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Properties of the multicomponent and gradient PVD coatings

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ABSTRACT

Purpose: This paper presents investigation results of the properties of the multicomponent (Ti,Al)N and gradient Ti(C,N) wear resistant coatings, deposited with the PVD process onto the substrate from the cemented carbides, cermets and Al_2O_3+TiC type oxide tool ceramics.

Design/methodology/approach: The methodology includes analysis of the mechanical and functional properties. The Ra parameter was assumed to be the value describing surface roughness. The microhardness tests using the Vickers method were made with use of dynamic ultra microhardness tester. The measurements were made in the „load - unload” mode. Tests of the coatings adhesion to the substrate material was made with use of the scratch test. Surface roughness tests were done both before depositing the coatings and after completing the PVD process. Cutting properties of the investigated materials were determined based on the technological continuous cutting tests of the EN-GJL-250 grey cast iron.

Findings: Main properties of the investigated materials were introduced. It has been stated, that properties of the cemented carbides, cermets and oxide tool ceramics with deposited multicomponent (Ti,Al)N and gradient Ti(C,N) PVD coatings increase in comparison with uncoated material. Multiple increase of tool life result among other things from almost double increase of microhardness of PVD coated materials in comparison with uncoated cemented carbides, cermets and oxide tool ceramics, increasing of thermal and chemical wear resistance and improving of chip formation and removing process’ conditions.

Practical implications: Pro-ecological dry cutting processes without the use of the cutting fluids and in the „Near-Net-Shape” technology.

Originality/value: Application of multicomponent (Ti,Al)N and gradient Ti(C,N) types of coatings onto sintered tool materials in order to improve cutting properties of tools.

Keywords: Tool materials; Gradient coatings; Cutting ability test; PVD

PROPERTIES

1. Introduction

At the present time, coatings obtained by physical vapor deposition (PVD) are widely used in the sintered tool materials industry. Coatings, which consist primarily of TiC, Ti(C,N), TiN, (Ti,Al)N, and their combinations, provide a considerable increase in tool life time of the coated tool materials, therefore have become popular as hard coatings for tools in recent years, in particular for higher speed cutting tools [1-7].

Gradient coatings are an innovative idea. The composition, microstructure and properties of gradient materials change continuously from the surface to the interior of the material. It is useful for increasing the adhesion strength between the coating and substrate material and provide expected functional properties of cutting tools, the investigated materials are used for. Moreover in case of continuous gradient coating problem of adhesion between particular layers of coating is eliminated in comparison with multilayer coatings [8-15].

In this paper is investigate the properties of the wear resistant multicomponent (Ti,Al)N and gradient Ti(C,N) types of coatings in the cathodic arc evaporation CAE-PVD method deposited onto cemented carbides, cermets and Al_2O_3+TiC type oxide tool ceramics.

2. Experimental procedure

Experiments were carried out on cemented carbides, cermets and Al_2O_3+TiC oxide ceramics using the PVD method of deposition from the gaseous phase in the cathodic arc evaporation process with the multicomponent (Ti,Al)N and functionally gradient layers Ti(C,N). Characteristics of the investigated materials has been presented in Table 1.

Coating thickness tests were made using the "kalotest" method consisting in measurement of the characteristic dimensions of the crater developed by friction of the steel ball with 20 mm diameter on the specimen surface. The diamond paste with the 1 μm granulation was introduced between the rotating ball and the specimen surface. Test duration time was assumed to be 120 s. Measurements of the wear land size were carried out on the NIKON Optiphot 100S light microscope equipped with the camera (Table 1).

The Ra surface roughness parameter measurements and observations of surfaces topography of the developed coatings were made on LSM 5 PASCAL confocal microscope.

The Vickers microhardness was measured using the Hanemann tester. The tests were made with the load of 0.98 N, making it possible to eliminate to the greatest extent the influence of the substrate material on the measurement results.

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 critical load L_C, at which coatings' adhesion is lost, was determined basing on the registered values of the acoustic emission AE.

