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# PVD and CVD coating systems on oxide tool ceramics

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**Materials**

## ABSTRACT

**Purpose:** Investigation of structure and properties of the $Al_2O_3$ based $Al_2O_3$+$ZrO_2$, $Al_2O_3$+TiC and $Al_2O_3$+$SiC_{(w)}$ type based oxide tool ceramics coated with the anti-wear mono- and multilayers of the TiN, TiAIN, TiN+TiAlSiN+TiN, TiN+multiAiAlSiN+TiN and TiN+TiAlSiN+AlSiTiN types in the cathode arc evaporation CAE-PVD and with the multilayers of the TiCN+TiN and TiN+$Al_2O_3$ types obtained in the chemical deposition from the gas phase CVD process.

**Design/methodology/approach:** The investigations were carried out on the multi-point inserts made from the $Al_2O_3$+$ZrO_2$, $Al_2O_3$+TiC, $Al_2O_3$+$SiC_{(w)}$ ceramics uncoated, coated in the PVD and CVD processes with thin coatings; Observations of the investigated coatings' structures were carried out on the transverse fractures on the scanning electron microscope; The diffraction examinations and examinations of thin foils were made on the transmission electron microscope; The measurements of textures and phase composition were made; The macro-stress values were calculated; Tribological tests were carried out on the „pin-on-disk" tester; the microhardness and adhesion tests of coatings were made; cutting ability of the investigated materials was determined basing on the technological continuous cutting tests.

**Findings:** It has been demonstrated that the creation of the developed coatings by the use of the PVD and CVD methods on oxide ceramic tool materials causes the increase of coatings hardness and allows to improve application features of multi point cutting tools for high speed machining, tools for fine cutting coated with them and dry cutting without using the cutting fluids in comparison to the multi point cutting tools produced from the same uncoated materials.

**Practical implications:** Putting down the anti-wear coatings onto the oxide ceramic tool materials is justified and the composite tool materials developed in this way may have the important application significance in the industry for cutting tools.

**Originality/value:** Comparison of the wide range of modern oxide tool ceramics with wide unique set of PVD and CVD coatings.

**Keywords:** Tool materials; PVD; CVD; Oxide ceramics; Cutting tools

## 1. Introduction

Research projects are ongoing in the Department of Materials Processing Technology and Computer Techniques in Materials Science of the Institute of Engineering Materials and Biomaterials of the Silesian University of Technology focused on various aspects of coatings deposited in the PVD and CVD processes. The research pertains to both the possibility of employing the multi-layer coatings to increase the corrosion resistance and evaluation of the deposition conditions on properties of coatings, but also to the possibility of improving the functional properties of tool materials, high-speed steels, sintered carbides, cermets, tool oxide and nitride ceramics resulting from deposition of hard coatings [1-6].

Results of the completed research projects indicate that it is the leading direction in cutting tools development, as the repeated tool life increase was found out in comparison to the uncoated tools thanks to the deposited coatings. The particular expectations should be connected with the multi-layer coatings developed by putting down successively layers with various chemical compositions and properties and coatings containing the metastable solid solutions of the multi-component and multi-phase composition. The diffusion processes taking place during deposition of such coatings cause development of interfaces making gradual change of properties across the coating section possible [1-16].

## 2. Experimental procedure

The investigations were carried out on the multi-point inserts made from the $Al_2O_3$+$ZrO_2$, $Al_2O_3$+TiC, $Al_2O_3$+$SiC_{(w)}$ ceramics uncoated, coated in the PVD and CVD processes with thin coatings. Specifications of the investigated materials are presented in Table 1.

Examinations of coatings' thicknesses were made using the "kalotest" method.

Observations of the investigated coatings' structures were carried out on the transverse fractures on the scanning electron microscope (SEM) Philips XL-3.

The diffraction examinations and examinations of thin foils were made on the JEOL JEM 3010CX transmission electron microscope.The diffraction patterns from the transmission electron microscope were solved using the „Eldyf" computer program.

