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Functional properties of the sintered tool materials with (Ti,Al)N coating

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Properties

ABSTRACT

Purpose: The paper presents investigation results of functional properties of the sintered tool materials: high-speed steel matrix composites (HSSMC), cemented carbides, cermets and Al_2O_3 type oxide tool ceramics with (Ti,Al)N coating deposited in the cathodic arc evaporation CAE-PVD method and comparing them with the uncoated tool materials.

Design/methodology/approach: Analysis of the mechanical and functional properties: surface roughness, microhardness tests, scratch tests, cutting tests. X-ray qualitative microanalysis of elements.

Findings: Deposition of (Ti,Al)N coating onto high-speed steel matrix composites (HSSMC), cemented carbides, cermet and Al_2O_3 type oxide tool ceramics substrate causes increase of wear resistance as well as reduces the exceeding of steady stresses critical levels. It causes multiple (up to 800%) increase of tool life. As a result of metallographic observations it was stated that linear and uniform character of wear was achieved in case of all deposited samples.

Practical implications: Employment of the hard coatings deposited onto sintered tool materials is reckoned as one of the most important achievements last year in the area of improvement of functional properties of cutting tools.

Originality/value: Combination of substrates (especially coatings deposited on high-speed steel matrix composite) is unique and very interesting in respect of achieved functional properties.

Keywords: Wear Resistance; Coating; Sintered tool materials; Tool life; Cutting test

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1. Introduction

Cutting tool wear is the result of load, friction, and high temperature between the cutting edge and the workpiece. Several wear mechanisms can occur during metal cutting: adhesive wear, abrasive wear, diffusion wear, oxidation wear, and fatigue wear. Typical tool wear model after cutting is presented in Fig. 1. The tribological properties of uncoated tool material never satisfy all performance requirements. Coated tools can generate high wear resistance on the surface with high toughness in the substrate material. Properly applied coatings increase the surface hardness of cutting tools at high cutting temperatures, thus minimizing abrasive wear. The coating provides a chemical barrier to decrease diffusion or reaction between the tools and the workpiece, thus reducing tool wear [1-9, 12-16].

In the development of new, contemporary materials the functionality is often improved by combining materials of different properties into composites. Coating composites are specifically designed to improve properties such as tribological, electrical, optical, electronic, chemical and magnetic ones. (Ti, Al)N coatings are characteristic for high hardness, good wear-resistance and excellent, high-temperature properties. Therefore, (Ti,Al)N coatings have become popular as hard coatings for tools in recent years [1-11, 17-19].

The goal of this work is to investigate the functional properties of the high-speed steel matrix composites (HSSMC), cemented carbides, cermets and Al_2O_3 type oxide tool ceramics with (Ti,Al)N coating deposited in the cathodic arc evaporation CAE-PVD method and comparing them with the uncoated tool materials.

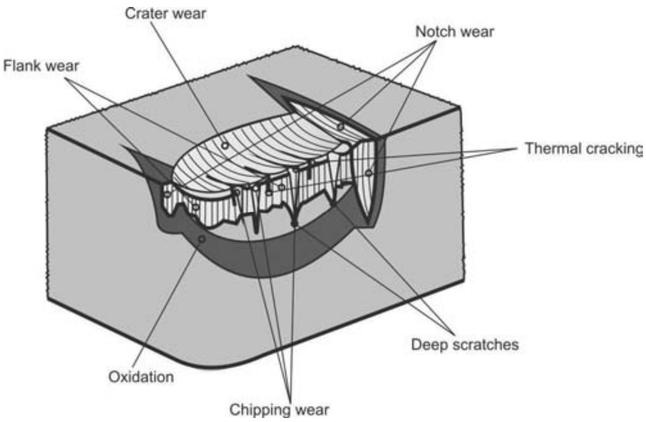


Fig. 1. Tool wear model [20]

2. Methodology of research

Experiments were carried out on high-speed steel matrix composites (HSSMC), cemented carbides, cermets and Al_2O_3 type oxide tool ceramics with (Ti,Al)N coating deposited in the PVD process which were later compared with the uncoated samples (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 based on the registered values of the acoustic emission AE.

