the g-$\sin^2\psi$ method at the constant glancing angle, worked out in the project. The microhardness tests of coatings were made on the SHIMADZU DUH 202 ultra microhardness tester. Adhesion evaluation of the coatings on the investigated inserts was made using the scratch test on the CSEM REVETEST device. The critical load L_C, at which coatings' adhesion is lost, was determined basing on the registered values of the acoustic emission AE and friction coefficient F_t. Additionally L_c was determined optically. Tribological tests were carried out on the CSEM „pin-on-disk" tester Cutting ability of the investigated materials was determined basing on the technological continuous cutting tests of the SL-25 grey cast iron with the hardness of about 250 HB. The VB=0.20 mm width of the wear band on the surface of the tool used for machining was the criterion of the cutting edge consumption evaluation. The following parameters were used in the machining capability experiments: feed rate f=0.15 mm/rev, depth of cut a_p=2 mm, cutting speed v_c=200 m/min. Investigations of surface roughness of SL-25 grey cast iron in machinability test were made on device SURTRONIC 10 TAYLOR-HOBSON.

3. DISCUSSION OF INVESTIGATION RESULTS

Investigated with TEM substrate of Al_2O_3+TiC oxide tool ceramic contains the aluminium oxide grains with the hexagonal lattice ($P6_3mc$ space group) and the TiC ones with the hexagonal lattice ($R\bar{3}c$ space group). All PVD and CVD coatings put down onto the Al_2O_3+TiC oxide tool ceramics are characterized by a structure without pores and discontinuities and by tight adherence to themselves and of the entire multilayer coating to the substrate. The comprehensive examinations on the transmission electron microscope (thin foil perpendicular to the layer surface) make it possible to find out, that TiN layer of TiCN+TiN coating the grain size is less then 10 nm. In case of the other coatings, even at the largest magnifications used, no grain boundaries were revealed, which may attest to their fine-grained structure which was confirmed by thin foils examinations on the transmission electron microscope.

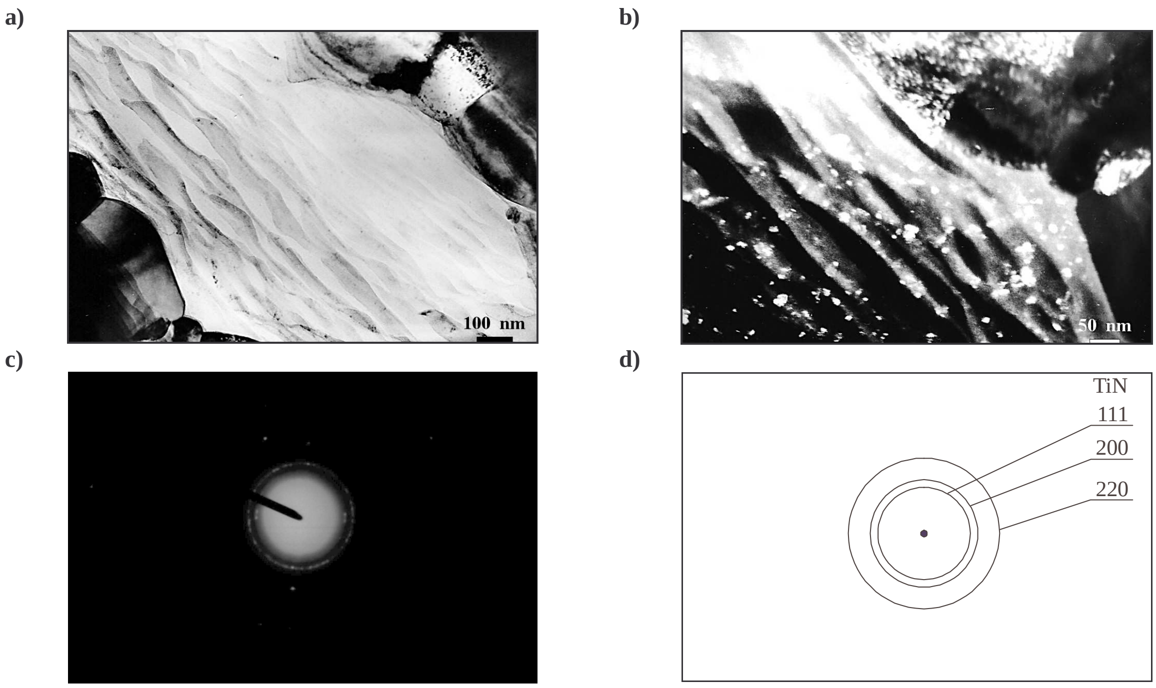

Figure 1. Structure of TiCN+TiN coating deposited on Al_2O_3+TiC substrate: thin foil structure perpendicular to the layer surface (TEM): a) light field, b) dark field of reflex (111) TiN, c) diffraction pattern as in figure a, d) diffraction pattern from the area II as in figure a.

