POLISH ACADEMY OF SCIENCES - COMMITTEE OF MATERIALS SCIENCE
SILESIAN UNIVERSITY OF TECHNOLOGY OF GLIWICE
INSTITUTE OF ENGINEERING MATERIALS AND BIOMATERIALS
ASSOCIATION OF ALUMNI OF SILESIAN UNIVERSITY OF TECHNOLOGY

Conference Proceedings

12th INTERNATIONAL SCIENTIFIC CONFERENCE
ACHIEVEMENTS IN MECHANICAL & MATERIALS ENGINEERING

Tribological properties of the PVD and CVD coatings put down onto the nitride tool ceramics*

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The tribological properties of the multi-layer PVD and CVD coatings put down onto the Si_3N_4 nitride tool ceramics are compared in the paper in relation to the fundamental mechanical properties like hardness, adhesion, and roughness.

1. INTRODUCTION

Covering tools with the thin wear resistant PVD and CVD coatings is currently the commonly used method to extend their life. Investigations of these coatings determining their mechanical properties, chemical composition, and structure, make it possible to pick out the optimum coatings for given industrial applications. Tribological tests play an important role here, making it possible to determine friction coefficient changes in the course of analysis for combinations of the employed materials, adhesion of coatings to the substrate, and first of all of their abrasion resistance [1,2]. The friction process between two surfaces, dependant on many factors, leads to their wear and is connected with energy losses. The detailed investigations of the worn surface make it possible to obtain information on the wear process of the investigated material under load. This type of tests plays an important role for the coating-substrate system, which – if used appropriately – increases wear resistance of machine elements or tools. The „pin-on-disk" test is one of the methods used often for determining the tribological properties of materials, in which the counter-specimen in the form of a roller or a ball is pressed to the investigated surface, and the contacting surfaces get damaged as a result of the load force and the relative rotation of the specimen [3÷5].

The goal of this work was to determine the tribological properties of the hard, wear resistant, thin coatings obtained in the PVD and CVD processes on the tool ceramics based on the silicon nitride.

* Authors participate in the CEEPUS No PL-013/03-04 project headed by Prof. L.A. Dobrzański.

2. EXPERIMENTAL PROCEDURE

The tests were carried out on the multi-point cutting inserts made from the Si_3N_4 nitride ceramics covered with thin coatings in the PVD and CVD processes. The inserts made from Si_3N_4 were coated with multiple layers in the high temperature CVD process with a combination of the TiC, TiCN, TiN and Al_2O_3 coatings and in the PVD process – cathode arc evaporation – with the multi-component coatings of the TiAlSiN type. Characteristics of the investigated materials are presented in Table 1.

The micro hardness tests of the coatings were carried out on the SHIMADZU DUH 202 ultra-microhardness tester with the 0.07 N load. The coating thickness was determined basing on measurement of the hollow depth developed during the "kalotest". The R_a roughness parameters for the uncoated and coated surfaces were determined on the RankTaylor Hobson Surftec 3+ profilometer with the base length l = 0.25 mm and with the measurement accuracy of 0.01 μm. Assessment of the adhesion of coatings on the investigated multi-point inserts was done with the scratch test on the CSEM REVETEST device, by moving the diamond penetrator along the investigated surface, loaded with the gradually incremented load force. The tests were made with the following parameters: load force range 0-100 N, load force increase rate (dL/dt) 100 N/min., penetrator travel speed (dx/dt) 10 mm/min., sensitivity of the acoustic emission detector 1. The L_c critical load at which coating adhesion is lost was determined basing on the recorded acoustic emission value AE.

Table 1
Characteristics of the PVD and CVD coatings put down on the Si_3N_4 nitride ceramics

Coating	Coating thickness, μm	Roughness, μm	Hardness, GPa	Critical load, L_c	Cycle number	Process type
TiN	0,8	0,34	22,12	20,14	2000	PVD
TiN+multiTiAlSiN+TiN	4,0	0,44	35,24	22,40	500	PVD
TiN+TiAlSiN+TiN	2,0	0,45	23,33	21,65	2000	PVD
TiN+TiAlSiN+AlSiTiN	2,5	0,32	26,79	18,30	250	PVD
TiCN+TiN	4,2	0,15	22,25	52,15	15000	CVD
TiCN+Al_2O_3+TiN	9,5	0,28	20,11	26,71	25000	CVD
TiC+TiN	5,4	0,25	19,82	67,24	10000	CVD
TiC+TiCN+Al_2O_3+TiN	7,8	0,27	29,68	32,17	10000	CVD
TiN+Al_2O_3	10	0,45	32,57	83,10	13000	CVD
Si_3N_4 – uncoated	–	0,06	18,50	–	–	–