Cutting ability of the investigated materials was determined based on the technological continuous cutting tests of the EN-GJL-250 grey cast iron with the hardness of about 250 HB (Fig. 2). The wear band VB=0.20 mm wide, on the surface of the tool used for machining, it was the criterion for the cutting edge consumption evaluation. The following parameters were used in the machining capability experiments: feed rate f=0.1 mm/trn, depth of cut a_p=1 mm, cutting speed v_c=150 m/min. The character of the developed failure was evaluated based on observations made on the light microscope and on the scanning electron microscope and analysis of the chemical composition of the tool wear using the X-ray energy dispersive spectrograph (EDS).

3. Results

Roughness of the substrates defined by R_a parameter is within 0.06-0.13 µm range. Depositing (Ti,Al)N coating onto the examined substrates causes increase of the roughness parameter from R_a=0.14 µm for the cemented carbide substrates, R_a = 0.12 µm high-speed steel matrix composite (HSSMC) and cermet substrates, to R_a=0.27 µm for the (Ti,Al)N coating deposited on Al_2O_3+TiC substrate.

Fig. 2. Machining test overview

The highest microhardness of the investigated uncoated materials has been stated in case of Al_2O_3+TiC substrate (2105 HV 0.1) and the lowest for the high speed-steel matrix composite (1150 HV 0.1). Depositing the (Ti,Al)N coating on such substrate results in a significant increase of the surface layer hardness, in the range of 2850-3170 HV 0.1. Therefore, depositing the wear resistant coatings onto the tool high speed-steel matrix composites, cemented carbides, cermets, 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.

The critical load values L_c (AE) were determined using the scratch method with the linearly increasing load ("scratch test"), characterising adhesion of the investigated (Ti,Al)N coating onto high-speed steel matrix composites, 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. The coatings deposited onto the investigated substrates are characterised by good adhesion (L_c = 57.1-69.5 N) (Table 1, Fig. 3). The very good adhesion of (Ti,Al)N coating to cermet substrates 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.

Table 1.
Characteristics of the (Ti,Al)N coatings deposited on the sintered tool materials

Substrate	Coating – Designation	Coating – Composition	Coating – Thickness, μm	Roughness, μm	Microhardness, HV	Critical load L_c, N	Tool life t, min
HSSMC	MC0	uncoated		0.08	1150	-	2.0
Cemented carbide	W0			0.14	1755	-	2.5
Cermet	M0			0.07	1850	-	2.5
Al_2O_3+TiC	C0			0.12	2105	-	18
HSSMC	MC1	(Ti,Al)N	1.9	0.12	2850	61.5	16
Cemented carbide	W1		2.2	0.13	3000	53.5	20
Cermet	M1		1.5	0.12	3150	66.5	19.5
Al_2O_3+TiC	C1		1.6	0.25	3170	57.1	40

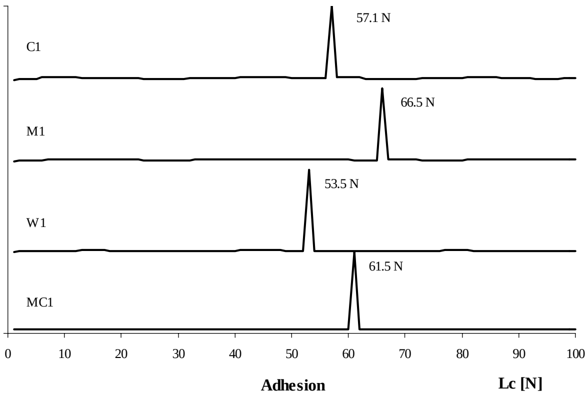


Fig. 3. Comparison of the critical load according to the scratch test of (Ti,Al)N coating deposited on high-speed steel matrix composites, cemented carbides, cermets and Al_2O_3 type oxide tool ceramics

