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Structure and mechanical properties of PVD coatings for tool materials

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Materials

ABSTRACT

Purpose: The goal of this work is to investigate and compare the properties of (Ti,Al)N, Ti(C,N) and (Ti,Al,Si)N coatings, deposited on cemented carbide and cermet substrates.
Design/methodology/approach: Coatings deposition were carried out using the PVD method by the cathodic arc evaporation (CAE) process. Investigations of surfaces and structures of the deposited coatings were carried out with use of SEM and TEM methods. Roughness parameter measurements, adhesion evaluation of the coatings on the investigated inserts, the Vickers microhardness measurements and detailed cutting tests were carried out to compare the properties of the investigated materials.
Findings: The results of the investigations carried out confirm the advantages of PVD coatings deposited onto both: cemented carbides and cermets, especially in case of (Ti,Al)N and (Ti,Al,Si)N coatings. Coatings deposited onto the investigated substrates are characterised by good adhesion, high microhardness, taking effect in very high increasing of wear resistance.
Practical implications: Deposition of hard, thin, multicomponent coatings on materials surface by PVD method features one of the most intensely developed directions of improvement of the working properties of materials. Employment of introduced combinations of substrates and coatings make it possible to transit of machining of semi-products from roughing to semi-finishing or finishing in one setting.
Originality/value: Coatings based on (Ti,Al)N, (Ti,Al,Si)N as well as Ti(C,N) were developed to provide better performance over titanium nitride since the incorporation of aluminum or carbon in TiN increased hardness, decreased coefficient of friction of the coatings. Tools with such coatings reveal a significant life extension in service compared to the uncoated tools or coated with simple coatings based on monolayers of nitrides 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.
Keywords: Tool materials; Multicomponent coatings; PVD

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1. Introduction

Cermets as well as modern cemented carbides coated with the anti-wear layers belong to the contemporary cemented tool materials with a fast growing importance in machining technology. Broader and broader employment of cermets – the fastest developing tool materials – is connected with transition of machining of semi-products from roughing to semi-finishing or finishing in one setting. Coatings based on (Ti,Al)N, (Ti,Al,Si)N as well as Ti(C,N) were developed to provide better performance over titanium nitride since the incorporation of aluminum or carbon in TiN increased hardness, decreased coefficient of friction of the coatings. Tools with such coatings reveal a significant life extension in service compared to the uncoated tools or coated with simple coatings based on monolayers of nitrides 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. [1-16] The goal of this work is to investigate and compare the properties of (Ti,Al)N, Ti(C,N) and (Ti,Al,Si)N coatings, deposited on cemented carbide and cermet substrates.

2. Experimental method

Experiments were carried out on cemented carbides and cermets substrates coated with multicomponent (Ti,Al)N, Ti(C,N) and (Ti,Al,Si)N coatings. Characteristics of the investigated materials has been presented in Table 1. Coatings deposition were carried out using the PVD method by the cathodic arc evaporation (CAE) process. Conditions of the process: substrate temperature: 500°C, pressure in the chamber: 0.04 Pa.

Observations of surfaces and structures of the deposited coatings were carried out on the transverse fractures in the scanning electron microscope SUPRA 35. To obtain the fracture images the Secondary Electrons (SE) detection method has been used with the accelerating voltage in the range of 15-20 kV and maximum magnification 30 000x.

The R_a 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 0.1 N, making it possible to minimalize 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 values L_c (AE) were determined using the scratch method with the linearly increasing load ("scratch test"), characterising adhesion of the investigated PVD coatings onto the substrate. The critical load was determined as the one corresponding to the acoustic emission increase signalling beginning of spalling of the coating.

Diffraction and thin film microstructure were made with use of the JEOL 3010 transmission electron microscope at the accelerating voltage 300 kV. The thin films were produced as a result of mechanical thinning and further ionic polishing using the Gatan apparatus. The electron diffractions from TEM were solved with use of Eldyf computer program.

