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Hard and wear resistance coatings for cutting tools

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Properties

ABSTRACT

Purpose: The paper presents investigation results of structure and properties of the cemented carbide tips and cermet tools, both uncoated and coated with single and multiple hard surface layers in the physical (PVD) and chemical (CVD) vapour deposition processes.

Design/methodology/approach: SEM, TEM, X-ray, Microhardness, Scratch test, Cutting test.

Findings: The TiN+gradient or multi (Ti,Al,Si)N+TiN system coatings deposited with the PVD method in the cathodic arc evaporation CAE onto the substrates from cermets and cemented carbides reveal better working properties in comparison to the commercial tool materials with the gradient- or multi-layer and single- and two-component coatings deposited in the PVD or CVD processes.

Practical implications: Dry cutting processes without the use of the cutting fluids.

Originality/value: In the paper the investigation of TiN+gradient or multi(Ti,Al,Si)N+TiN nanocrystalline coatings deposited in the CAE process on cemented carbides and cermets were carried out in order to improve the tool cutting properties.

Keywords: Tool materials; Coatings; PVD; SEM; TEM; X-ray; Cutting

1. Introduction

The main objective of the contemporary machining technology is a constant increase of durability of highly efficient cutting tools manufactured by a powder metallurgy method enabling machining at a high speed. The rapid development of techniques and technologies creates the necessity of more rigorous requirements of sintered tool materials as regards their mechanical properties and wear resistance. At the same time the solution of that issue enables the increase of capacity and quality of machining and the decrease its energy and material consumption. Together with the development of technology the optimal factors enabling the decrease of costs of manufacturing by the use of machining are looked for, taking into consideration a kind of cutting tool materials, geometry of tool and machining parameters. All the above mentioned factors are to ensure the good quality of machined elements and machining capacity. That is why the investigations leading to the improvement of tool materials wear resistance and cutting dynamics dependent on bending strength are carried out. The improvement of the application properties of tools and the reduction of ecological dangers can be achieved by the use of hard coatings deposited on tools in the PVD or CVD processes mainly by the improvement of conditions of the tribological contact in the area of cutting and the eliminations of cutting fluids. The deposition of coatings on cutting tools surfaces such as cermets and cemented carbides results is increase of tool life by the decrease of cutting edge wear in comparison to uncoated tools, the improvement of conditions of tribological contact tool-workpiece and the protection of a tool tip against oxidation and overheating [1-16].

The objective of this work was to investigate the structure and properties of cemented carbides and cermets coated with the TiN+gradient or multi(Ti,Al,Si)N+TiN type coatings using the PVD method and comparing them with the commercial sintered tool materials: uncoated and coated in the PVD/CVD processes.

2. Experimental procedure

The investigations were carried out on cemented carbides and cermets: uncoated and coated using the PVD method in the CAE process, with the TiN+gradient or 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. A specification of the investigated cemented carbides and cermets is given in Table 1. The coating deposition was carried out in the arc-vacuum device based on the arc evaporation method – Cathodic Arc Evaporation. Parameters of the coating deposition process: substrate polarisation -200 V, substrate temperature 550°C, pressure in the chamber 0.2 Pa.

Observations of surfaces and structures of the developed coatings were carried out on the transverse fractures with use of the SEM attachment ZEISS SUPRA 25 and on the PHILIPS XL-30 one.

The examinations of thin foils were made on the JEOL 3010CX TEM at the accelerating voltage of 300 kV.

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 X-ray tube under the voltage of 40 kV and tube current 20 mA.

Microhardness of the deposited coatings and substrate hardness were tested using Vickers method on the Shimadzu DUH 202 tester. The load of 70 mN was employed in order to eliminate to the greatest extent the influence of the substrate material on the results of measurement.

Adhesion evaluation of the coatings on the investigated inserts was made using the scratch test on the CSEM REVETEST device, by moving the diamond penetrator along the examined specimen's surface with the gradually increasing load. The tests were made with the following parameters: load range 0-200 N, load increase rate (dL/dt) 100 N/min, penetrator's travel speed (dx/dt) 10 mm/min, acoustic emission detector's sensitivity AE 1. The critical load L_C, at which coatings' adhesion is lost, was determined basing on the registered values of the acoustic emission AE.

Working properties of the developed coatings were determined with use of 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= 400 m/min. Insert life was determined taking into account wear land measurements on the tool flank, measuring the average wear land VB after cutting for a predetermined period. Cutting tests were interrupted when the VB values exceeded the assumed criterion for test termination, i.e., VB= 0.2 mm.

3. Results

It has been demonstrated in the paper that deposition of the multi- or gradient layer coatings with the PVD method in the cathodic arc evaporation process on tools made from cemented carbides and 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 materials, as well as an important improvement of the working properties of cutting tools coated with the TiN+gradient or multi (Ti,Al,Si)N+TiN system coatings, compared with the same sintered tool materials, but uncoated or coated with simple coatings.