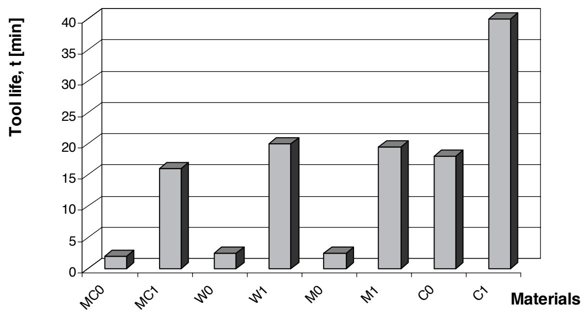


Fig. 4. Comparison of tool life for tools from high-speed steel matrix composites, cemented carbides, cermets, and oxide ceramic with the (Ti,Al) coatings

Depending on used substrate material, life period of uncoated tools was in rage of 2 min. in case of tool made of high-speed steel matrix composites, 2.5 min. of tool made of cemented carbides and cermets to 18 min. in case of tools made of oxide tool ceramics. Depositing of investigated (Ti,Al)N coating onto all used sintered tool materials caused significant increase of tool life measured during cutting tests (Fig. 4). Comparison of the approximated values of the VB wear of the sintered tool materials: uncoated and coated with the (Ti,Al)N coating, depending on machining time is shown in Figs. 6-9.

In case of machining tests carried out with use of HSSMC and cermet samples, very quick edge fracture occurred (Fig. 10). Deposition of (Ti,Al)N coating onto HSSMC as well as onto cermet substrates causes increasing of wear resistance as well as reduces the exceeding of steady stresses' critical levels. It causes multiple (up to 800%) increase of tool life (Figs. 6-8). As a result of metallographic observations it was stated that linear and uniform character of wear was achieved in case of all deposited samples (Figs. 5, 11).

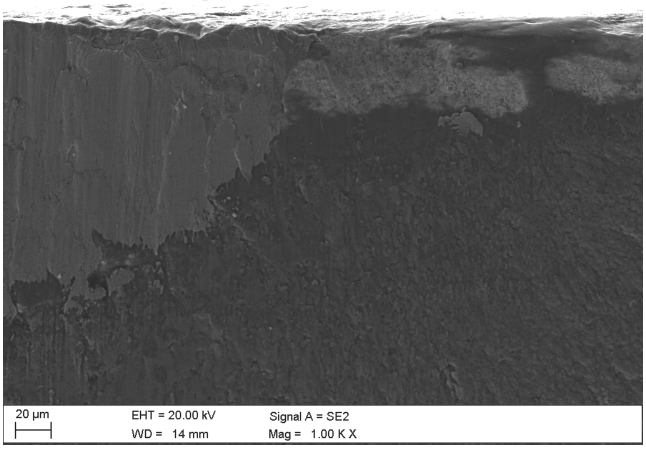


Fig. 5. Character of wear of the high speed-steel matrix composites (HSSMC) sample with (Ti,Al)N coating, investigated with SEM after cutting test

In X-ray energy dispersive spectrum (Fig. 13) any signal obtained from substrate material was detected in the worn area of the cermets sample coated by (Ti,Al)N (area "a" Fig. 12). Metallographic observations confirm that (Ti,Al)N coating was worn evenly and gradually. Obtained results indicate very high adhesion of investigated coatings. As a result of carried out EDS analysis, the occurrence of Fe was detected in a area “b” (Fig. 14). It confirms, that built-up edge was formed in analyzed area. The built-up edge is relatively small and it does not influence significantly on increasing of wear connected with friction as well as should not decrease the quality of work-piece. The X-ray energy dispersive spectrum from area “c” in Fig. 12, located outside the wear zone, is presented in Fig. 15.

Oxide ceramics is characterized by high wear resistance, but is very susceptible to brittle cracking caused by critical increase of steady stresses (Fig. 8). Damage of the edge is a consequence of tool material chipping and mechanical damage testimony of the sample. As a result of SEM investigations it was stated, that most common identified types of uncoated samples’ wear are: flank face abrasion, crater making in rake face area, chipping of edges and forming the built-up edge (Fig. 16a). Oxide ceramics employed in machining processes is connected with very restrict requirements of machining conditions (rigidity of the machine) and of high quality of the work-piece (very low level of discontinuity).

Deposition of (Ti,Al)N coating onto oxide ceramic substrate causes significant increase of functional properties first of all by changing of the tool wear character, minimization of disadventageous processes (built-up edge forming and brittle cracking). As a result of metallographic observations it was stated that, in spite of partially delamination of coating deposited onto oxide ceramics, built-up edge forming and brittle cracking was much more lower than in case of uncoated samples. In spite of partially delamination of coating, being most probably an effect of deposition process disturbance, wear of coated sample was uniform (Fig. 16b).