Tribological tests were carried out on the CSEM „pin-on-disk" tester in the following conditions: counter-specimen – ball made from the WC titanium carbide with the 6 mm diameter, counter-specimen load – 5 N, friction radius – 5 mm, linear velocity – 0.1 m/sec, ambient temperature - 20°C. The character of the developed failure was evaluated basing on observations on the light microscope and on the scanning electron microscope.

3. DISCUSSION OF THE EXPERIMENTAL RESULTS

Evaluation of the adhesion of the CVD coatings put down onto the investigated Si_3N_4 material was done basing on the critical load L_c (AE) values, at which coating adhesion to the substrate is lost. It was found out basing on the determined L_c (AE) values and on the metallographic examinations of the developed failures that the investigated bi-layer CVD coatings of the $TiN+Al_2O_3$, TiCN+TiN and TiC+TiN types are characterized by a good adhesion to the substrate unlike the PVD coatings (Table 1).

It turns out from the wear resistance tests made with the „pin-on-disc" method that the PVD coatings have inferior tribological properties compared to coatings put down with the CVD technology. Nearly in all cases coating failure occurs down to the Si_3N_4 nitride ceramics substrate zone. Failures of these coatings are accompanied by the extensive adhesion failures (Fig. 1).

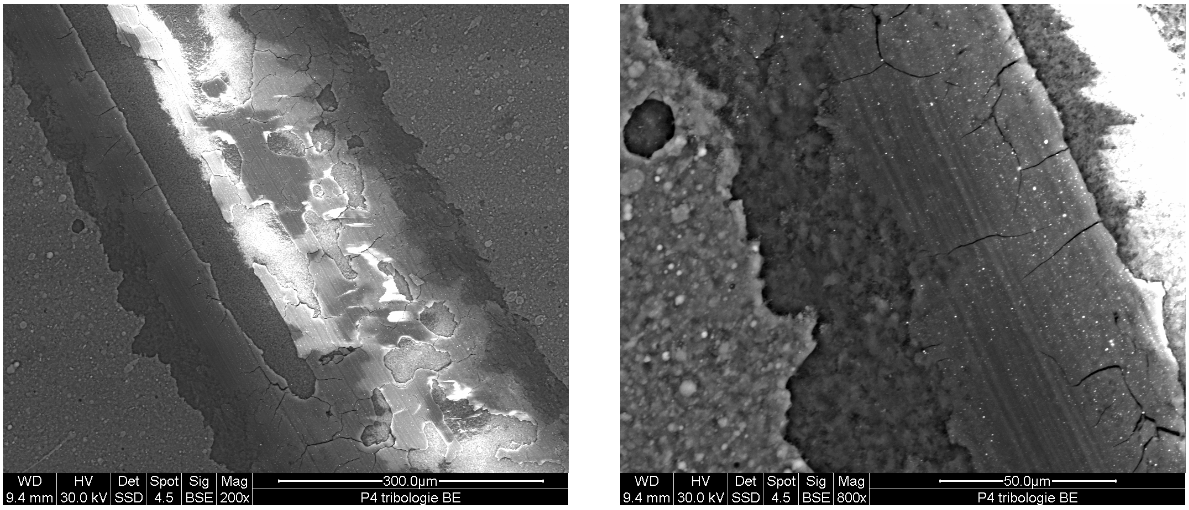

Fig. 1. Trace of the tribological failure on surface of the TiN+TiAlSiN+AlSiTiN coating put down onto the Si_3N_4 nitride ceramics, number of cycles 250

