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# Cutting ability improvement of coated tool materials

**L.A. Dobrzański*, K. Gołombek, J. Mikuła, D. Pakuła**
Division of Materials Processing Technology and Computer Techniques in Materials Science, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: leszek.dobrzanski@polsl.pl

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**Materials**

## ABSTRACT

**Purpose:** It has been demonstrated in the paper that deposition of the multilayer and gradient coatings with the PVD and CVD methods on sintered tool materials.
**Design/methodology/approach:** TEM, SEM, scratch test, microhardness tests, roughness tests, cutting tests.
**Findings:** It has been demonstrated in this work that deposition of the multilayer or gradient coatings with the PVD (Cathodic Arc Evaporation) or CVD process on tools made from nitride, oxide ceramics and cermets results in the increase of coatings' hardness and improvement of their adhesion to the substrate, in comparison with the multiple-layer coatings deposited using the PVD/CVD methods on the same substrate materials, deciding improvement of the working properties of cutting tools coated with the TiN+gradient or multi(Ti,Al,Si)N+TiN system coatings, compared with coatings developed on the same sintered tool materials, but uncoated or coated with simple coatings.
**Practical implications:** Pro-ecological dry cutting processes without the use of the cutting fluids and in the „Near-Net-Shape" technology.
**Originality/value:** In the paper the research of multilayer and gradient TiN+(Ti,Al,Si)N+TiN nanocrystalline coatings deposited in the PVD method on sintered tool materials carried out in order to improve the tool cutting properties.
**Keywords:** Tool materials; Cutting; Thin & thick coatings

## 1. Introduction

The causes of the cutting tools wear are as follows: mutual interactions - mechanical, thermal, and molecular of the edge with the machined material and formed chip, occurring in the contact zone. Several cutting tools wear have been developed, taking into account the qualitative and quantitative effects of their causes. Wear of the cutting tools edges takes place in the complex conditions caused, among others, by the mutual interactions of the mechanical- and fatigue wear, and plastic strain, as well as phenomena connected with the adhesion, thermal-, and diffusion wear and oxidation [1-11].

The goal of this work is investigation of the functional properties of cermets, $Si_3N_4$ and $Al_2O_3$ based ceramics, coated with the PVD and CVD multilayer and gradient coatings and comparison them with the commercial uncoated and coated tool materials.

## 2. Materials and methods

Experiments were carried out on the multi-point inserts made from the $Si_3N_4$ nitride ceramics, $Al_2O_3$+$ZrO_2$ oxide ceramics and cermets with the multi-layer and multi-component layers deposited in the PVD process with the (Ti,Al,Si)N type coatings, and in the CVD process with the $Al_2O_3$ and TiN coating combination, which were later compared with the commercial inserts (Table 1).

The microhardness tests using the Vickers method were made on the Shimadzu DUH 202 tester.

Adhesion evaluation of the coatings on the investigated inserts was made using the scratch test on the CSEM REVETEST device.

The roughness measurements of the developed coatings and substrate were made Surtronic3+ device.

Topography examinations of the worn tool surface were carried out on the OLYMPUS LEXT OLS3000 confocal microscope.

Cutting ability of the investigated materials was determined basing on the technological continuous cutting tests of the EN-GJL-250 grey cast iron and C45E steel. The VB = 0.20 (oxide ceramics, cermets) and 0.30 mm (nitride ceramics) 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 = 0.10; 0.15; 0.20 mm/rev; depth of cut ap = 1; 2 mm; cutting speed vc = 200; 400m/min.

## 3. Results

In order to explain reasons of the improvement of cutting ability of coated tools made of $Si_3N_4$ and $Al_2O_3$+$ZrO_2$ ceramics and cermets, research of mechanical properties including microhardness and adherence of deposited coatings and research of coating chemical composition and structure were made.

The microhardness tests revealed that the uncoated nitride, oxide ceramics and cermet has hardness equal to 18.5 to 24.50 GPa respectively. Deposition of the PVD and CVD coatings onto the specimens causes the surface layer hardness increase reaching from 19.20 to 40.90 GPa, that is up to 100% more compared to the substrate hardness (Table 1).

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/CVD coatings to the 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 adherence ($L_c$ = 40-137 N), only to the TiN+(Ti,Al,Si)N+TiN gradient coating deposited onto the nitride ceramic substrate has a lower adherence equal $L_c$=22 N (Table 1).