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/trn, depth of cut a_p=1 mm, cutting speed v_c=150 m/min. The character of the developed failure was evaluated basing on observations 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).

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	Tool life t, min
Cemented carbide*	uncoated	-	0.13	1755	-	2,5
	(Ti,Al)N	2.2	0.14	2750	47	20,0
	Ti(C,N)	1.5	0.13	2600	44	5,0
	(Ti,Al,Si)N	2,7	0.14	2850	41	18,0
Cermet**	uncoated	-	0.06	1850	-	2,5
	(Ti,Al)N	1.5	0.13	2900	54	19,5
	Ti(C,N)	1.5	0.12	2950	42	8,0
	(Ti,Al,Si)N	2,9	0.14	2920	45	18,5

* phase composition: WC, TiC, TaC, Co,
** phase composition: TiCN, WC, TiC, TaC, Co, Ni.

3. Results and discussion

It was found out, basing on the metallographic examinations of fractures made on the scanning electron microscope (SEM) that the investigated materials are characteristic of the dense, compact structure, there have been identified no pores, fractures and discontinuities. The (Ti,Al)N, Ti(C,N) and (Ti,Al,Si)N coatings were deposited uniformly onto the investigated substrates. They present a characteristic columnar, fine-graded structure, depending on the coating type employed. Investigated coatings adhere tightly to the substrate (Fig. 1).

Basing on the thin foils examinations of thin foils from (Ti,Al,Si)N coatings it was stated that, according to the original assumptions, coatings containing the TiN type phases were deposited onto the substrate. It is not feasible to differentiate these phases from the diffraction point of view, due to isomorphism of the TiN and Ti(C,N) phases. The average size of coatings crystallites is less then 100 nm, on deposited coatings can be classificated as nanostructural coatings. TEM investigation results of the (Ti,Al,Si)N coating deposited onto the cermet substrate are presented in Fig. 2.

Roughness of the cemented carbide and cermet substrates defined by R_a parameter is within 0.06-0.13 µm range. Depositing the (Ti,Al)N, Ti(C,N) and (Ti,Al,Si)N coatings onto the examined substrates increase of the roughness parameter from R_a = 0.12-0.14 (Table 1).

The microhardness of the investigated uncoated materials is in range of 1755 HV for cemented carbides and 1850 HV for cermet substrates.