The relatively high micro hardness values were measured for the PVD coatings. This property was credited with the main influence on the wear resistance. In case of the CVD coatings the micro hardness values of coating and substrate demonstrate the biggest differences. All the same, the investigated CVD coatings have the relatively good tribological properties, which are proven also by a high number of load cycles – up to 25,000. The $Ti(C,N)+Al_2O_3+TiN$ coating demonstrates a high wear resistance with this static load method. The failures of this coating type do not reach the substrate material after loading with 25,000 cycles, albeit its micro hardness does not attain the values assumed as sufficient for this coating system. The $TiN+Al_2O_3$ coating, which also does not get damaged, has very good tribological properties too. It is very difficult during the tribological analysis to assess the dimensions of the failure, especially in case of coatings whose failures do not reach the substrate material. During observations made using the light microscope in the tribological failure trace the particles of the damaged coating or of the counter-specimen are revealed as defects reaching down to the substrate material, which results in stopping the analysis too early. In case of the commercial coatings on the nitride ceramics the coating failure down to the substrate material occurs only for the $TiN+Al_2O_3+TiN$ coating. This failure is initiated after a relatively big number of cycles, which with the remaining coatings from this series are about half of that value. From this point of view one can consider this series of inserts as wear resistant. Generally, the CVD coatings, and most of all the $Ti(C,N)+Al_2O_3+TiN$ i $TiN+Al_2O_3$ ones may be regarded as the most wear resistant coatings.

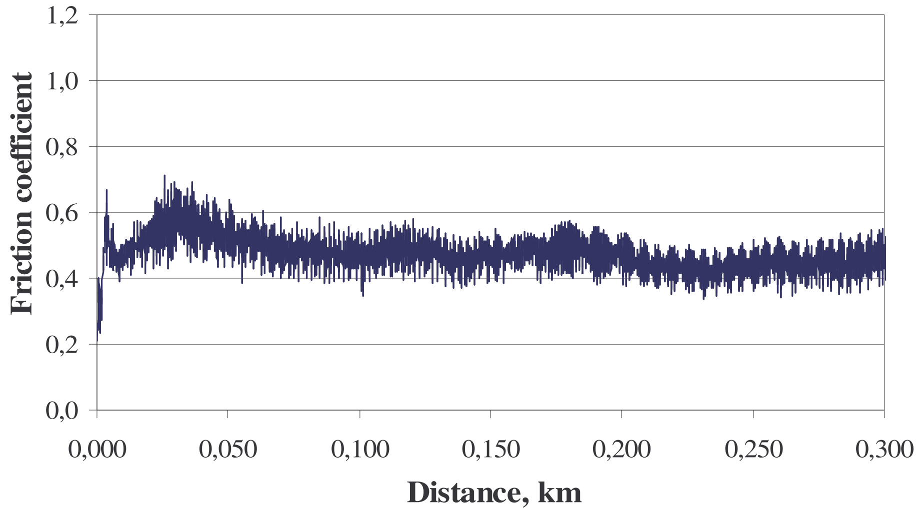

Fig. 2. Friction coefficient plot versus friction trace length during the „pin-on-disk" test for the TiC+Ti(C,N)+Al_2O_3+TiN coating put down onto the Si_3N_4 nitride ceramics substrate

It is hard to generalize the tribological analysis results, to which – first of all – friction coefficient, ball wear, and the tribological trace depth belong, mostly because of the adhesion contact in the tangential area of the trace of the pair subjected to friction. Basing on the analyses carried out one may judge that adhesion occurs most of all during the contact with the Al_2O_3 layer in case of the CVD coatings. Increase of the friction coefficient results also from this phenomenon. Friction coefficient tests (Fig. 2) and cycles numbers reveal that the values are not uniform and in many cases do not display a monotonic character. In this case the PVD coatings demonstrate the least satisfactory results, as their friction coefficient reaches the relatively high values.

4. SUMMARY

Basing on the tribological test made with the „pin-on-disk" method in respect to the hardness and adhesion investigations the correlation was revealed between these two properties. The CVD coatings demonstrate high abrasion resistance in comparison with the PVD ones, whose adhesion to the nitride ceramics is low.

BIBLIOGRAPHY

1. L.A. Dobrzański: Fundamentals of Materials Science and Physical Metallurgy. Engineering Materials with Fundamentals of Materials Design, WNT, Warszawa, 2002 (in Polish).
2. L.A. Dobrzański, D. Pakuła, M. Pancielejko: Proc. 7th International Research/Expert Conference "Trends in the Development of Machinery and Associated Technology", TMT 2003, Lloret de Mar, Barcelona, Spain, 2003, 213-216.
3. W. Kwaśny, A. Křiž, L.A. Dobrzański: Proceedigs of the XXVIII School of Materials Engineering, Kraków-Szczawnica, 2000, 421-424.
4. S. Hogmark, S. Jacobson, M. Larsson: Wear, 246, 2000, 20-33.
5. W. Grzesik, Z. Zalisz, P. Nieslony: Surface and Coatings Technology, 155, 2002, 37-45.