Evaluating differences of textures of the TiN layers obtained with the PVD and CVD methods one can state that – in the most general understanding – the method of physical deposition from the gaseous phase favours development of the relatively weak texture. It is the {100} + {110} double texture most often; however the {100} component is usually stronger.

It was found out that in the investigated coatings the compression stresses occur and take values below 500 MPa, so they may be considered as small. Moreover, the qualitative relationship was revealed between the obtained internal stresses values and some mechanical and tribological properties of the investigated materials. The increase of the compression stresses is connected with the increase of hardness and adherence of the investigated coatings.

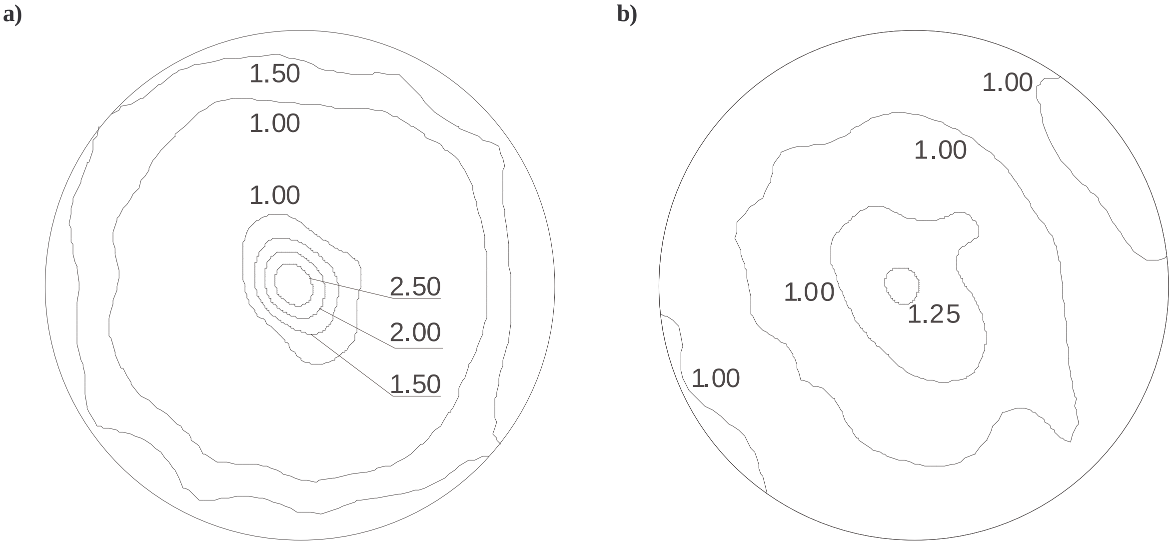

Figure 2. Texture analysis of TiCN+TiN coating deposited on Al_2O_3+TiC substrate: a) pole figure from planes {100} b) pole figure from planes {110}.

The Al_2O_3+TiC ceramics microhardness grows significantly after deposition of the PVD and CVD coatings. The roughness parameter Ra value grows after deposition of the coatings, which should be connected with the CAE process character and with the structure of the coatings put down. The coatings put down demonstrate good adhesion to the substrate; the TiAlN coating displays the best adhesion.

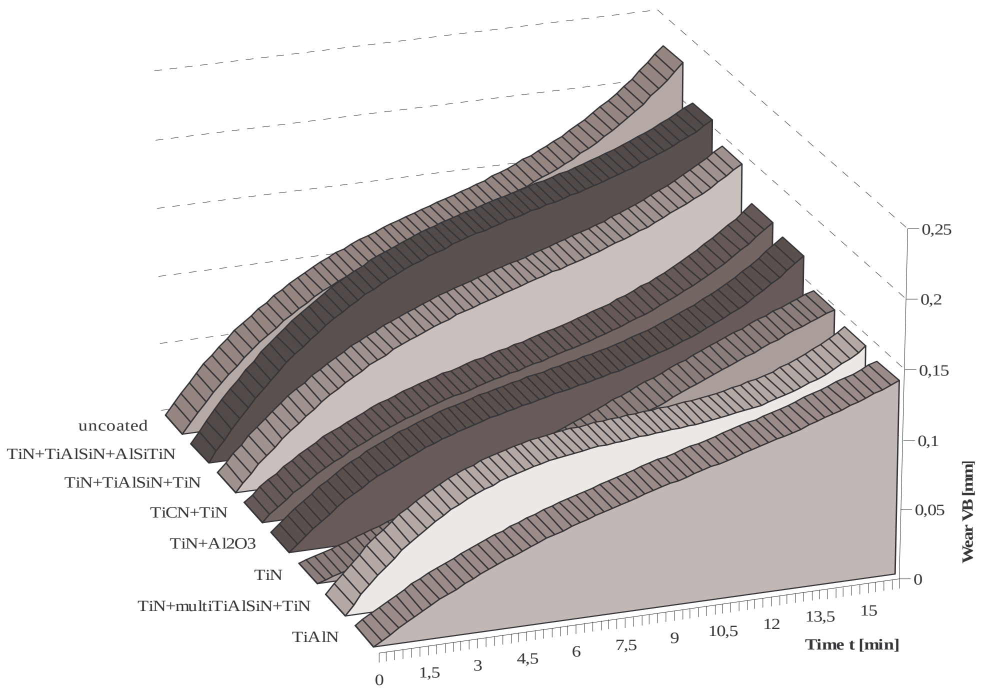

Figure 3. Comparison of the approximated values of the VB wear of the Al_2O_3+TiC based ceramics: uncoated and coated, depending on machining time.