In the case of TiN+gradient (Ti,Al,Si)N+TiN and TiN+multi (Ti,Al,Si)N+TiN coatings deposited by the use of PVD method on $Al_2O_3$+$ZrO_2$ ceramic and cermet substrates the clear correlation between the improvement of abrasive wear resistance and wear resistance of multi-point inserts and the increase of surface layer microhardness and good adherence were stated. 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. Therefore, not only the adhesion decides the adherence, but also the diffusion mixing of elements in the interlayer, between the substrate and the coating, with two simultaneously available sources of diffusion of elements constituting the coatings and titanium from the coating to the substrate, and also of nitrogen, and perhaps also titanium from the substrate to the coating, the more so, as the substrate temperature during the process is 550°C. However, the coatings deposited by the use of PVD methods on $Si_3N_4$ substrate do not cause the increase of cutting tool life as a result of weak substrate adherence in spite of the increase of microhardness.

Table 1.
Characteristics of the PVD and CVD coatings deposited on the sintered tool materials

| Substrate | Coating | | | Process type | Roughness, µm | Microhardness, GPa | Critical load $L_c$, N (max load) |
|---|---|---|---|---|---|---|---|
| | Type | Composition | Thickness, µm | | | | |
| $Si_3N_4$ | uncoated | | | | 0,06 | 18.50 | – |
| $Al_2O_3$+$ZrO_2$ | uncoated | | | | 0.21 | 18.50 | – |
| Cermet[1)] | uncoated | | | | 0.22 | 24.50 | – |
| $Si_3N_4$ | gradient layer | TiN+ (Ti,Al,Si)N+TiN | 2.0 | PVD | 0.45 | 23.30 | 22 (100) |
| $Al_2O_3$+$ZrO_2$ | gradient layer | TiN+ (Ti,Al,Si)N+TiN | 2.0 | PVD | 0.43 | 19.20 | 40 (100) |
| Cermet[1)] | gradient layer | TiN+ (Ti,Al,Si)N+TiN | 4.0 | PVD | 0.60 | 33.00 | 137 (200) |
| $Si_3N_4$ | multi layer | TiN+multi (Ti,Al,Si)N+TiN | 4.0 | PVD | 0.40 | 35.20 | 23 (100) |
| $Al_2O_3$+$ZrO_2$ | multi layer | TiN+multi (Ti,Al,Si)N+TiN | 2.3 | PVD | 0.37 | 40.90 | 76 (100) |
| Cermet[1)] | multi layer | TiN+multi (Ti,Al,Si)N+TiN | 4.0 | PVD | 0.62 | 33.90 | 121 (200) |
| Cermet[1)] | multi layer | TiN+TiC+TiN[2)] | 5.0 | PVD | 0.79 | 30.00 | 79 (200) |
| $Si_3N_4$ | two layer | TiN+$Al_2O_3$ | 10.0 | CVD | 0.45 | 32.50 | 83 (100) |
| $Al_2O_3$+$ZrO_2$ | two layer | TiN+$Al_2O_3$ | 6.0 | CVD | 0.40 | 34.10 | 73 (100) |
| $Si_3N_4$ | two layer | $Al_2O_3$+TiN[2)] | 2.6 | CVD | 0.25 | 26.25 | 47 (100) |

[1)] chemical composition (mass concentr. of elements, %): C 0,80; N 2,00; Ti 48,70; Ta 13,50; Ni 4,70; Co 8,60; W 21,65.
[2)] commercially available inserts from various manufacturers