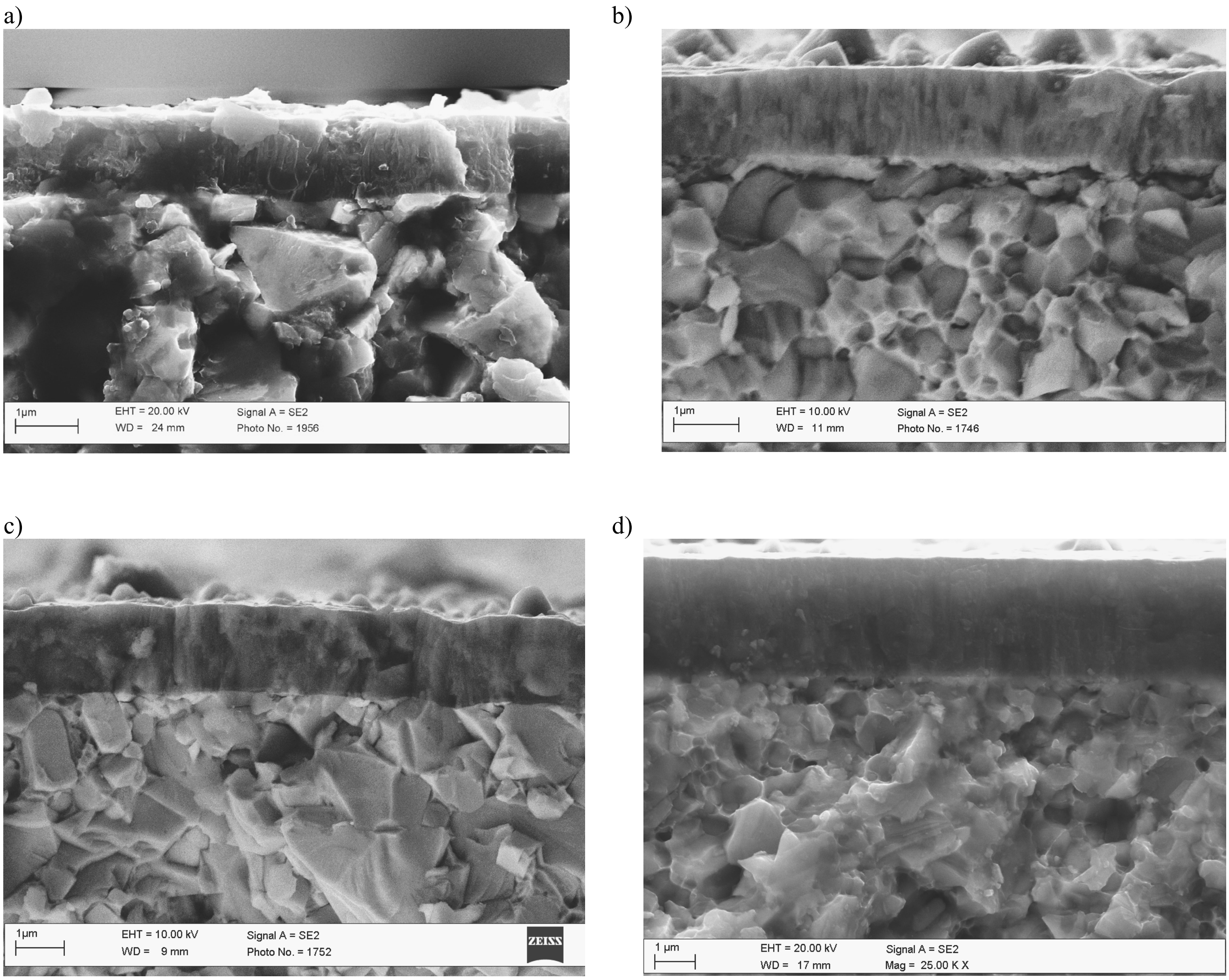


Fig. 1. Structure of the: a) Ti(C, N) coating deposited onto the cemented carbide substrate b) Ti(C, N) coating deposited onto the cermet substrate, c) (Ti,Al)N coating deposited onto the cemented carbides substrate, d) (Ti,Al,Si)N coating deposited onto the cermet substrate

Depositing the (Ti,Al)N, Ti(C,N) and (Ti,Al,Si)N coatingss on such substraes results in a significant increase of the surface layer hardness, in the range of 2600-2950 HV (Table 1). Therefore, depositing the wear resistant coatings onto the tool cemented carbides and cermets, 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.

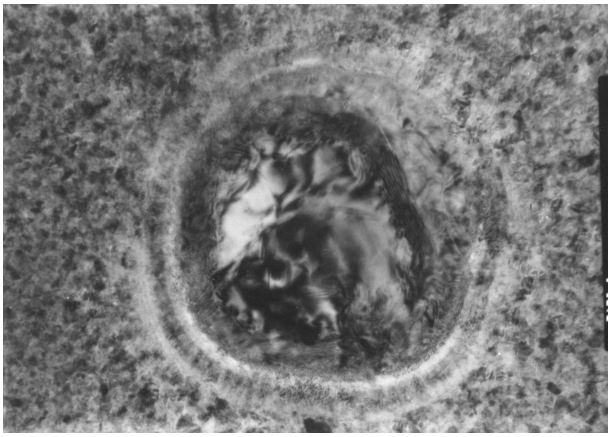
Deposited (Ti,Al)N, Ti(C,N) and (Ti,Al,Si)N coatings onto cemented carbide and cermet substrates are characterised by good and similar adhesion (L_c = 41.0-54 N) (Table 1, Figs. 3, 4).