Evaluation of the phase composition of the investigated coatings was made using the DRON 2.0 X-ray diffractometer, equipped with filtered cobalt lamp X-rays with the voltage of 40 kV and heater current of 20 mA. Measurements were made within the 2θ angle range between 35-105°.

Cutting ability of the investigated materials was determined basing on the technological continuous cutting tests of the EN-GJL-250 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=0.1 mm/rev, depth of cut a_p=1 mm, cutting speed v_c=200 m/min. The character of the developed failure was evaluated basing on observations on the light microscope and on the scanning electron microscope.

3. Research results and discussion

Roughness of the substrates defined by R_a parameter is within 0.06-0.13 μm range. Depositing the multicomponent (Ti,Al)N and gradient Ti(C,N) coatings onto the examined substrates causes increase of the roughness parameter from R_a=0.14 μm for the multicomponent (Ti,Al)N coating deposited on cemented carbide substrate, R_a = 0.12 μm for the multicomponent (Ti,Al)N coating deposited on cermet substrate, to R_a=0.27 μm for the multicomponent (Ti,Al)N coating deposited on Al_2O_3+TiC substrate. In case of gradient Ti(C,N) coating deposited on cemented carbide substrate the roughness parameter decreased in comparison to uncoated substrate but R_a parameter of gradient Ti(C,N) coating deposited on cermet and Al_2O_3+TiC substrate is significantly higher than in case of the uncoated material surfaces (Fig. 1).

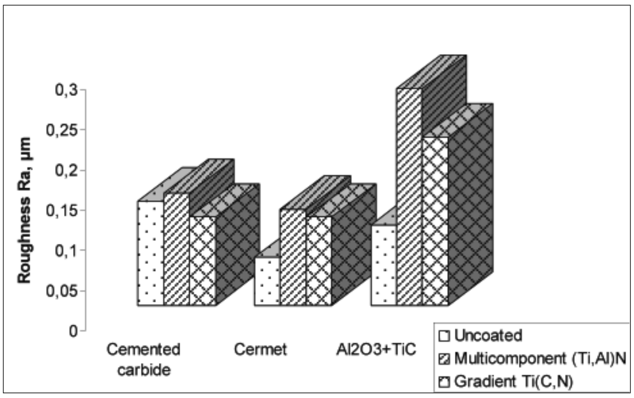

Fig. 1. Comparison of the roughness values of the investigated coatings and substrates

The highest microhardness of the investigated uncoated materials has been found in case of Al_2O_3+TiC substrate (2105 HV 0.1) and the lowest for the cemented carbide (1755 HV 0.1). Depositing the multicomponent (Ti,Al)N and gradient Ti(C,N) coatings on such substrate results in a significant increase of the surface layer hardness, in the range of 2850-3170 HV 0.1 (Fig. 2). Therefore, depositing the wear resistant coatings onto the tool cemented carbide, cermet, and oxide tool ceramics results in a significant increase of the surface layer microhardness, contributing in this way in machining to the decrease of the flank wear intensity of cutting tools' flanks.

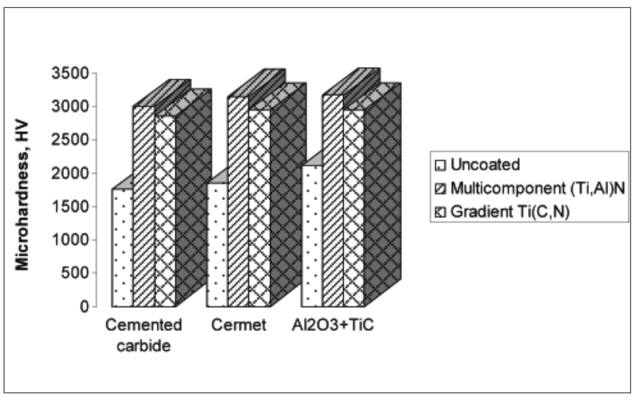

Fig. 2. Comparison of the microhardness values of the investigated coatings and substrates

