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Structure and properties of the cutting tools made from cemented carbides and cermets with the TiN+mono, gradient or multi (Ti,Al,Si)N+TiN nanocrystalline coatings

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Abstract: The paper presents results of the structural examinations, tests of mechanical and working properties of thin coatings of the TiN+ mono or gradient (Ti,Al,Si)N+TiN and TiN + multi (Ti,Al,Si)N + TiN type, deposited in the PVD process (CAE – Cathodic Arc Evaporations) onto the substrate from the cermets and cemented carbides.

Keywords: Gradient coatings; Monolayer coatings; Multilayer coatings; Cemented carbides; Cermets; PVD; TEM; SEM

1. INTRODUCTION

Wide choice of coatings available nowadays and technologies for their deposition is an effect of the growing in the last years demand for the state-of-the-art surface modification methods. An increased interest is observed in coatings having joint properties like resistance to tribological wear and corrosion. Tools covered with coatings based on carbides, borides, nitrides, and oxides can work at higher service parameters (temperature, load, etc.). Moreover, the multilayer and multicomponent coatings developed relatively not so long ago make it possible to constitute freely properties of the entire coating as well as of its transition layer, ensuring good adhesion, compensation of the internal stresses, and transmission of the external loads. Tools with such coatings reveal a significant life extension in service compared to the uncoated tools or coated with simple coatings based on mononitrides or carbonitrides, improvement of the tribological contact conditions in the tool-chip-machined material contact zone, and protection of the tool edge from oxidation and extensive overheating [1÷10].

Therefore, cemented carbides and cermets were investigated in this project, coated with the PVD method in the cathode arc evaporation processes with the composite multilayer III generation coatings of the TiN+ mono or gradient (Ti,Al,Si)N+TiN and TiN + multi (Ti,Al,Si)N + TiN, and they were compared with the commercially available uncoated tool materials and those coated in the PVD and CVD processes with the single- and multilayer wear resistant coatings.

2. EXPERIMENTS

The investigations were carried out on cemented carbides and cermets uncoated and coated using the PVD method in the CAE process, with the TiN+ mono or gradient(Ti,Al,Si)N+TiN and TiN + multi(Ti,Al,Si)N + TiN wear resistant coatings. Commercial brands of cemented carbides and cermets for similar applications according to the ISO classification, coated both in the PVD or CVD processes, were used for comparative tests. Specifications of the tested materials are presented in Table 1.

Evaluation of the phase composition of the investigated coatings and substrates was made using the DRON 2.0 X-ray diffractometer, using the filtered cobalt lamp rays with the voltage of 40 kV and heater current of 20 mA.

The metallographic examinations of the investigated materials were made on the Philips XL-30 SEM with the accelerating voltage in the range of 15÷20 kV.

The examinations of thin foils were made on the JEOL 3010CX TEM at the accelerating voltage of 300 kV. The diffraction patterns from the transmission electron microscope were solved using the „Index" computer program.

The microhardness tests using the Vickers method were made on the DUH 202 tester.

The working properties of the developed coatings were determined basin on the technological cutting tests carried out at room temperature. The machined material is the C45E steel quenched and tempered. Multipoint SNMG 120408 (designation according to ISO 1832:1991) inserts were used for the continuous turning, fixed in a universal tool post preserving the geometrical features of the cutting insert. The following parameters were used in cutting tests: feed f=0.1 mm/rev, depth of cut a_p=1 mm, cutting speeds v_c=250, 315, 400 m/min. Cutting tests were interrupted when VB value exceeded the assumed criterion for finishing, i.e. VB = 0.2 mm.

3. RESULTS

It was demonstrated, using the X-ray qualitative phase analysis methods, that the sintered carbides substrate consists from the high-melting WC carbides (CC1 sintered carbide) and WC as well as TiC (CC2 sintered carbide) ones, and the cobalt matrix. In case of cermets, occurrences of the Ti(C,N) carbonitride, TiC and WC carbides, and cobalt-nickel matrix were revealed. It was confirmed, by observations on the scanning electron microscope and analysis