Multiple increase of tool life results among other things from very high increase of microhardness of PVD coated materials in comparison with uncoated HSSMC, cemented carbides, cermets and oxide tool ceramics.

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 the process conditions.

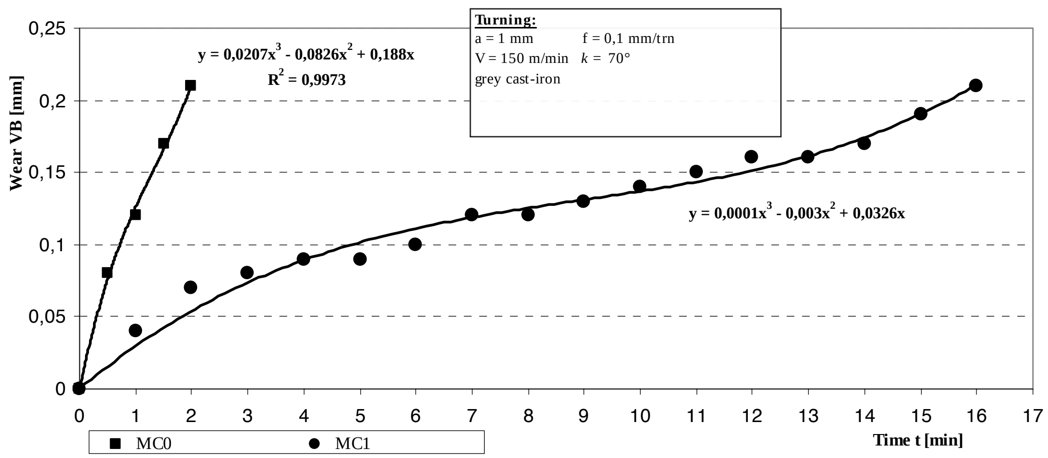


Fig. 6. Comparison of the approximated values of the VB wear of the high-speed steel matrix composites sample: uncoated and coated with the (Ti,Al)N coating, depending on machining time

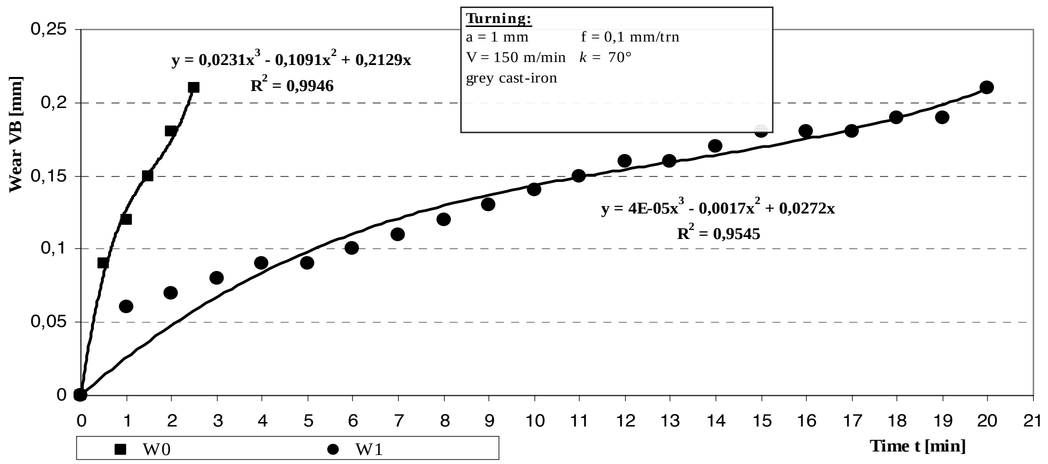


Fig. 7. Comparison of the approximated values of the VB wear of the cemented carbides sample: uncoated and coated with the (Ti,Al)N coating, depending on machining time