Table 1.
Characteristics of the investigated materials

Substrate	Coating	Coating thickness, µm	Roughness, R_a µm	Microhardness, HV 0.1	Critical Load, L_c, N
Cemented carbide*	uncoated	-	0.13	1755	-
Cermet**		-	0.06	1850	-
Al_2O_3+TiC		-	0.10	2105	-
Cemented carbide*	(Ti,Al)N	2.2	0.14	3000	53.5
Cermet**		1.5	0.12	3150	69.5
Al_2O_3+TiC		1.6	0.27	3170	51.7
Cemented carbide*	gradient Ti(C,N)	1.5	0.11	2850	44.0
Cermet**		1.5	0.11	2950	57.7
Al_2O_3+TiC		1.3	0.21	2950	19.4

* phase composition: WC, TiC, TaC, Co,
** phase composition: Ti(C,N), WC, TiC, TaC, Co, Ni.

The critical load values L_c (AE) were determined using the scratch method with the linearly increasing load („scratch test"), characterising adherence of the investigated PVD coatings to the cemented carbides, cermets and tool ceramics. The critical load was determined as the one corresponding to the acoustic emission increase signalling beginning of spalling of the coating.

a)

b)

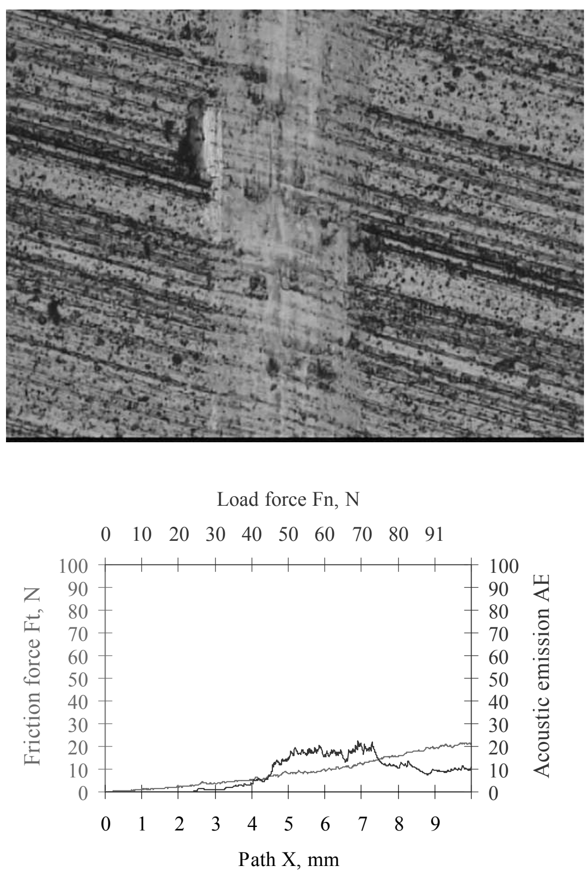

Fig. 3. a) Indenter trace with the optical L_c load, b) scratch test results of the Ti(C,N) coating surface deposited on cemented carbide substrate

The coatings deposited onto the investigated substrates are characterised by good adherence (L_c = 44.0-69.5 N) (Fig. 3), only in case of the Ti(C,N) gradient coating deposited onto the Al_2O_3+TiC oxide ceramic substrate the adherence value L_c=19.4 N (Table 1). Lower adherence of Ti(C,N) coating to ceramic substrate could be caused by local defect in substrate purification process before deposition. The very good adherence of PVD coatings to cermet substrate is a result of the fact that the source of the nitrogen for the developing coating is not only the working gas, but also nitrogen coming from the substrate alone, making diffusion mixing of elements in the interlayer easier.

Phase composition of the investigated PVD coatings and of the substrate was examined using the X-ray qualitative phase analysis method. It was demonstrated that according to the initial assumptions coatings containing the (Ti,Al)N and Ti(C,N) phases were developed on surfaces of the investigated cemented carbides, cermet and oxide ceramics (Fig. 4).

