Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 42
ISSUES 1-2
September-October
2010

The investigations of (Ti,Al)N and (Al,Ti)N coatings obtained by PVD process onto sintered cutting tools

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Received 30.06.2010; published in revised form 01.09.2010

Manufacturing and processing

ABSTRACT

Purpose: The main aim of this research was an investigation of both the coatings structure and mechanical properties deposited by the cathode arc evaporation physical vapor deposition (CAE-PVD) on sintered carbides and sialon tool ceramics substrates.

Design/methodology/approach: The (Ti,Al)N and (Al,Ti)N coatings were investigated. Microstructure was characterized using the scanning and transmission electron microscopy. Phases composition analysis was carried out by the XRD and GIXRD method. Investigation of surface roughness was done. The mechanical properties were determined on basis of following research: a measurement of hardness using Vickres's method, a measurement of roughness, adhesion using Scratch Test method. The cutting ability was defined on basis of technological cutting trials.

Findings: The investigations made by use of the glow discharge optical emission spectrometer indicate the existence of the transition zone between the substrate material and the coating. The results shows that (Al,Ti)N coating presents good adhesion onto booth substrates and (Ti,Al)N coating presents good adhesion onto sintered carbides substrate. All the coatings demonstrate a high hardness.

Research limitations/implications: The good adhesion (Al,Ti)N coating to sialon substrate is connecting with the same type of bonding in coat and sialon substrate.

Originality/value: The good properties of the PVD gradient coatings make them suitable for various engineering and industrial applications.

Keywords: Thin and thick coatings; Surface treatment; PVD coatings; Tool materials

Reference to this paper should be given in the following way:
L.A. Dobrzański, M. Staszuk, M. Pawlyta, J. Konieczny, The investigations of (Ti,Al)N and (Al,Ti)N coatings obtained by PVD process onto sintered cutting tools, Journal of Achievements in Materials and Manufacturing Engineering 42/1-2 (2010) 148-155.

1. Introduction

Physical Vapour Deposition techniques are one of the most frequently applied method of manufacturing hard coatings resistant to wear at present. In recent years, both an intensive development and improve of depositing thin layers techniques using PVD methods is observed. Today, coatings resistant to wear are often using on all tool materials, also these the hardest [1-7, 15]. Coatings, used in tribological systems, owe their good properties such as: density and adherence to substrate from to high positive ions energy of molecules, which form a coat of bombing most often connected with bias substrate. High kinetic ions energy causes a removal of atom impurities and growth temperature of covering substrate. This has very beneficial an influence on forming a coat, which is characterized by high purity and advantageous stresses distribution close an interface substrate-coating [16, 17].

In recent years, many research works [1-5, 7] concern covering coats resistant to wear tool ceramics have verified a view that coating a tool ceramics is unfounded for the sake of it's high hardness. It was found that coating this type of tools is by all means justified, because on one hand it causes an increase of cutting edge tool life machining as a result of decrease a separated heat during machining through decrease a friction force on a charge surface. On the other hand, it was found that coats coating some pores on surface of tool ceramics eliminate places of creating some chipping, however protective coatings cause postpone a process of diffusion wear.

Wear resistant coatings can be classified for the sake of kind interatomic bonding, which prevail in a given kind of coating. Among all type of coating materials most group determine materials with majority of metallic bond. Nitrogens and transition metals, also some borides and silicides belong to this group. Metallic – covalence bonds occur in most of these connections, therefore these materials join in themselves a high hardness and abrasion resistance with a resistance on brittle cracking higher rather than connections about both covalent and ionic bond. Materials with prevail ionic bond are an another group of coating materials. However, the last group is a group of materials with prevail covalent bonds into which are belonged diamond coatings and also from a boron nitride. This group shows the highest hardness [6, 17].