It was found out, basing on the technological turning test of grey cast iron workpiece with the cemented carbides and cermets, that tool life doesn't depend on kind of substrate and was 2.5 min.

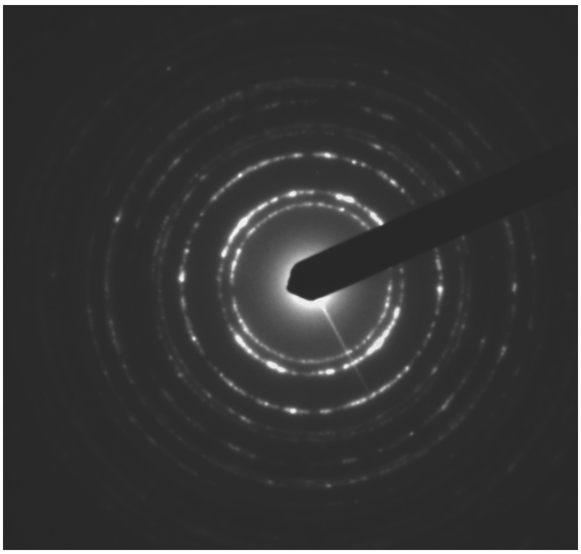
Depositing of investigated (Ti,Al)N and (Ti,Al,Si)N coatings onto all used sintered tool materials caused significant increase of tool life measured during cutting tests (Table 1).

Much lower results was achieved in case of Ti(C,N) kind of coatings. It can be connected with increased wear of Ti(C,N) coating over 400°C and relatively high wear resistance of (Ti,Al)N coatings at elevated temperature, which could appear at assumed test's conditions. Comparison of the approximated values of the VB wear of all combinations of investigated materials depending on machining time is shown in Figs. 5-10. As a result of metallographic observations it was stated that linear and uniform character of wear was achieved in case of all deposited samples (Fig. 11).

a)



b)



c)

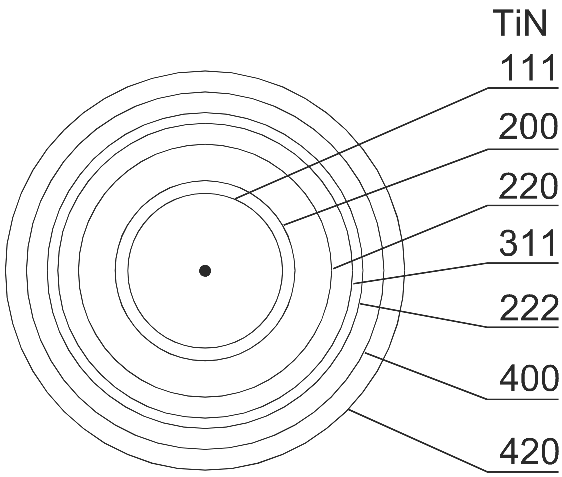
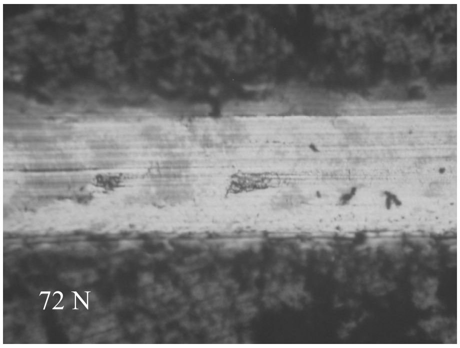


Fig.2. a) Structure of the thin foil from the (Ti,Al,Si)N coating deposited on cermet substrate, b) diffraction pattern for the area as from figure a, c) solution of the diffraction pattern from figure b.

a)

b)



c)