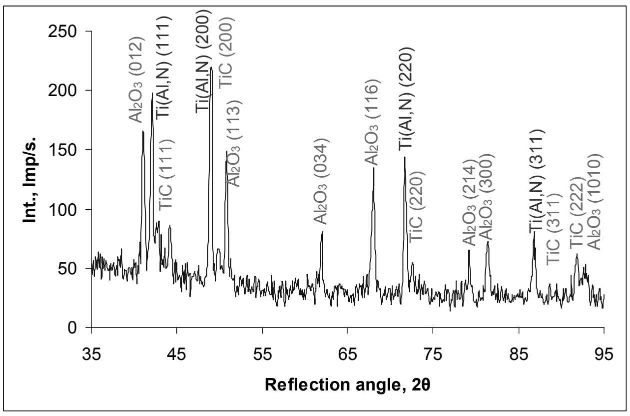

Fig. 4. X-ray phase analysis of the gradient (Ti,Al)N coating deposited on the Al_2O_3+TiC oxide ceramic substrate

Depending on used substrate material, life period of uncoated tools was in rage of 0.5 min. in case of tool made of cemented carbides and cermets to 12.5 min. in case of tools made of oxide tool ceramics. Depositing of investigated PVD coatings onto all used sintered tool materials caused significant increase of tool life measured during cutting tests. The highest increase of tool life was found in case of multicomponent (Ti,Al)N coating irrespective of substrate material used (Fig. 5). Multiple increase of tool life result among other things from almost double increase of microhardness of PVD coated materials in comparison with uncoated cemented carbides, cermets and oxide tool ceramics. Moreover, the increase of tool life should be connected with increasing of thermal and chemical wear resistance caused by occurrence of diffusion and thermal barrier. Increasing of tool life is most probably also caused by improving of chip formation and removing process' conditions.

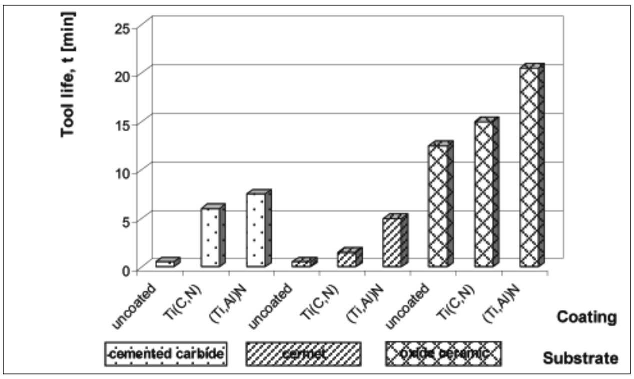

Fig. 5. Comparison of tool life for tools from cemented carbides, cermets, and oxide ceramic with the multicomponent (Ti,Al)N and gradient Ti(C,N) coatings

4. Conclusions

The results of the investigations of the cemented carbide, cermet and Al_2O_3+TiC type oxide tool ceramics coated with the multicomponent (Ti,Al)N and gradient Ti(C,N) types of coatings with use of the cathodic arc evaporation CAE-PVD method are given in the paper. The results of roughness and microhardness tests confirm the advantages of the multicomponent (Ti,Al)N and gradient Ti(C,N) coatings. As results of the examination of coating microhardness it has been found that multicomponent and gradient coatings on the investigated materials causes the 35-76 % increase of microhardness value. The coatings deposited onto the investigated substrates are characterised by good adherence. The very good adherence of PVD coatings to cermet substrate is a result of the fact that the source of the nitrogen for the developing coating is not only the working gas, but also nitrogen coming from the substrate alone, making diffusion mixing of elements in the interlayer easier. Multiple increase of tool life result among other things from almost double increase of microhardness of PVD coated materials in comparison with uncoated cemented carbides, cermets and oxide tool ceramics, increasing of thermal and chemical wear resistance and improving of chip formation and removing process' conditions.

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