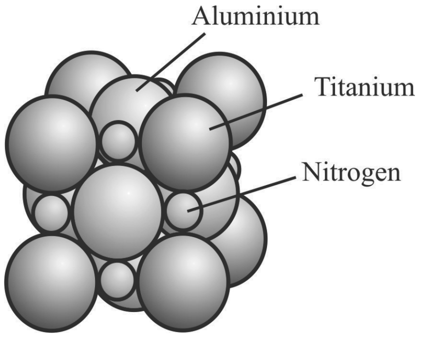

Fig. 1. Location of atoms in a crystalline structure (Ti,Al)N [15]

The titanium aluminium nitride (Ti,Al)N is a coating material, which plays an important role in tool industry. (Ti,Al)N has a titanium nitride structure, where each second titanium atom is replacement with a aluminum. (Fig. 1) [8, 9]. High temperature stability exploitation this chemical compound in a friction condition is much higher from generally used coatings of TiN and Ti(C,N) type. The boundary of stability exploitation excess 970 K temperature. This is caused by aluminium presence, which is a substitutional atom in a basic TiN lattice. In raise temperature on the (Ti,Al)N surface has formed a Al_2O_3 compact layer in a condition of exploitation, which is a diffusion barrier for a atmospheric oxygen [10,11]. In the course of last years, the coating researches of (Ti,Al)N type have developed in a way of aluminum increase concentration in coatings in aim to amplify a protection of aluminum influence on the properties these layers [12, 13]. Moreover, both (Ti,Al)N and (Al,Ti)N meta stable coatings combine diverse properties of metallic-covalence materials (TiN) and covalence materials (AlN), which are not possible to obtain as solid materials for the sake of diverse structure and different character of bonds [14].

2. Experimental

The investigations were carried out on the multi-point inserts uncoated and coated by the (Ti,Al)N and (Al,Ti)N gradient PVD coatings. Inserts were made using both sintered carbides WC-Co and sialon tool ceramics. Experimental methodology was presented in [1, 2].

3. Results

It was fund on the basis of PVD coatings fractures that coatings obtained on both substrates and a coat (Ti, Al)N obtained on sintered carbides showed a structure, which was classified to a II zone or T zone according to Thornton's model (Fig. 2). However, a (Ti,Al)N coating manufactured on substrate from sialon ceramics showed a structure about thicker columnar grains (II zone according to Thornton's model).

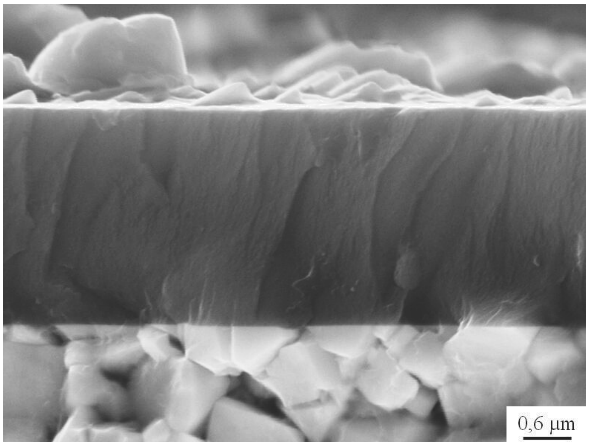

Fig. 2. Fracture of the (Al,Ti)N coating deposited onto the sintered carbides substrate

Coating morphology shows a considerable structural inhomogeneity connected with occurring solidified micro droplets (Fig. 3). Occurring of these morphological defects is characteristic for coatings obtained using the cathodic arc evaporation method. Coating morphology has an effect on increase surface roughness coated cutting edges with a relation to uncoated edges (Table 1).

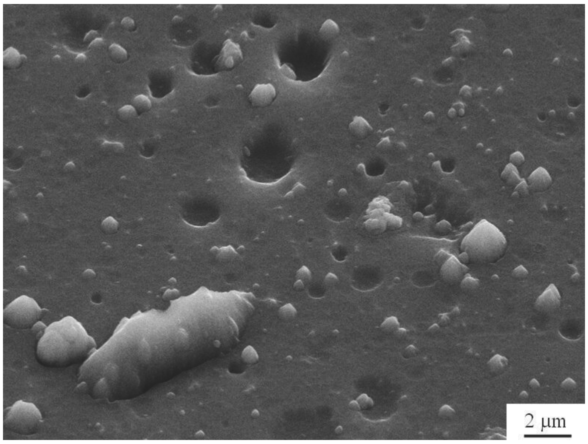

Fig. 3. Surface topography of the (Al,Ti)N coating deposited onto the sintered carbides substrate

The GDOS tests also indicate the existence of the transition zone between sintered carbide substrate material and coatings, improving adhesion of the deposited coatings to the substrate (Fig. 4). In the transition zone the concentration of elements included in the substrate grows, while the concentration of elements constituting the coatings decreases rapidly. Its development maybe also connected with high energy ions causing transfer of the elements in the joint zone, increase of desorption of the substrate surface, and development of defects in the substrate. It should be emphasised, however, that the results obtained with the use of the GDOS cannot be interpreted unequivocally, due to the inhomogeneous vaporization of the specimen material during the tests. Fig. 4 presents the changes of the chemical concentrations of the coating constituents and cemented carbide substrate material upon tests carried out on the glow-discharge optical emission spectroscope.