Figure 1. Thin foil structure from the CC2 cemented carbide

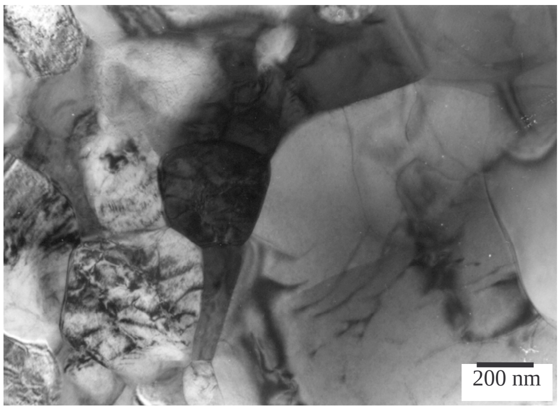
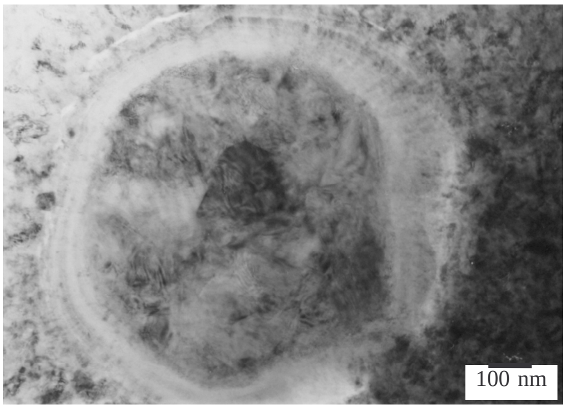
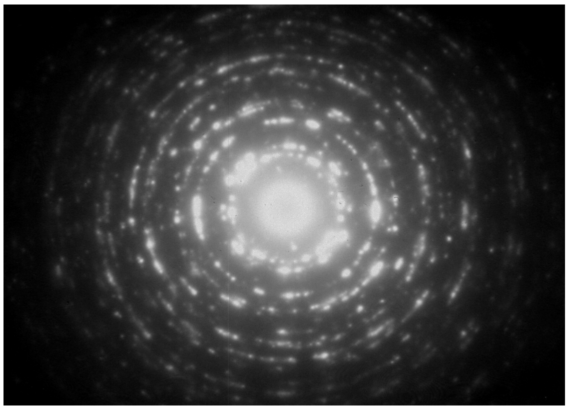


Figure 2. Thin foil structure from the CM2 cermet





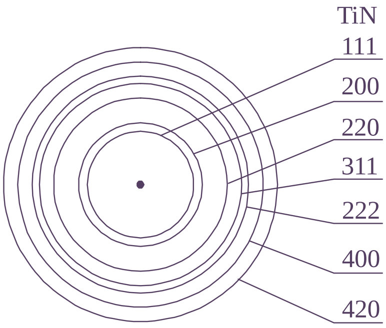


Figure 3. a) Structure of the thin foil from the TiN+multi (Ti,Al,Si)N+TiN coating deposited onto the CC1 type cemented carbide, b) diffraction pattern from the area as in figure a, c) solution of the diffraction pattern from figure b

of the chemical composition of the substrate fracture surface using the X-ray energy dispersive spectrograph EDS, that the sintered carbides substrate is characteristic of the evenly distributed high-melting carbides and nitrides in the cobalt matrix.

Basing on the examinations of thin foils in the TEM it was found out that the structure of the investigated cemented carbides (CC2 type – Fig. 1) is the γ solid solution of cobalt with dispersed carbides, mostly of the WC type. Basing on the examinations of thin foils from the cermet substrate it was found out that the structure consists of the γ solid solution of cobalt and nickel, filling the hard skeleton formed mostly from the Ti(C,N) particles (C2 type – Fig. 2).

It was demonstrated, using the X-ray qualitative phase analysis methods, that – according to the initial assumptions – coatings containing the TiN type phases, and most probably the complex (Ti,Al,Si)N nitride one, were developed on surfaces of the investigated cemented carbides and cermets. Differentiation of the TiN and (Ti,Al,Si)N phases using the diffraction methods is impossible due to their isomorphous nature, as (Ti,Al,Si)N is – in fact – the secondary solid solution based on titanium nitride TiN.

Examinations of thin foils from coatings confirm that, according to the original assumptions, coatings containing the TiN type phases were deposited onto the cemented carbides and cermets substrates. It is not feasible to differentiate these phases from the diffraction point of view, due to isomorphism of the TiN and (Ti,Al,Si)N phases. Structures of coatings deposited onto the cemented carbides and cermets are presented in Figure 3. Occurrence of the titanium mono-crystals was revealed inside of both TiN+mono or multi (Ti,Al,Si)N+TiN coatings. Occurrence of the titanium mono-crystals in the coating results from the character of the coating deposition process itself (cathode arc evaporation).