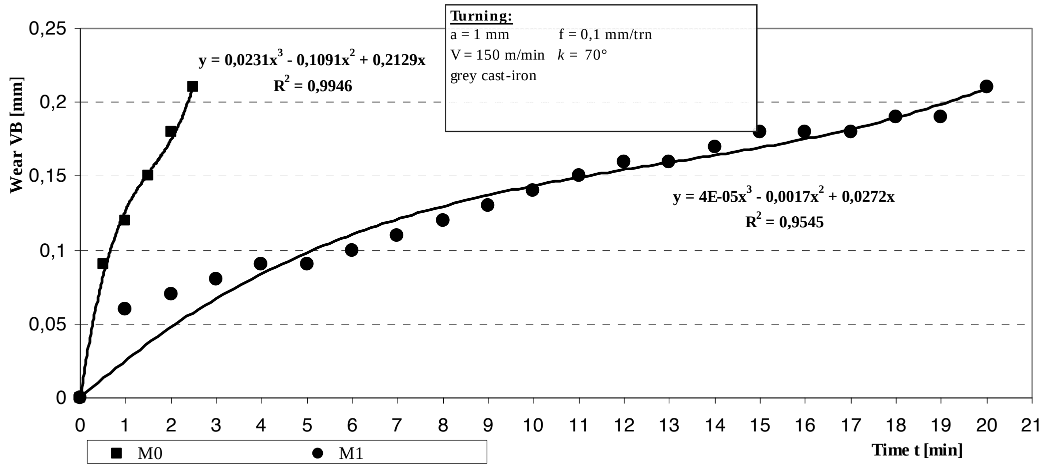


Fig. 8. Comparison of the approximated values of the VB wear of the cermets sample: uncoated and coated with the (Ti,Al)N coating, depending on machining time