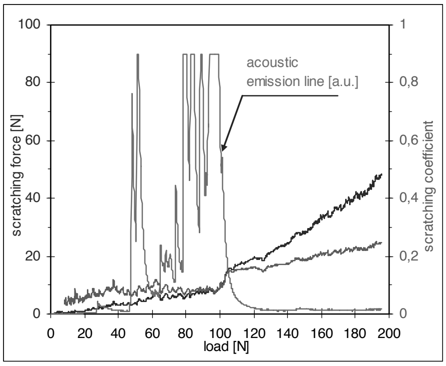
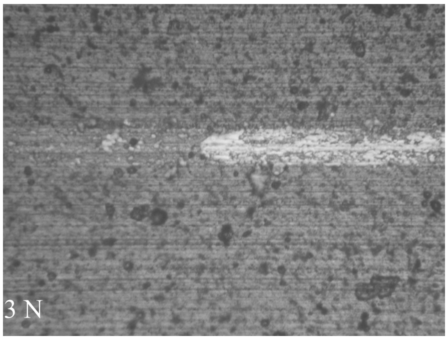
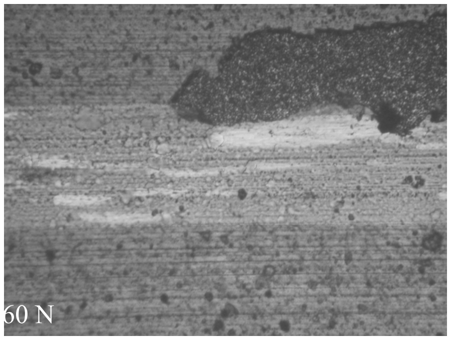


Fig. 3. a), b): Indenter trace with the optical L_c load, c) scratch test results of the (Ti,Al,Si)N coating surface deposited on cemented carbide substrate

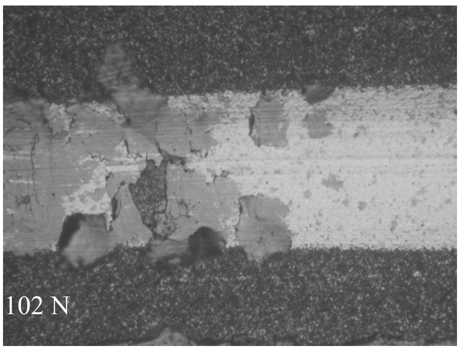
a)



b



c)



d)

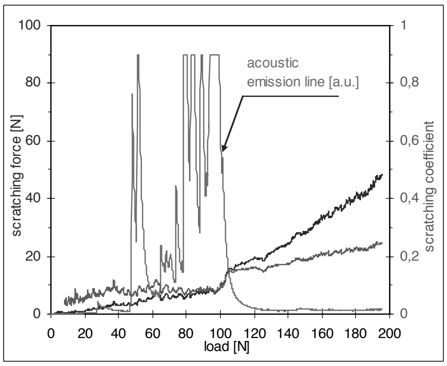


Fig. 4. a), b), c): Indenter trace with the optical Lc load, d) scratch test results of the (Ti,Al,Si)N coating surface deposited on cermet substrate