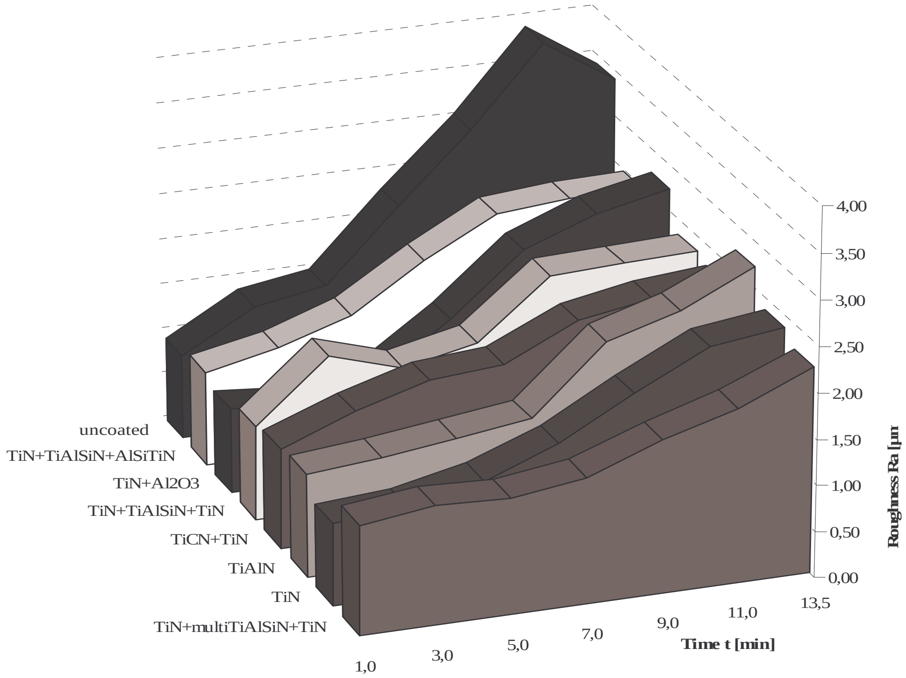

Figure 4. Comparison of the R_a roughness parameter values of the grey cast iron surface machined with the Al_2O_3+TiC based toolsuncoated and coated with the PVD and CVD coatings, depending on machining time.

The Al_2O_3+TiC ceramics microhardness grows significantly after deposition of the PVD and CVD coatings. The roughness parameter Ra value grows after deposition of the coatings, which should be connected with the CAE process character and with the structure of the coatings put down.

The coatings put down demonstrate good adhesion to the substrate; the TiAlN coating displays the best adhesion. Depositing the PVD and CVD coatings onto the oxide tool ceramics results in the significant increase of the tool life and in lowering the roughness parameter value for the machined material, and finally in improvement of its quality, especially at the final machining process stage.

Table 2.
Comparison of mechanical and functional properties of uncoated and coated Al_2O_3+TiC tool ceramics.

Coating	Roughness R_a, µm	Microhardness $HV_{0,07}$, MPa	Critical load L_c, N	Macro-stresses, MPa
-	0.07	1970	-	-
TiN	0.21	3360	47	-218
TiN+TiAlSiN+TiN	0.37	2530	40	-238
TiN+multiTiAlSiN+TiN	0.27	4030	71	-216
TiN+TiAlSiN+AlSiTiN	0.24	3070	77_{opt}	-120
TiAlN	0.07	3620	80	-300
TiCN+TiN	0.07	1870	15	-196
Al_2O_3+TiN	0.29	3470	17	-223

4. CONCLUSION

It was demonstrated, that adhered closely to each other were characterized by good adhesion to the substrate. It was demonstrated, basing on the technological cutting tests of grey cast iron, that putting down onto the tool ceramics the thin anti-wear coatings in the PVD and CVD processes increases their abrasion wear resistance, which has a direct effect on extending the tool edge life. Basing on the roughness parameter R_a of the machined cast iron surface after the cutting tests, improvement was revealed of the machined material properties, cut with coated oxide ceramics compared to material machined with the uncoated tools.

Therefore, it was determined that putting down the anti-wear coatings onto the oxide ceramic tool materials is justified and the composite tool materials developed in this way may have the important application significance in the industry for cutting tools.

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