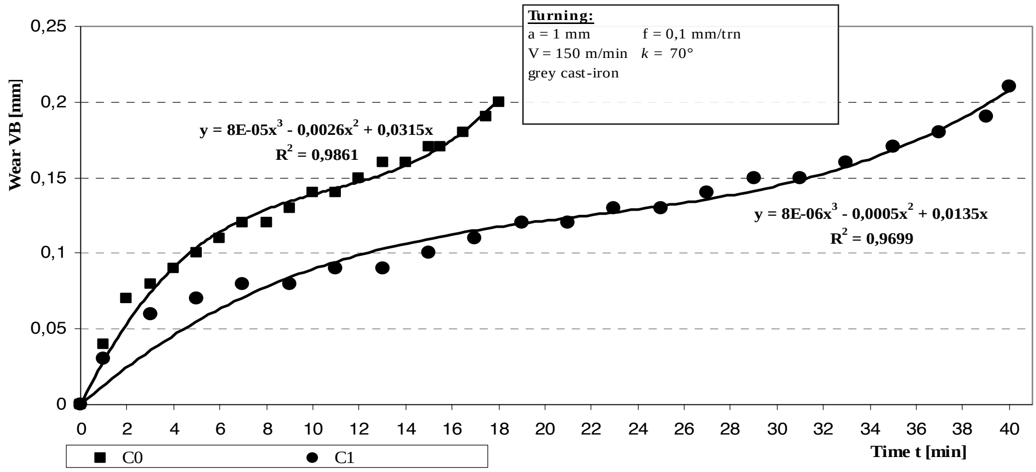
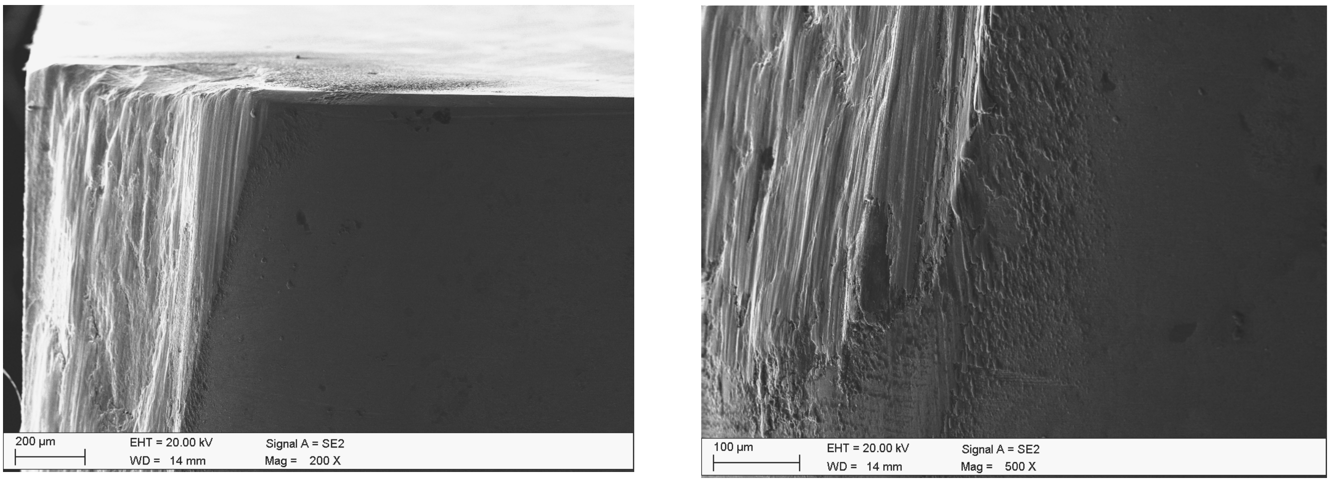
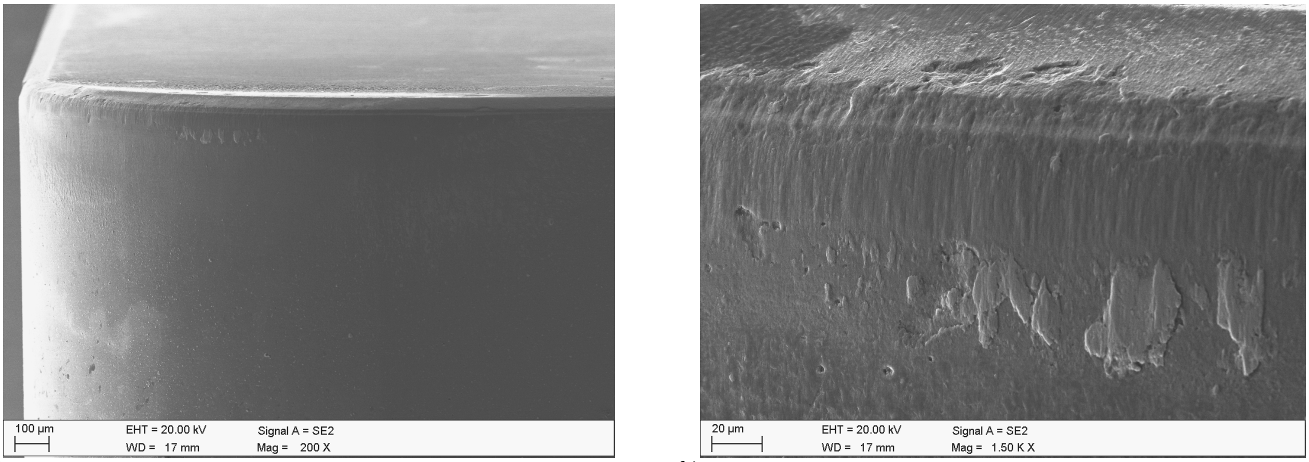


Fig. 9. Comparison of the approximated values of the VB wear of the Al_2O_3 type oxide tool ceramics sample: uncoated and coated with the (Ti,Al)N coating, depending on machining time



a) b)

Fig. 10.(a) Character of wear of the cermets sample uncoated, investigated with SEM after cutting test, (b) the detail of (a)



a) b)

Fig. 11.(a) Character of wear of the cermets sample with (Ti,Al)N coating, investigated with SEM after cutting test, (b) the detail of (a)