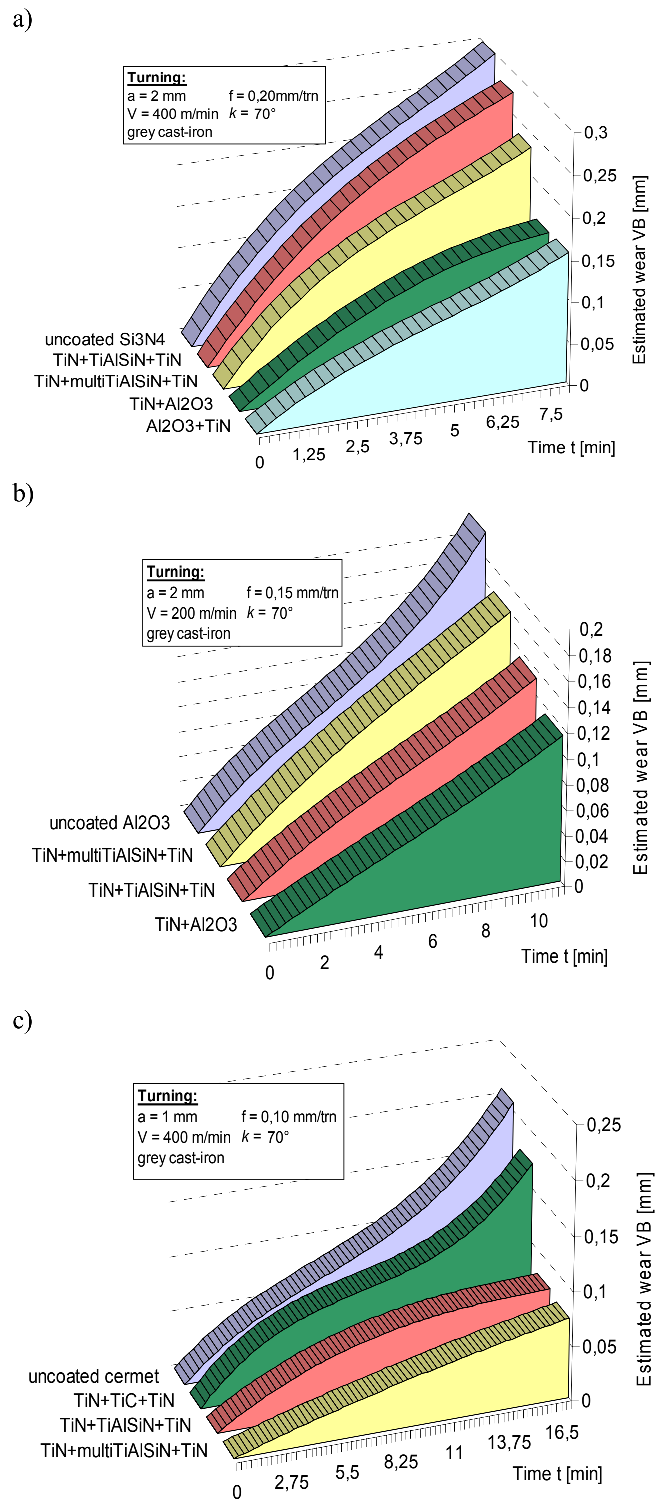


Fig. 1. Comparison of the values of the VB wear of the: a) $Si_3N_4$ ceramics, b) $Al_2O_3$+$ZrO_2$ ceramics, c) cermets uncoated and coated, depending on machining time