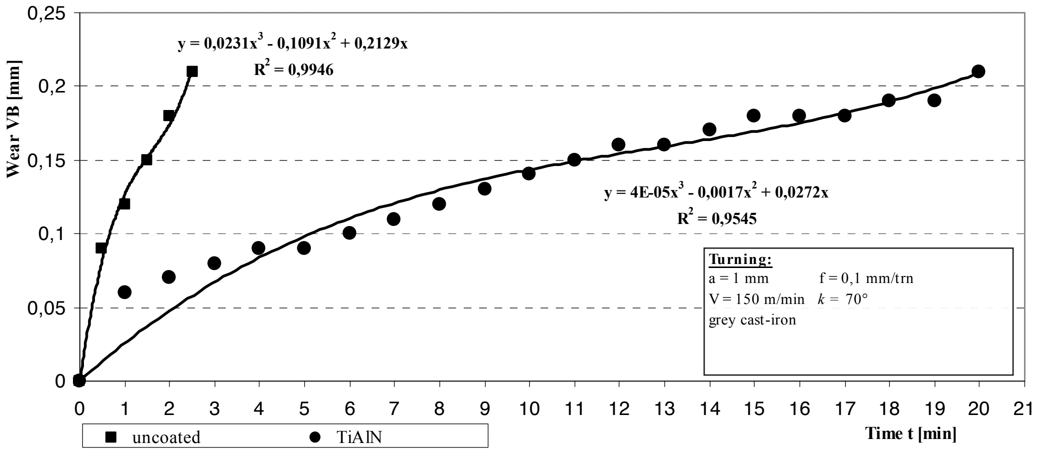


Fig. 5. Comparison of the approximated values of the VB wear of the cemented carbide sample: uncoated and coated with the (Ti,Al)N coating, depending on machining time

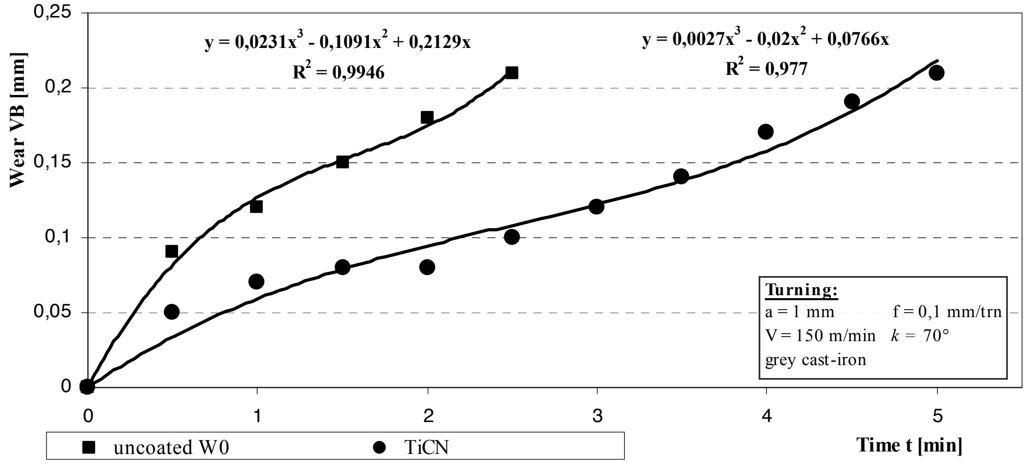


Fig. 6. Comparison of the approximated values of the VB wear of the cemented carbides sample: uncoated and coated with the Ti(C,N) coating, depending on machining time

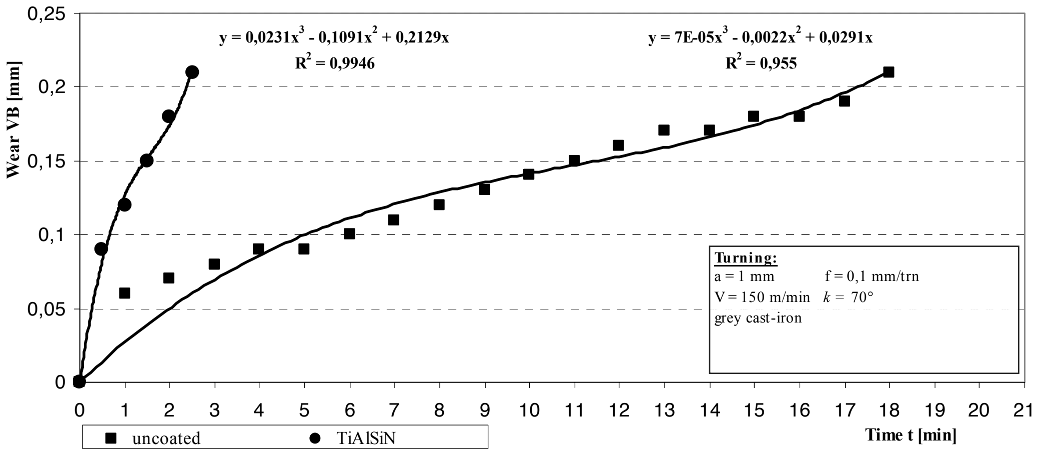


Fig. 7. Comparison of the approximated values of the VB wear of the cemented carbide sample: uncoated and coated with the (Ti,Al,Si)N coating, depending on machining time