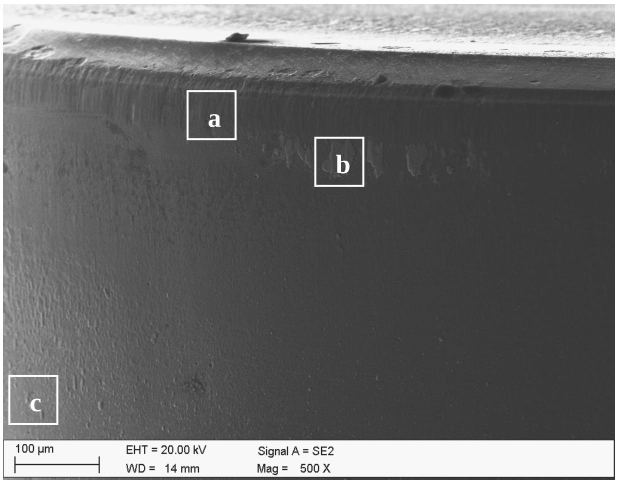


Fig. 12. Character of wear of the cermets sample with (Ti,Al)N coating, investigated with SEM

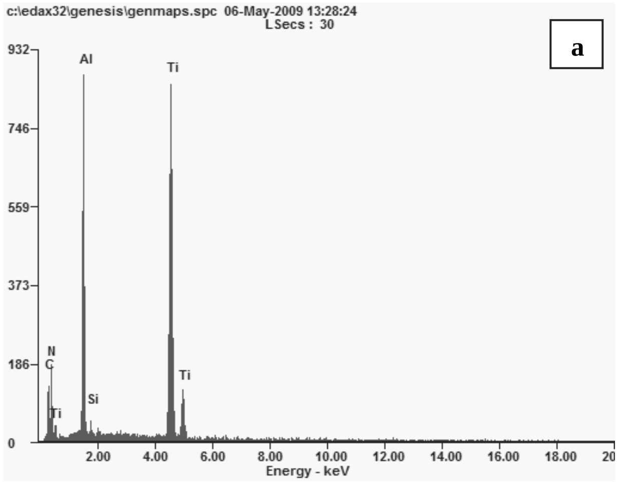


Fig. 13. X-ray energy dispersive spectrum from the surface of the (Ti,Al)N coating deposited on cermets substrate. Area of point on Fig. 12

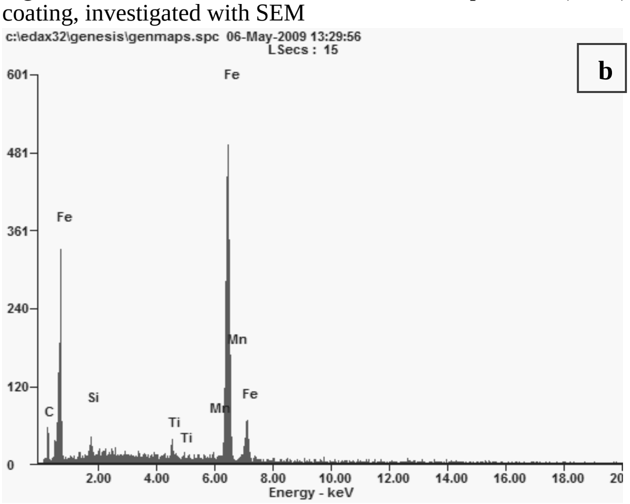


Fig. 14. X-ray energy dispersive spectrum from the surface of the (Ti,Al)N coating deposited on cermets substrate. Area of point on Fig. 12