All PVD gradient and multi coatings deposited onto the cemented carbides and cermets are characterised by a structure without pores and discontinuities and by tight adherence to themselves and of the entire multilayer coating to the substrate (Fig. 1). Roughness of the coatings defined by Ra 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+gradient or multi (Ti,Al,Si)N+TiN coatings should be attributed to the CAE process character and occurrence of the characteristic micro-particles (Fig. 2), due to deposition of the pure titanium droplets, coming from the sputtered disk.

The TiN+gradient or multi (Ti,Al,Si)N+TiN coatings applied both onto the substrate from the cermets and cemented carbides are characterised by the columnar structure of the TiN layer– corresponding to II zone of the Thornton's model, however, in case of the (Ti,Al,Si)N coating to zone IV (T) with the fine-grained, dense structure without pores and discontinuities, demonstrating a strong axial texture <111> (Fig. 3).

Investigations carried out with use of the transmission electron microscope of thin foils prepared 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. The structure of coatings is characterised by fine-graininess, and the size of particles of TiN type phase does not exceed 50 nm. Structures of coatings deposited onto the cemented carbides and tool cermets are presented in Figure 4.

The TiN+gradient or multi (Ti,Al,Si)N+TiN coatings are characterised by a very good adhesion to the substrate from the cemented carbides (L_c=57.2-90.1 N) and a clearly better than this one adhesion to cermets (L_c=106.8-131.2 N), which is due not only to adhesion but also to the diffusion mixing of elements in the transition zone (Table 1). The clearly better adhesion to substrate, of the TiN+gradient or multi(Ti,Al,Si)N+TiN coatings to the cermets than to the cemented carbides results also from the low roughness of the cermet substrate (R_a=0.20-0.22 μm) which influences a good anchoring of the developing coating without the unfavourable shadowing.

Microhardness of the uncoated cermets increases from, respectively, 2450-2500 $HV_{0,07}$, and of the cemented carbides from 1800-1900 $HV_{0,07}$ to 3100-3520 $HV_{0,07}$ due to deposition of the TiN+gradient or multi (Ti,Al,Si)N+TiN coatings, adding to increasing the tools' life – both made from the cemented carbides and cermets during cutting, from 1-17 minutes for the cemented carbides and uncoated cermets, to 20-60 minutes for the TiN+gradient or multi(Ti,Al,Si)N+TiN coatings, and besides the multilayer coatings demonstrate 10% longer life than the gradient layer coatings (Table 1).

Table 1.
Specification of the investigated materials

Type	Coating	Dimension g, mm	Roughness Ra, mm	Microhardness $HV_{0,07}$	Critical load Lc, N	Tool life T, min
W1	-	-	0.36	1800	-	1
W2	-	-	0.35	1900	-	4
C1	-	-	0.20	2500	-	14
C2	-	-	0.22	2450	-	17
W3	TiN	2.0	0.59	2000	49.6	8
W4	TiCN	4.0	0.55	2250	53.6	17
W5	TiN+TiC/TiN	7.5	0.53	2400	57.2	21
W6	TiCN+Al_2O_3+TiC	12.5	0.51	2590	51.4	19
W7	TiCN+Al_2O_3+TiN	10.5	0.60	2300	77.5	23
C3	TiN+TiC+TiN	5.0	0.79	3000	79.2	35
W1	TiN+multi(Ti,Al,Si)N+TiN	3.5-4.5	0.67	3200	59.5	27
W2			0.66	3280	90.1	33
C2			0.63	3520	106.8	43
C1			0.62	3390	120.9	60
W1	TiN+gradient(Ti,Al,Si)N+TiN		0.65	3100	57.2	20
W2			0.64	3190	77.1	22
C2			0.62	3330	114.8	43
C1			0.60	3310	131.2	55

W – cemented carbides; C – cermets

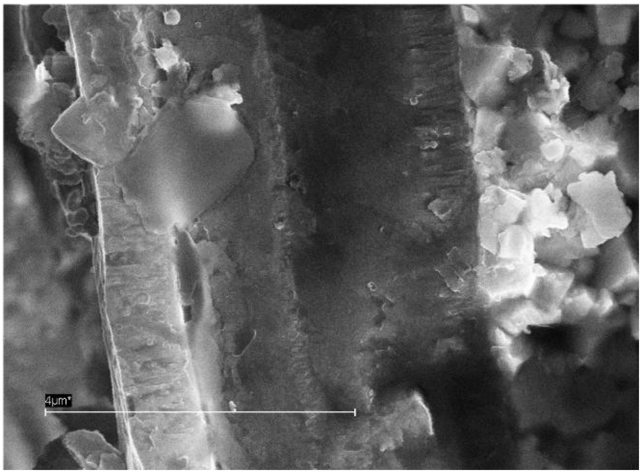

Fig. 1. Fracture surface of the TiN+multi(Ti,Al,Si)N+TiN coating deposited on the C1 cermet substrate