The measurements of textures and phase composition were made with the diffractometric Schulz X-ray reflection method on the Bruker D8 Advance diffractometer equipped with Euler disk.

The macro-stress values were calculated using the g-$\sin^2\psi$ method at the constant glancing angle.

Tribological tests were carried out on the CSEM „pin-on-disk" tester.

The microhardness tests of coatings were made on the SHIMADZU DUH 202 ultra microhardness tester.

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

Cutting ability of the investigated materials was determined basing on the technological continuous cutting tests of the SL-25 grey cast iron with the hardness of about 250 HB. Detailed characteristics of the test are presented in Table 1.

Investigations of surface roughness workpieces after machinability test were made on device SURTRONIC 10 TAYLOR-HOBSON.

Table 1.
Characteristics of the investigated materials and comparison of results

| substrate | coating | coating thickness, µm | Micro hardness, GPa | – Critical load, N | Stresses, MPa | cutting test: cutting conditions | cutting test: VB $_{(8\ min)}$, mm | cutting test: cutting quality, $R_a$, µm | cutting test: Tool life, min |
|---|---|---|---|---|---|---|---|---|---|
| $Al_2O_3$+$ZrO_2$ | uncoated | - | 18.5 | - | - | a = 2 mm, f = 0,15 mm/trn, V = 200 m/min, k = 70°, grey cast iron | 0.15 | 1.80 | 11'00" |
| | TiN | 0.8 | 22.7 | $(45)_{opt.}$ | -615 | | 0.14 | 2.43 | 11'00" |
| | TiN+TiAlSiN+TiN | 1.9 | 19.22 | 40 | 45 | | 0.10 | 1.70 | 15'00" |
| | TiN+multiTiAlSiN+TiN | 2.3 | 40.9 | 76 | -170 | | 0.12 | 1.77 | 14'00" |
| | TiN+TiAlSiN+AlSiTiN | 2.2 | 21.0 | $(78)_{opt.}$ | -141 | | 0.11 | 1.17 | 16'00" |
| | TiAlN | 2.2 | 32.9 | 82 | -37 | | 0.09 | 1.23 | 16'00" |
| | TiCN+TiN | 1.5 | 14.5 | 62 | 551 | | 0.13 | 1.87 | 13'00" |
| | TiN+$Al_2O_3$ | 6.0 | 34.1 | 73 | 114 | | 0.08 | 1.87 | 17'00" |
| $Al_2O_3$+TiC | uncoated | - | 19.7 | - | - | a = 2 mm, f = 0,15 mm/trn, V = 200 m/min, k = 70°, grey cast iron | 0.13 | 2.30 | 13'30" |
| | TiN | 1.2 | 33.6 | $(47)_{opt.}$ | -218 | | 0.08 | 1.43 | 18'00" |
| | TiN+TiAlSiN+TiN | 1.8 | 25.3 | 40 | -238 | | 0.11 | 1.63 | 17'30" |
| | TiN+multiTiAlSiN+TiN | 1.5 | 40.3 | 71 | -216 | | 0.08 | 1.37 | 19'00" |
| | TiN+TiAlSiN+AlSiTiN | 2.0 | 30.7 | $(77)_{opt.}$ | -120 | | 0.14 | 1.97 | 16'00" |
| | TiAlN | 2.2 | 36.2 | 80 | -300 | | 0.09 | 1.40 | 19'30" |
| | TiCN+TiN | 1.1 | 18.7 | $(15)_{opt.}$ | -196 | | 0.09 | 1.70 | 16'30" |
| | TiN+$Al_2O_3$ | 5.8 | 34.7 | 17 | -223 | | 0.09 | 1.60 | 16'30" |
| $Al_2O_3$+$SiC_{(w)}$ | uncoated | - | 18.7 | - | - | a = 2 mm, f = 0,2 mm/trn, V = 250 m/min, k = 70°, spheroidal cast iron | 0.30 | 1.53 | 8'00" |
| | TiN | 0.9 | 27.8 | $(38)_{opt.}$ | n.d. | | 0.25 | 1.93 | 9'30" |
| | TiN+TiAlSiN+TiN | 2.5 | 24.8 | 70 | n.d. | | 0.21 | 1.37 | 10'30" |
| | TiN+multiTiAlSiN+TiN | 2.8 | 40.2 | 58 | n.d. | | 0.20 | 1.13 | 11'00" |
| | TiN+TiAlSiN+AlSiTiN | 2.5 | 23.8 | $(80)_{opt.}$ | n.d. | | 0.21 | 1.40 | 10'30" |
| | TiAlN | 2.8 | 33.7 | $(99)_{opt.}$ | n.d. | | 0.20 | 2.43 | 11'00" |
| | TiCN+TiN | 2.6 | 22.7 | 40 | n.d. | | 0.28 | 1.80 | 8'30" |
| | TiN+$Al_2O_3$ | 7.9 | 36.7 | 18 | n.d. | | 0.13 | 2.20 | 16'00" |