It was found out, basing on the metallographic examinations of fractures made on the SEM, that the TiN+multi (Ti,Al,Si)N+TiN coatings deposited onto the investigated cemented carbides and cermets have the laminar packing (Fig. 4). It was found out during the observations on the SEM that all the investigated single- and multi-layer coatings developed in the PVD or CVD processes were put down evenly on the substrates of the commercial cemented carbides. The coatings are compact without any pores and cracks and adhere tightly to their substrates. Only in case of the single-layer TiN coating put down using the PVD method on the CC3 cemented carbide substrate the coating thickness unevenness was encountered. The fractographic examinations of fractures of the analysed sintered carbides with the TiN+ mono or gradient (Ti,Al,Si)N+TiN and TiN + multi (Ti,Al,Si)N + TiN coatings put down and also of the commercial materials do not reveal delamination of the fracture along the parting face between the coating and substrate, which also indicates to the good adhesion of the obtained coatings.

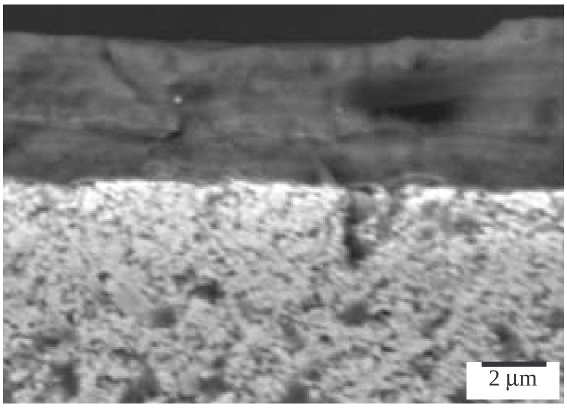


Figure 4. Fracture surface of the TiN+multi (Ti,Al,Si)N+TiN coating deposited onto the CC1 type cemented carbide substrate

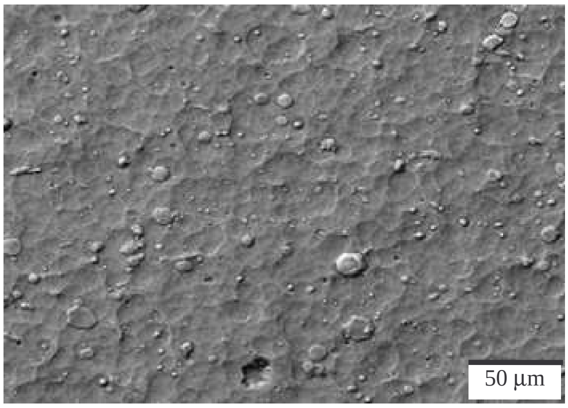


Figure 5. Topography of the TiN+(Ti,Al,Si) N+ TiN gradient coatings surface, deposited onto the CC1 type cemented carbide substrate

Roughness of the coatings defined by R_a parameter is within 0.60÷0.67 µm range and is significantly higher than in case of the uncoated material surfaces. The surface roughness increase resulting from deposition of the TiN+multi (Ti,Al,Si)N+TiN coatings should be attributed to the CAE process character and occurrence of the characteristic micro particles (Fig. 5), due to deposition of the pure titanium droplets, coming from the sputtered disk. Examinations of chemical composition of the micro-particles using the X-ray energy dispersive spectrograph EDS indicate that titanium prevails inside of the micro-particles, which suggests that these are the molten metal drops solidifying on the substrate surface.