The real life tests confirm the quality of the newly-developed TiN + gradient or multi (Ti,Al,Si)N+TiN coatings obtained with the PVD technique in the cathodic arc evaporation process on the cemented carbides and cermets, as the material that significantly decreases the abrasive wear, thermal and adhesion wear, which immediately affects, among others, extension of the cutting edge life, which influences immediately the tool cutting edge life compared to the uncoated tools, and with the gradient- or multiple-layer coatings deposited using the CVD or PVD methods. The desired decrease of the particular wear types (abrasive, thermal, and adhesion ones) of the cutting tools, demonstrated by extension of the tool life, by deposition of the wear resistant coatings on their working surfaces, should be connected with a high microhardness of the coatings at the „room" temperature and at the elevated temperatures, with the low chemical affinity of tool edge material to the machined material (mostly to iron and carbon) and protecting the tool edge from oxidation and excessive overheating. The TiN+gradient or multi (Ti,Al,Si)N+TiN system coatings deposited with the PVD method in the cathodic arc evaporation CAE onto the substrates from cermets and cemented carbides reveal better working properties in comparison with the commercial tool materials with the gradient- or multi-layer and single- and two-component coatings deposited in the PVD or CVD processes 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.

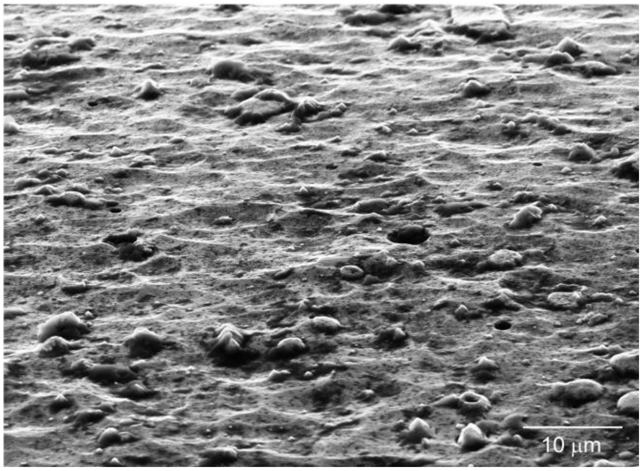

Fig. 2. Topography of the TiN+(Ti,Al,Si)N+TiN gradient coating surface, deposited on the W2 cemented carbide substrate

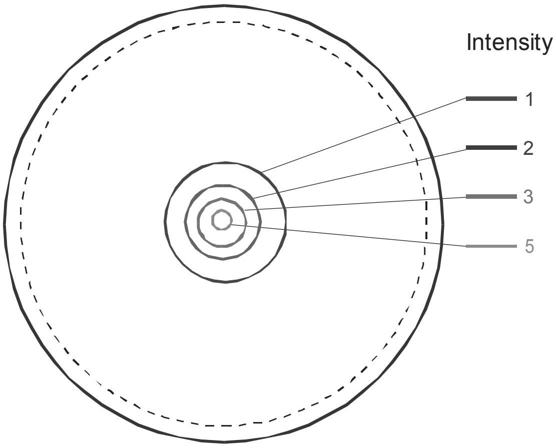

Fig. 3. Polar figure {111} of the TiN+multi (Ti,Al,Si)N+TiN coating deposited on the C1 cermet substrate

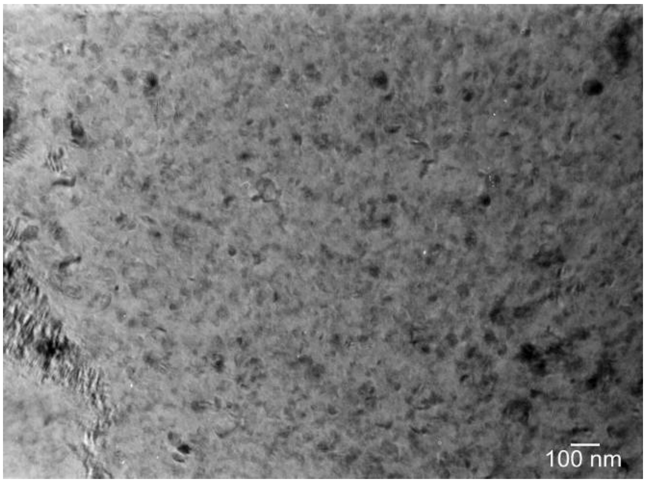

Fig. 4. Thin foil structure of the TiN+(Ti,Al,Si)N+TiN gradient coating deposited on the C2 cermet substrate

4. Conclusions

Coatings of the TiN+gradient or multi(Ti,Al,Si)N+TiN systems deposited with the PVD method in the CAE process onto the substrates of cermets and cemented carbides demonstrate better working properties than the commercially available tool materials with the single – and multiple-layer, as well as single- and double-component coatings deposited both in the PVD and CVD processes. Cutting tests confirm that the advantages of the TiN+gradient or multi(Ti,Al,Si)N+TiN type coatings obtained with the PVD method in the cathodic arc evaporation process on the cemented carbides and cermets, as a material significantly reducing abrasive, thermal and adhesion wear, which directly influences, among others, extension of tool life in comparison with commercially available uncoated tools and with the single- and multiple-layer coating deposited with the PVD/CVD methods.

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