## 3. Discussion of results

The coatings were put down onto the investigated substrate materials are characteristic of the single-, double-, multi-layer or gradient structure, depending on the coating type employed, and the particular layers adhere tightly to themselves and to the substrate. It was found out that the $TiN+Al_2O_3$ coating deposited onto the particular substrates is characteristic of the columnar structure of the particular layers, and in case of the other coatings, even at the largest magnifications used, no grain boundaries were revealed, which may attest to their fine-grained structure which was confirmed by thin foils examinations on the transmission electron microscope (Fig 1).

It was found out basing on texture examinations that its axial nature confirms the columnar structure of the investigated coatings. The texture of the investigated coatings is relatively weak and the advantageous compression stresses prevail in the upper layer of the coatings, affecting hardness and adherence of the deposited layers to the substrate (Table 1).

The inhomogeneity of the TiN, TiN+TiAlSiN+TiN, TiN+multi TiAlSiN+TiN, and TiN+TiAlSiN+AlSiTiN coatings surfaces is connected with occurrences of the multiple drop shaped micro-particles, developed in the coating deposition process.

The best adherence to the substrate, measured with the highest critical load value $L_c$=82 N measured by the acoustic emission registration is demonstrated by the TiAlN coating deposited onto the $Al_2O_3+ZrO_2$ ceramics substrate. In case of the TiAlN coating put down on the $Al_2O_3+SiC_{(w)}$ substrate no sudden increase of the acoustic emission was registered; however, the metallographic observations make it possible to determine optically the critical load of $L_{c(opt)}$=99 N, which gives grounds for statement that the TiAlN coating has the best adherence of all deposited coatings, regardless of the substrate type used from the tool oxide ceramics. Employment of the TiAlN coating, regardless of the substrate material used, results in hardness increase by more than 75% in comparison to the uncoated material (Table 1).

High hardness and good adherence to the substrate connected with occurrence of the advantageous compression stresses causes that regardless of the substrate material used deposition of the TiAlN coating results with the evident tool life improvement. Very good results (above 35% of the tool life increase) were also obtained during cutting with the $Al_2O_3+ZrO_2$ ceramics with the TiN, TiN+multiTiAlSiN+TiN, TiCN+TiN coating put down, and with the $Al_2O_3+SiC_{(w)}$ ceramics with the TiN+multiTiAlSiN+TiN and TiN+TiAlSiN+AlSiTiN coating. Moreover, in case of all employed coatings improvement of tool life with the deposited coating compared to the uncoated edge was observed in case of each of the employed coatings, except the TiN coating put down onto the $Al_2O_3+ZrO_2$ ceramics - in this case tool life after depositing the coating does not change. The most evident improvement of too life, more than 100%, was found out in case of the $TiN+Al_2O_3$ coating put down onto the $Al_2O_3+SiC_{(w)}$ ceramics substrate. Therefore, it was determined that putting down the anti-wear coatings onto the oxide ceramic tool materials is justified and the composite tool materials developed in this way may have the important application significance in the industry for cutting tools (Table 1).