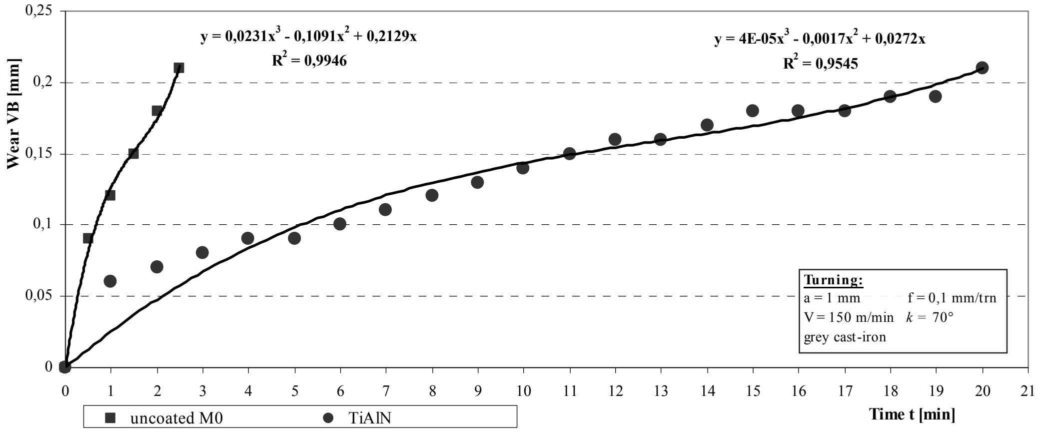


Fig. 8. Comparison of the approximated values of the VB wear of the cermet sample: uncoated and coated with the (Ti,Al)N coating, depending on machining time

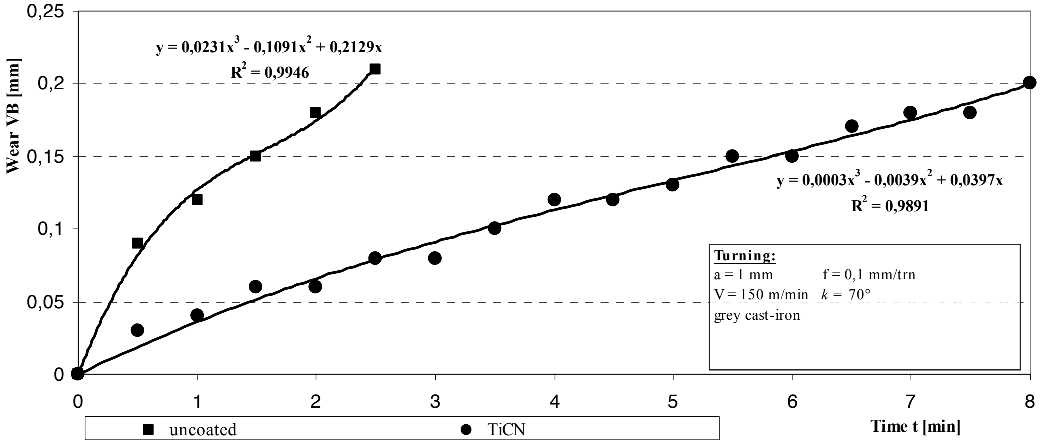


Fig. 9. Comparison of the approximated values of the VB wear of the cermet sample: uncoated and coated with the Ti(C,N) coating, depending on machining time