It was found, on the basis of researches of thin foils from (Al,Ti)N coating that this coating contains a AlN phase about hexagonal lattice (space group $P6_3mc$) (Fig. 5) and a TiN phase. All observed structures reveal considerable fine-grained.

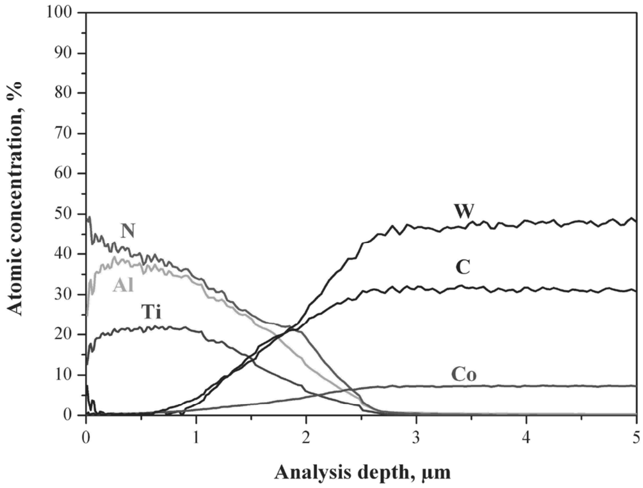

Fig. 4. Changes of constituent concentration of the (Al,Ti)N coating and the sintered carbides substrate material

Qualitative analysis phase composition carried out by the XRD method confirmed that on both substrates from sintered carbides and sialon tool ceramics were carried out according to coating assumptions contained TiN phase, in a case of (Ti,Al)N coating as well as TiN and AlN phases about hexagonal lattice in a case of (Al,Ti)N coating. The XRD patterns show an occurrence of reflections from both WC as well as Si_3N_4, which are presented in materials of substrates (Fig. 6). Presence reflections from phases belonged to a substrate is connected with a thickness of coating, which is smaller rather than a depth of penetration XRD radiation in a depth of material. As a result of researches by the grazing incident X-ray diffraction technique (GIXRD), with low glancing angle primary X- ray beam registered some peaks only from thin surface layers (Fig. 7).

The results of microhardness tests for coatings deposited on both investigating substrates as well as uncoated substrates were presented in Table 2 and Figure 8. The microhardness of substrates is equal 1826 HV for sintered carbides as well as 2035 HV for sialon tool ceramics and in each case increase after deposited a coating. Microhardness of investigated coatings is included in a range from 2961 HV0.05 to 3600 HV0.05. It was found that a (Ti,Al)N coating shows higher hardness on substrate from sintered carbides, however a (Al,Ti)N coating reveals considerably higher hardness on substrate from sialon ceramics.

Table 1.
Thickness of investigated coatings and roughness of investigated samples

Substrate	Coating	Thickness, μm	Roughness R_a, μm				
			min. value	max. value	mean value	Standard deviation	Confidence interval for α=0.05
Sintered carbides	Uncoated	-	0.06	0.06	0.06	0	±0
	(Ti,Al)N	3.5	0.24	0.78	0.39	0.20	±0.21
	(Al,Ti)N	2.5	0.14	0.26	0.18	0.04	±0.05
Sialon ceramics	Uncoated	-	0.06	0.06	0.06	0	±0
	(Ti,Al)N	5.0	0.24	0.32	0.28	0.03	±0.04
	(Al,Ti)N	3.0	0.14	0.18	0.15	0.02	±0.02