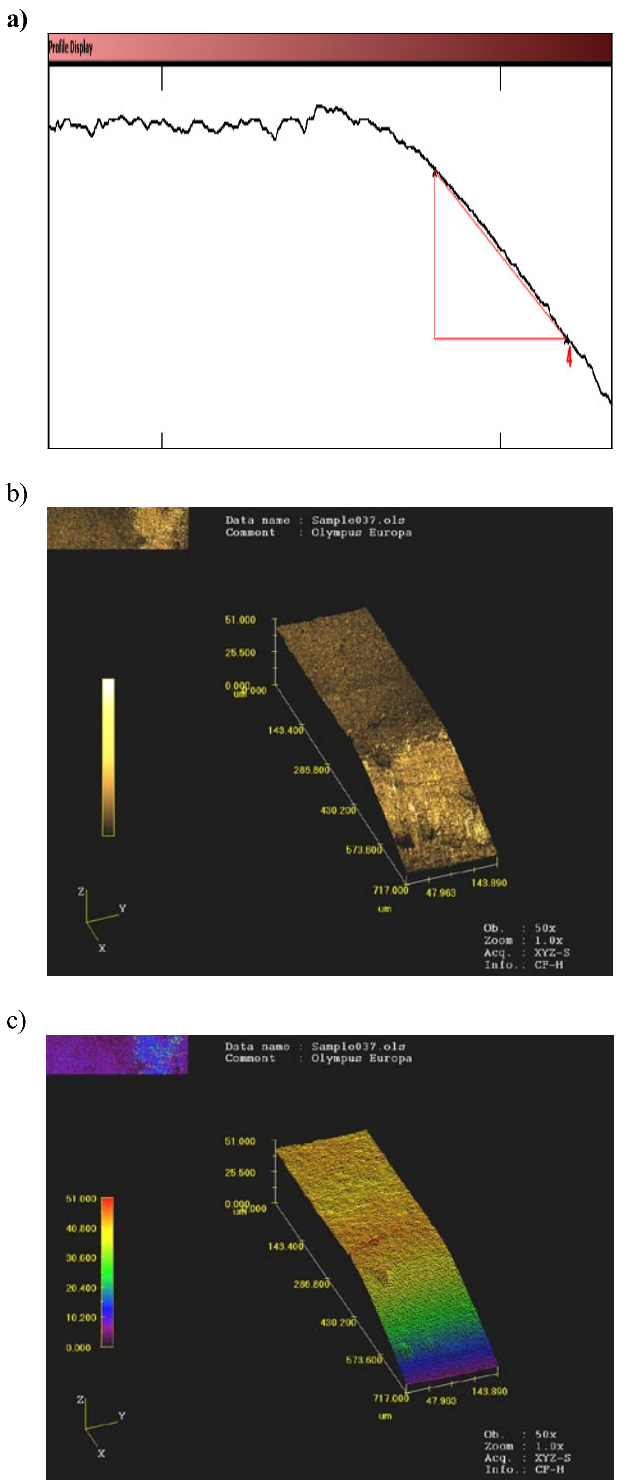


Fig. 2. Major cutting edge characteristics after machining with $Al_2O_3$ based tool ceramics with TiN+TiAlSiN+TiN coating (confocal micro scope); a) wear profile, b), c) surface topography of flank face wear

Undoubtedely, the influence on such significant differences in adherence of examined coatings has the fact that $Si_3N_4$ based nitride ceramic does not conduct current, what to a great degree makes the creation of PVD coatings on such substrate difficult. Clearly better adherence of CVD coatings to nitride and oxide substrates can come from the character of the same high temperature process and the fact that the substrate can be the source of the chemical element creating the layer like in the processes thermically activated. The chemical element coming from the substrate in that case nitride enables the elements to intermix diffusionally in the interlayer between the coating and the substrate. Adhesion but also diffusional intermixture of elements in the interlayer between the substrate and the coating decides about adherence.

The detailed analysis was carried out of the relationships between the service properties of the investigated ceramic tool materials and their structure, as well as their mechanical properties, taking into account the physical phenomena occurring during the coating deposition process. The comparative results of the analyses carried out are presented in [1-3].

As a result of carried out researches it was found out that the deposition of multilayer and gradient nanocrystalline coatings by the use of PVD and CVD method causes the increase of cutting properties of tools made of cermets and $Al_2O_3$+$ZrO_2$ comparing to adequately uncoated tools. The increase of cutting properties indicates also tools made of $Si_3N_4$ with two-layer TiN+$Al_2O_3$ coating, analogical to tools coated by the similar system of coatings available on the market.

Therefore, the real life tests (Fig. 1) confirm the quality of the III generation coatings of the TiN+ multi (Ti,Al,Si)N+TiN and TiN+gradient (Ti,Al,Si)N+TiN types obtained with the PVD technique in the cathode arc evaporation CAE process on the oxide and nitride ceramics and on tool cermets, as the material that significantly decreases the abrasive wear, thermal and adhesion wear, which immediately affects, among others, extension of the tool life, compared to the uncoated tools, and those with the multiple-layer coatings deposited using the CVD or PVD methods. The desired decrease of the particular wear types (abrasive, thermal, and adhesion ones) of the cutting tools, demonstrated by extension of the tool life, by deposition of the wear resistant coatings on their working surfaces, should be connected with a high micro-hardness of the coatings at the „room" temperature and at the elevated temperatures, with the low chemical affinity of cutting tool material to the machined material (mostly to iron and carbon) and with protecting the tool edge from oxidation and excessive overheating.

It was found in examinations on the confocal microscope of the tool flank and rake face after cutting that the wear surface of the examined cutting tools with the deposited coatings is characteristic of a very low roughness confirmed by the scanning profile line run, which indicates to the uniform abrasive wear of the investigated tools and has a direct effect on the obtained high quality of the machined surface, Figure 2.

## 4. Conclusions

Employment of the hard wear resistant coatings deposited onto the sintered ceramic tool materials with the physical deposition from the gaseous phase (PVD) is reckoned as one of the most important achievements in the last years in the area of improvement of the service properties of ceramic cutting tools. Depositing the anti-wear coatings of the gradient and multi TiN+(Ti,Al,Si)N+TiN types onto the investigated ceramic tool materials makes it possible to achieve the clear improvement of their tool life and also of the quality of the machined surfaces, reduction of machining costs and elimination of cutting fluids used in machining. The widespread use in machining of oxide and nitride ceramics, as well as of cermets with the complex nanocrystaline coatings deposited in the PVD processes contributes to the increased interest in the contemporary "Near-Net-Shape" technology, i.e., manufacturing semi-products with the shape and dimensions as close as possible to those of the finished products.

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