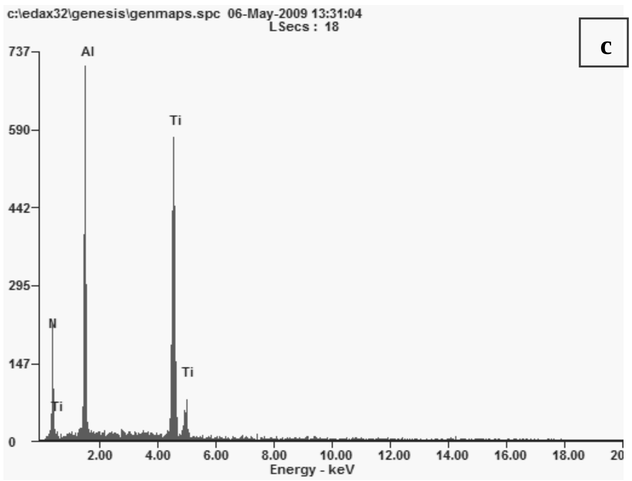
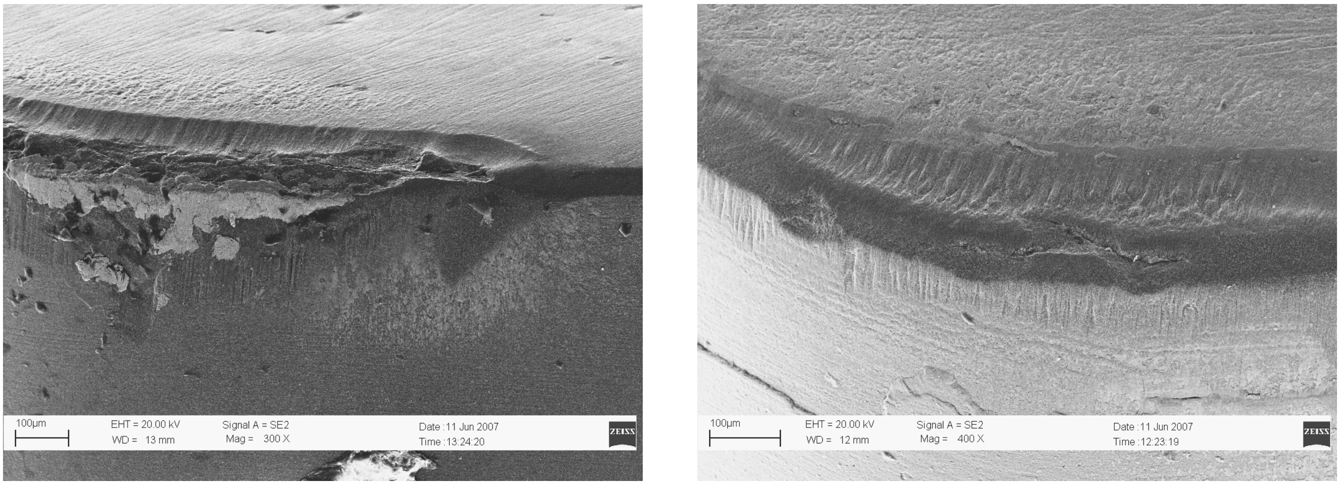


Fig. 15. X-ray energy dispersive spectrum from the surface of the (Ti,Al)N coating deposited on cermets substrate. Area of point on Fig. 12



a) b)

Fig. 16.(a) Character of wear of the Al_2O_3 type oxide tool ceramics sample uncoated, and (b) Al_2O_3 type oxide tool ceramics sample with (Ti,Al)N coating, investigated with SEM after cutting test

4. Conclusions

The results of the investigations of the high-speed steel matrix composites (HSSMC), cemented carbides, cermets and Al_2O_3+TiC type oxide tool ceramics coated with the (Ti,Al)N coating 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 (Ti,Al)N coating. As results of the examination of coating microhardness it has been found that (Ti,Al)N coating on the investigated materials causes the 47-148 % increase of microhardness value. The coatings deposited onto the investigated substrates are characterised by good adhesion. The very good adhesion of PVD coatings to cermet substrate is a result of the fact that the source of the nitrogen to develop a coating is not only the working gas, but also nitrogen coming from the substrate alone, making diffusion mixing of elements in the interlayer easier.

It was found out, on the basis of the metallographic analysis carried out on the scanning electron microscope, that the tribological defect types occurring most often, identified in the investigated materials are as follows: mechanical defects and abrasive wear of the tool flank, development of the crater on tool face, thermal cracks on tool flank, spalling of the cutting edge, and build-up edge from the chip fragments.

Uniform wear model on the tool flank, was observed in case of all coated samples. Deposition of (Ti,Al)N coating onto HSSMC as well as onto cermet substrate causes increasing of wear resistance as well as reduces the exceeding of steady stresses' critical levels. It causes multiple (up to 800%) increasing of tool life. Such significant increase of tool life results among other things from very high increase of microhardness of PVD coated materials in comparison with uncoated samples, increase of thermal and chemical wear resistance and improvement of chip formation and process conditions removal.

Increase of thermal and chemical wear resistance caused by occurrence of diffusion and thermal barrier, the most important reason is the increase of tool life.

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