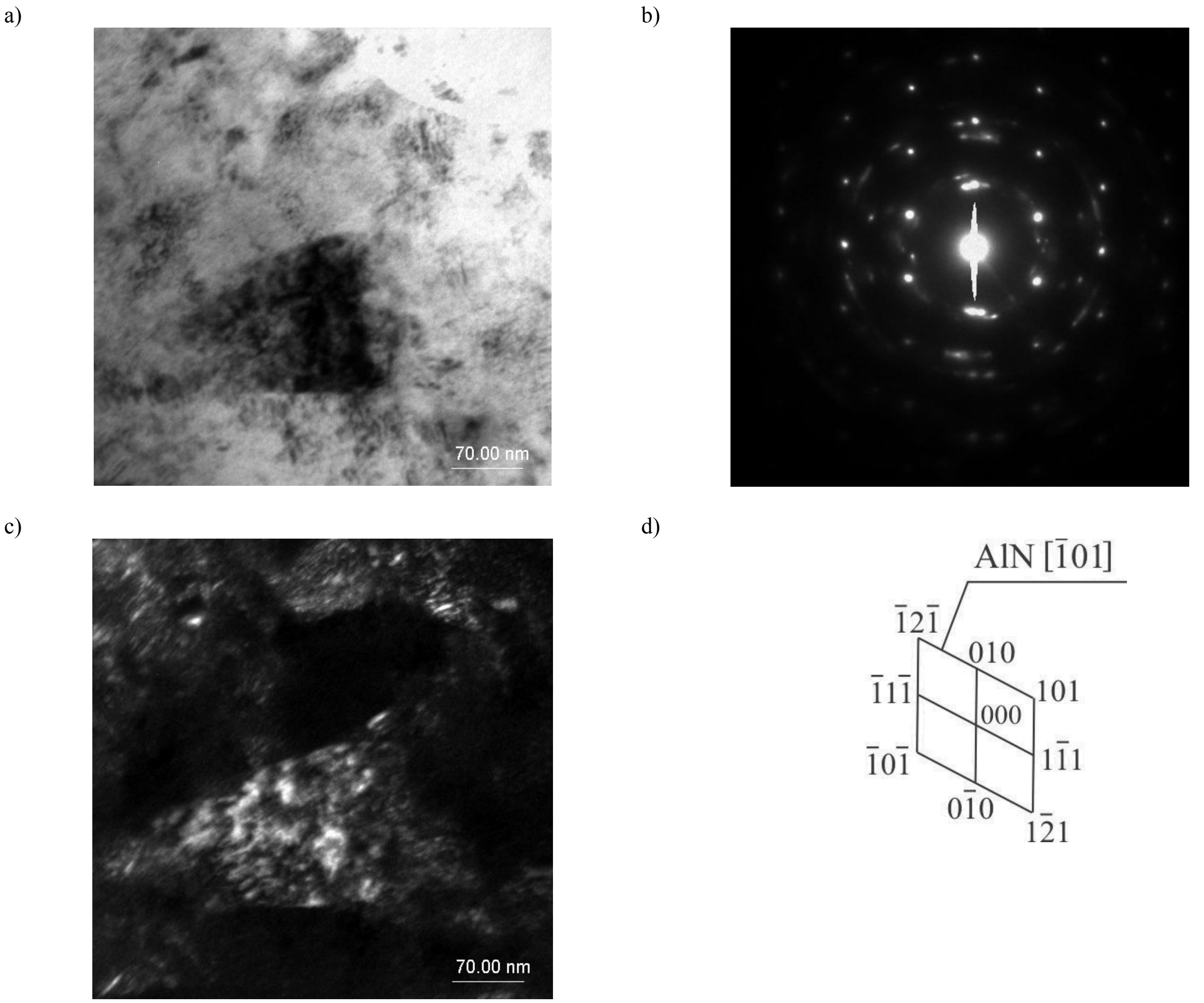

Fig. 5. Structure of thin foil from (Al,Ti)N coating a) bright field; b) dark field from $\bar{1}\,1\,\bar{1}$ reflex; c) diffraction pattern from area a and d) solution of the diffraction pattern

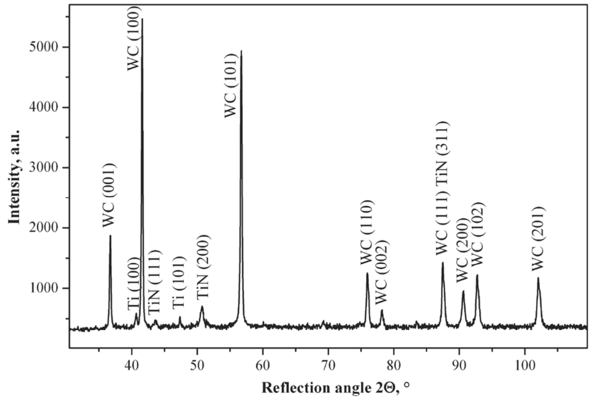

Fig. 6. X-ray diffraction pattern of (Ti,Al)N coating deposited on the sintered carbides substrate