It was revealed basing on the micro-hardness tests carried out that the CM1 and CM2 cermets have the highest hardness from the investigated uncoated materials, whose hardness is 2450 and 2500 $HV_{0,07}$ respectively; whereas, it is by 25% lower for the sintered carbides and is within the range of 1800÷1900 $HV_{0,07}$ (Table 1). Deposition of the TiN+(Ti,Al,Si)N+TiN coating onto the specimens causes the significant surface layer hardness increase within the range of 3100÷3330 $HV_{0,07}$. In case of the TiN+multi(Ti,Al,Si)N+TiN coatings the significant increase of the surface layer was also observed. Hardness of the TiN+multi(Ti,Al,Si)N+TiN coating is 3200÷3520 $HV_{0,07}$. No dependence was revealed between the substrate hardness and hardness of the deposited surface layer. To verify correlation between hardness of the investigated materials and working properties of the multipoint inserts, single point turning tests were made. All work tests have the comparative character, i.e., life of inserts was determined basing on the wear land width measurements on the tool flank after machining, at the same turning parameteres, for a predetermined period of time. The evident wear resistance effect of the presence of the TiN+(Ti,Al,Si)N+TiN gradient coating, as well as of the TiN+multi(Ti,Al,Si)N+TiN multi-layer coating on the inserts' life was revealed in the machining tests carried out with the tool cermets and with the sintered carbides. In case of inserts with the TiN+multi(Ti,Al,Si)N+TiN coating put down, it was found out for the following turning conditions: cutting speed of v_c = 400 m/min, feed rate f = 0.1 mm/rev, and depth of cut a_p = 1.0 mm, that the longest cutting edge life corresponds to the CM1 type cermet, for which the criterion flank wear band width of VB=0.2 was exceeded after 60 minutes of the continuous cutting. The shortest tool life is characteristic of the CC1 sintered carbide, for which the flank wear band width criterion was exceeded after 27 minutes. Similar ranking was obtained in case of the cutting inserts with the TiN+(Ti,Al,Si)N+TiN gradient coating put down.

The comparative tests of the uncoated inserts from cermets and sintered carbides carried out at the same cutting conditions indicate that the longest tool life corresponds to the CM1 type cermet for which the criterion flank wear band width of VB=0.2 mm was exceeded after 17 minutes of the continuous turning. The CC1 sintered carbide is characteristic if the shortest tool life, for which the criterion of the cutting edge consumption evaluation was exceeded after 1 minute of the experiment duration with the following cutting parameters: cutting speed v_c = 315 m/min, feed rate f = 0.1 mm/rev, depth of cut a_p = 1.0 mm. The comparative tests of the multi-edge inserts from sintered carbides and cermets coated in the CVD or PVD processes carried out at the same cutting conditions indicate that the longest tool life corresponds to the CM3 type cermet for which the criterion flank wear band width of VB=0.2 mm was exceeded after 35 minutes of the continuous turning; whereas the shortest tool life is characteristic of the CC3 sintered carbide, for which the criterion flank wear band width was exceeded after 8 minutes of the experiment duration with the following cutting parameters: cutting speed v_c = 315 m/min, feed rate f = 0.1 mm/rev, depth of cut a_p = 1.0 mm.

Table 1
Specification and comparison of properties of the investigated cemented carbides and cermets

Designation	Coating		Coating thickness, μm	Microhardness $HV_{0.07}$	Tool life T, min
	Type	Composition			
CC1	uncoated		–	1800	1
CC2			–	1900	4
CM1			–	2450	17
CM2			–	2500	14
CC3	monolayer	TiN		2000	8
CC1	gradient layer	TiN+ (Ti,Al,Si)N+TiN	4.0	3100	20
CC2			4.0	3190	22
CM1			4.0	3310	55
CM2			4.0	3330	43
CC1	multilayer	TiN+multi(Ti,Al,Si)N+TiN		3200	27
CC2				3280	33
CM1				3390	60
CM2				3520	43
CC4		TiN+TiC/TiN	7.5	2400	21
CC5		$TiCN+Al_2O_3$ +TiN	10.0	2300	23
CM3		TiN+TiC+TiN	5.0	3000	35

4. CONCLUSION

The following conclusions were drawn basing on the tests carried out:

1. Deposition of the gradient, multi-layer and multi-component coatings with the PVD method in the cathode arc evaporation CAE process, whose basis is the Al and Si solid secondary solution in the TiN titanium nitride, isomorphous with the alternating pure titanium nitride TiN, on tools made from sintered carbides and tool cermets, results in the increase of coatings' hardness and improvement of their adhesion to the substrate, in comparison with the single- or multiple-layer simple coatings deposited using the PVD or CVD methods on the same substrate tool materials, deciding thus the improvement of the working properties of cutting tools coated with the TiN+mono or multi (Ti,Al,Si)N+TiN system coatings, compared with coatings developed on the same sintered tool materials, but uncoated or coated with simple coatings.
2. The TiN + mono or multi (Ti,Al,Si)N + TiN system coatings deposited with the PVD method in the cathode arc evaporation CAE onto the substrates from cermets and sintered carbides reveal better working properties in comparison to the commercial tool materials with the mono- or multi-layer and single- and two-component coatings deposited in the PVD or CVD processes, and therefore, and also because of the possibility of employing them in the pro-ecological dry cutting processes without any cutting fluids they qualify for multiple industrial applications for cutting tools.

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