a)

b)

c)

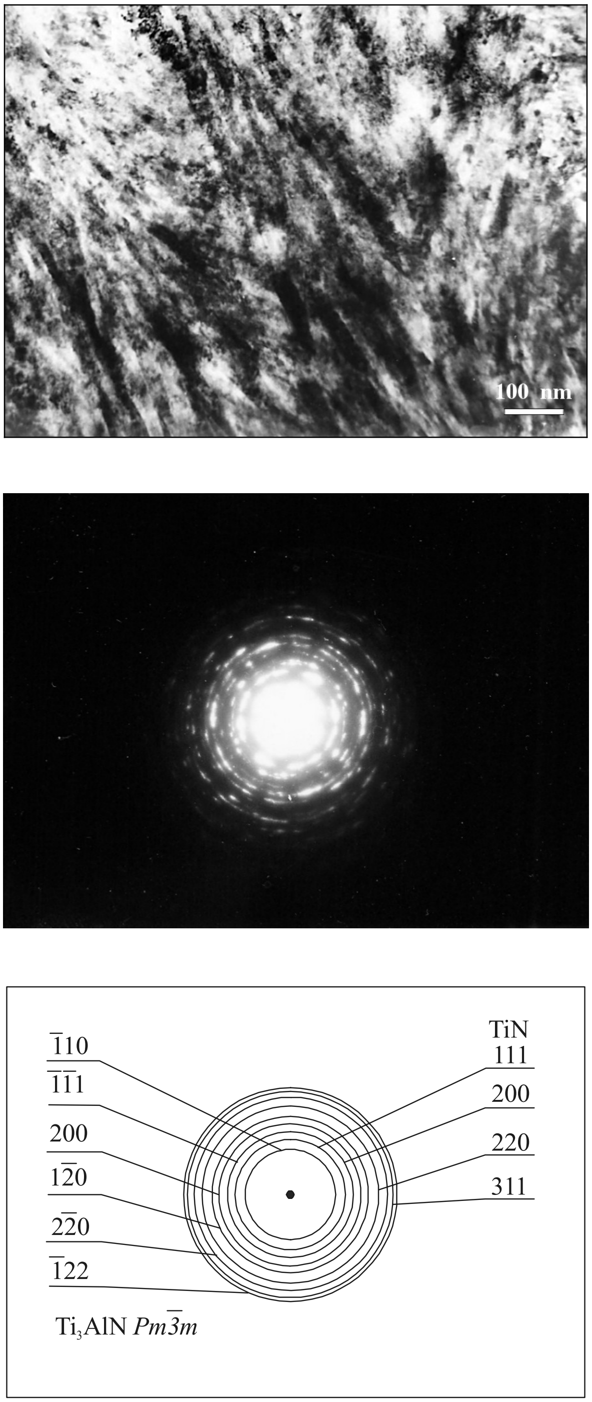


Fig. 1. Structure of (Ti,Al)N coating: thin foil structure perpendicular to the layer surface (TEM): a) light field, b) diffraction pattern as in figure a, c) diffraction pattern from the area as in figure b

## 4. Summary

It has been demonstrated that the creation of the TiN+TiAlSiN+TiN, TiN+multiTiAlSiN+TiN, TiN+TiAlSiN +AlSiTiN and TiAlN multi-layer and multi-component coatings by the use of the PVD method in the cathode arc evaporation and TiCN+TiN and TiN+$Al_2O_3$ coatings by the use of the CVD processes on $Al_2O_3$+$ZrO_2$, $Al_2O_3$+TiC, $Al_2O_3$+$SiC_{(w)}$ oxide ceramic tool materials causes the increase of coatings hardness and allows to improve application features of multi point cutting tools for high speed machining, tools for fine cutting coated with them and dry cutting without using the cutting fluids in comparison to the multi point cutting tools produced from the same uncoated materials.

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