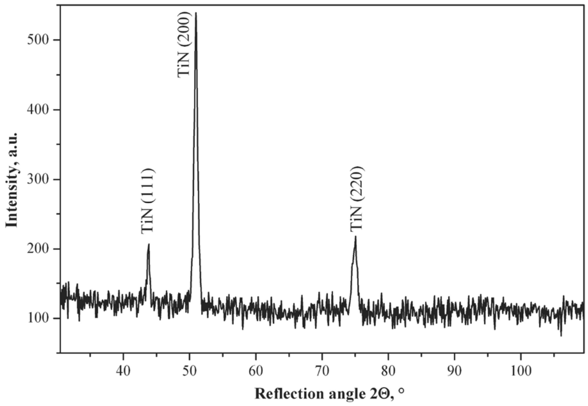

Fig. 7. X-ray diffraction pattern of (Ti,Al)N coating deposited on the sintered carbides substrate obtained by GIXRD method (α=2)

Table 2.
Critical load of investigated coatings and microhardness of investigated samples

Substrate	Coating	Critical load L_c, N	Microhardness, HV				
			min. value	max. value	mean value	Standard deviation	Confidence interval for α=0.05
Sintered carbides	Uncoated	-	1789	1865	1826	26.89	±21.84
	(Ti,Al)N	109	2757	3822	3327	494.37	±401.78
	(Al,Ti)N	100	2802	3861	3301	369.96	±300.67
Sialon ceramics	Uncoated	-	1990	2080	2035	31.82	±25.86
	(Ti,Al)N	21	2545	3259	2961	249.80	±203.02
	(Al,Ti)N	112	3117	3884	3600	314.09	±255.26

The characteristic critical load L_C was determined by scratch test method. During scratch testing the friction force Ft and acoustic emission AE were registered as a function of the load Fn. The value of the critical load L_C is a point on the curve of the friction force at which first damage of the coating was observed and corresponding acoustics emission signal was registered (Fig. 10a). Scratch adhesion tracks were analysed using the light microscope coupled with a measuring gauge. Thus the values of the critical load L_c could be obtained on the basis of metallographic observations(Fig. 10b).

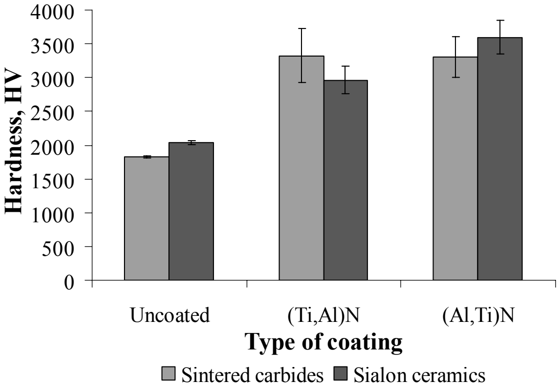

Fig. 8. The comparison between microhardness inserts on sintered carbides and sialon ceramics, both uncoated and coated

The results of the scratch test measurement for the studied coatings are shown in Table 2 and Figure 9. It was fund that both coatings show very good adherence to substrate from sintered carbides L_c = 100 and 109 N. However, in a case of coatings obtained on sialon ceramics only a coating (Al,Ti)N shows considerable adherence to substrate. The (Ti,Al)N coating adherence to sialon substrate is low. Observations in the scanning electron microscope of scratches arose as result of the Scratch Test show that a dominant mechanism of failure coatings with very good adherence was both a abrasion and cohesion cracking. In a case of coating indicate low adherence, it was found that both a delamination and extensive cracks as well as crushing.

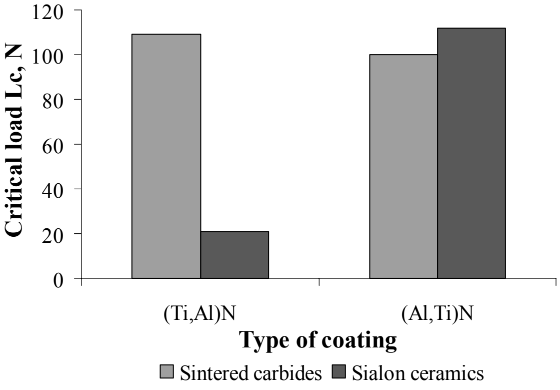

Fig. 9. The comparison between critical loads L_c of coatings deposited on sintered carbides and sialon ceramics

In order to determine wear resistance properties of deposited coatings, technological cutting trials were made. The investigation has a comparative character. This means, that the criterion, which determines the tool life was the time *T* of cutting grey cast iron measured until the width of flank wear VB_B=0.20 mm was achieved. Both coatings deposited on sialon ceramics and one (Al,Ti)N coating deposited on sialon ceramic have an effect on considerable increase tool life investigated cutting edges (Fig. 11).