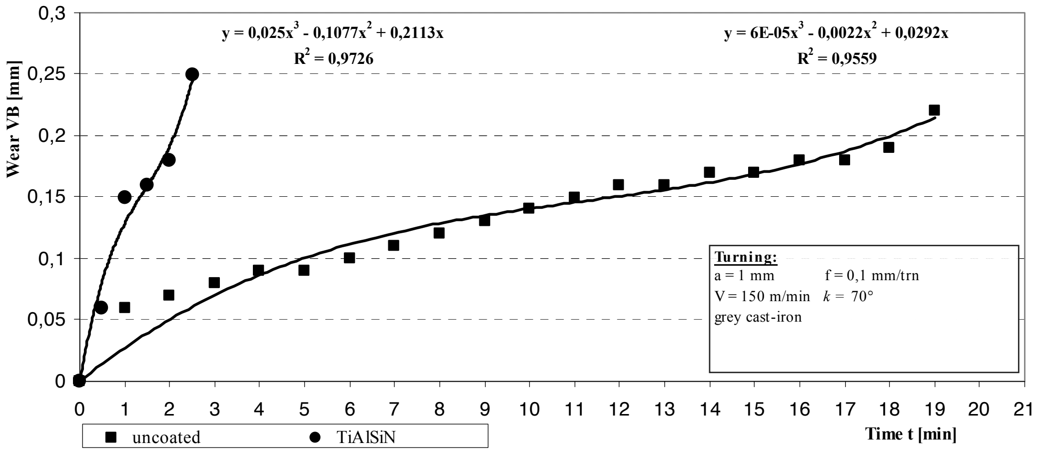


Fig. 10. Comparison of the approximated values of the VB wear of the cermets sample: uncoated and coated with the (Ti,Al,Si)N coating, depending on machining time

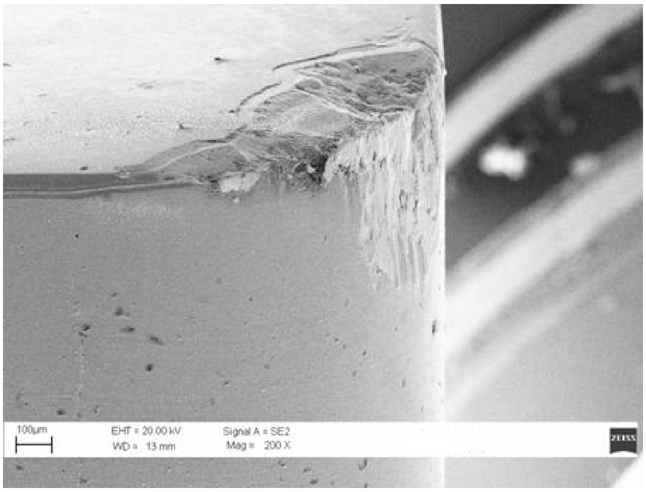


Fig. 11. Character of wear of cermet sample with (Ti,Al)N coating, investigated with SEM after cutting test

4. Conclusions

The results of the investigations of the cemented carbides and cermets tool materials coated with the (Ti,Al)N, Ti(C,N) and (Ti,Al,Si)N types of coatings with use of the cathodic arc evaporation CAE-PVD method are given in the paper. Coatings deposited onto cemented carbides and cermets have a dense, compact structure, there have been identified no pores, fractures and discontinuities. The coatings were deposited uniformly onto the investigated substrate materials and showed a characteristic columnar, fine-graded structure.

Coatings deposited onto the investigated substrates are characterised by good adhesion, high microhardness, taking effect in very high increasing of wear resistance. The results of the investigations carried out confirm the advantages of PVD coatings deposited onto both: cemented carbides and cermets, especially in case of (Ti,Al)N and (Ti,Al,Si)N coatings. Lower results was achieved in cutting tests in case of Ti(C,N) kind of coatings. It can be connected with increased wear of Ti(C,N) coating over 400°C and relatively high wear resistance of (Ti,Al)N coatings at elevated temperature, which could appear at assumed test's conditions.

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Additional information

Selected issues related to this paper are planned to be presented at the 16th International Scientific Conference on Contemporary Achievements in Mechanics, Manufacturing and Materials Science CAM3S'2010 celebrating 65 years of the tradition of Materials Engineering in Silesia, Poland and the 13th International Symposium Materials IMSP'2010, Denizli, Turkey.

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