While, a (Ti,Al)N coating deposited on sialon ceramics does not cause increase a tool life. However, a coating damages formed as a result of cutting trials show dependence from adherence to a substrate. Coatings showed a very good adherence, present a wear as a result of abrasion, alike as during a Scratch Test (Fig. 12). In a case of (Ti,Al)N coating on sialon ceramic, which shows a low operational properties, observed wear has a character of extensive chipping (Fig. 13).

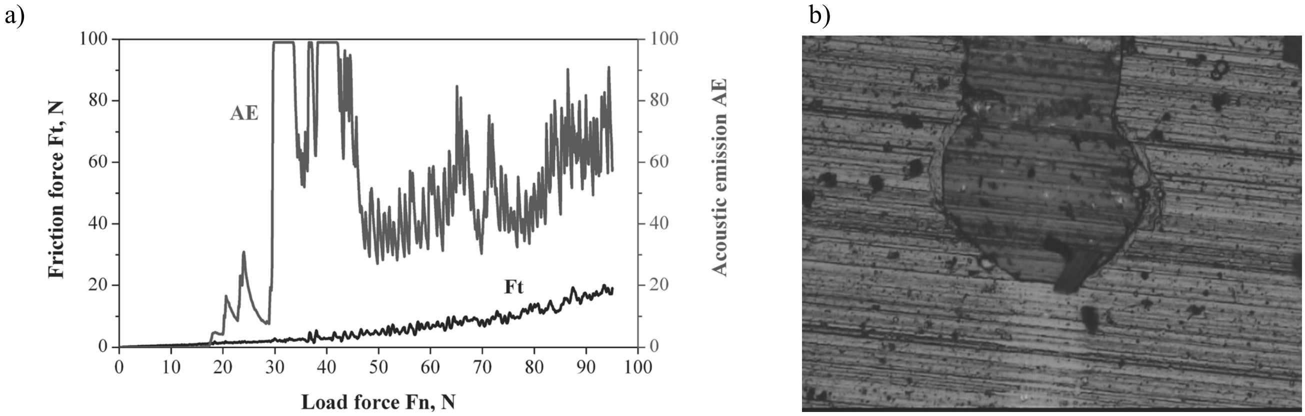

Fig. 10. (a) Acoustic emission (AE) and friction force Ft as a function of the load Fn for (Ti,Al)N gradient coating on sialon tool ceramics; (b) scratch failure at L_c (opt) = 21 N

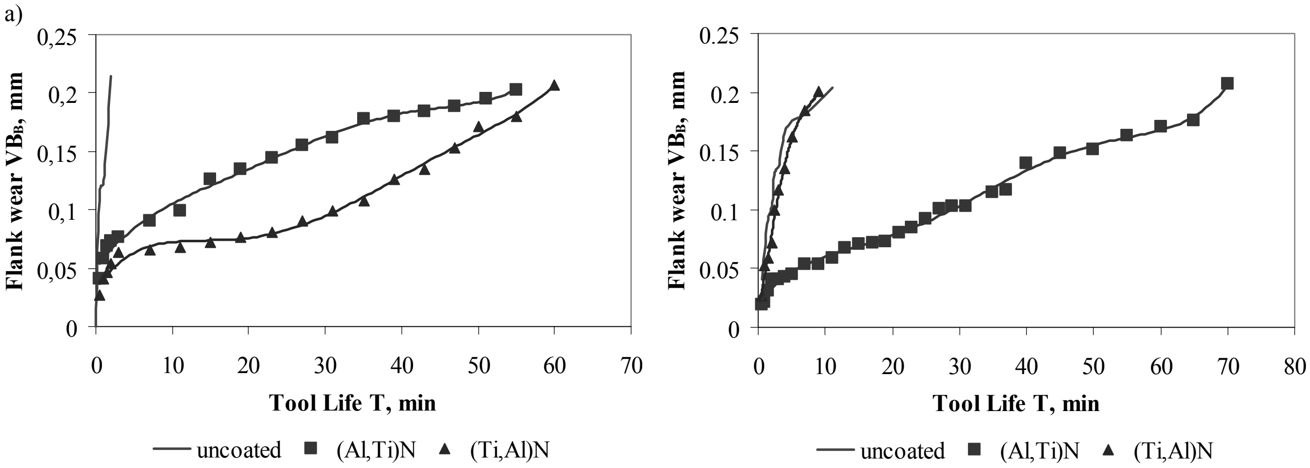

Fig. 11. Wear plots, substrate: a) sintered carbides; b) sialon tool ceramics

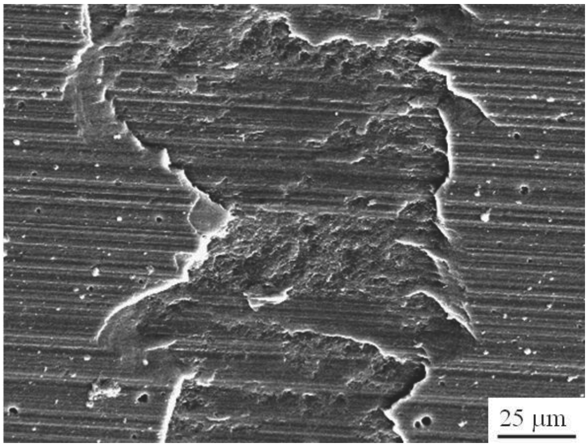

Fig. 12. Characteristic failure obtained by Scratch Test of the (Ti,Al)N coating deposited on sialon tool ceramics

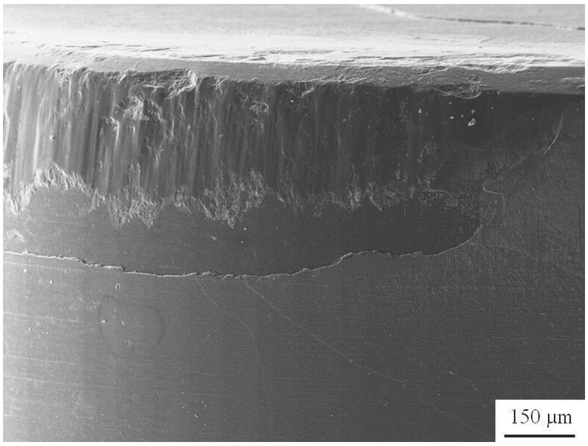

Fig. 13. Characteristic wear of tool flank of sialon tool ceramics inserts with (Ti,Al)N coating

4. Summary

The very important aspect of presented investigations is an influence on a coating structure on their properties and cutting ability deposited cutting edges from sialon ceramics. While, a (Al,Ti)N coating obtained on sialons shows: high hardness, very good adherence, but edges deposited this coating high cutting ability, so a (Ti,Al)N coating obtained on ceramic substrate in reverse shows lower hardness, a weak adherence, but coated edges this coating showed a low cutting ability. It was fund dependence coating properties on chemical constitution and phase composition. The (Ti,Al)N coating contains a TiN phase shows a low adherence to substrate ceramic, what is the consequence of low cutting ability. Whereas, a (Al,Ti)N coating contains a AlN phase about hexagonal lattice show very good adherence to ceramic substrate as well as very good cutting ability. It should be noted that sialons belong to a covalence ceramic, whereas in coatings contained a TiN phase occur metallic bonds. Different kind of bonds in both a coating and substrate have an impact on low adherence of these coatings to ceramic substrate. In a case of AlN coatings about hexagonal lattice occur the covalence bonds as like in a ceramic substrate, what as a result of giving a good adhesion and high cutting abilities. This observation could determine an important clue especially in case of the selection a coating material on the ceramic edges, because dielectric properties of ceramics and the lack of polarization of the substrate during the PVD process makes it difficult to obtain coatings about good properties.

Adherence coating to sintered carbides substrate depends on adhesion as well as the existence of the transition zone between the substrate material and the coating. This is a result of high energy ion implantation bombardment substrate connected with bias voltage. Therefore, both coatings show good exploitative properties on a substrate from sintered carbides.

Acknowledgements

The research was financed partially within the framework of the research project N N507 493438 of the Polish State Committee for Scientific Research, headed by Dr Daniel Pakuła.

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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