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Cutting Characteristics of PVD and CVD - Coated Ceramic Tool Inserts

RESEARCH

The paper presents investigation results of cutting characteristics of the modern sintered ceramic tool inserts coated with PVD and CVD coatings. It was demonstrated, basing on the technological cutting tests, that putting down onto the ceramic tool inserts the thin wear-resistant coatings increases their abrasion wear resistance, which has a direct effect on extending the tool life. Basing on the roughness parameter R_a of the machined cast iron surface after the cutting tests, improvement was revealed of the machined material properties, cut with coated ceramic inserts compared to material machined with the uncoated ones.

Keywords: Ceramic inserts, PVD, CVD, Multi-layer coatings, Tool wear

1. INTRODUCTION

The main goal of the research of the wear mechanisms of cutting tools is determining the effect of various conditions and machining parameters in life and reliability of tool service. Identifying and evaluating the influence of the possibly big number of factors determining tool life makes development of more and more accurate models of cutting tools wear possible. Analysis of these models facilitates solving problems of the contemporary machining technology connected with the continuous life extension of the highly efficient cutting tools made with the powder technology, making high speed cutting possible. Solving this problem makes machining productivity and quality improvement possible with its simultaneous energy - and material consumption reduction [1-11].

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 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 [4-11].

The rapid development of the PVD technology connected with the widespread use of the high-melting compounds of carbon, nitrogen, and boron, especially with the transition metals for depositing the thin, hard, anti-wear coatings is one of the most important tool wear limiting methods. Limiting the wear rate and extending the life, low thermal conductivity coefficient, resistance to high temperature and in many cases limiting the oxidation and corrosion processes decide mostly use of coatings obtained in the PVD process for coating tool materials [4-11].

The possibilities of constituting the coatings resulting from the mutual interactions among the manufacturing process, properties, and efficiency of the developed system give the possibility, by their appropriate selection, to develop coatings characteristic of the expected optimum service properties. The appropriate selection of the coating material is conditioned by limiting the thermal-, mechanical-, or corrosion wear deciding tool failure [4-14].

The goal of this work is investigation of the cutting characteristics 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.

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2. EXPERIMENTAL PROCEDURE

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).

Table 1: Specification of the investigated cutting tool materials

Substrate	Coating			Process type	Micro hardness GPa	Critical load L_c, N (max load)
	Type	Composition	Thickness, μm			
Si_3N_4	uncoated				18.50	–
$Al_2O_3+ZrO_2$	uncoated				18.50	–
Cermet [1)]	uncoated				24.50	–
Si_3N_4	gradient layer	TiN+(Ti,Al,Si)N+TiN	2.0	PVD	23.30	22 (100)
$Al_2O_3+ZrO_2$	gradient layer	TiN+(Ti,Al,Si)N+TiN	2.0	PVD	19.20	40 (100)
Cermet [1)]	gradient layer	TiN+(Ti,Al,Si)N+TiN	4.0	PVD	33.00	137 (200)
Si_3N_4	multi layer	TiN + multi (Ti,Al,Si)N +TiN	4.0	PVD	35.20	23 (100)
$Al_2O_3+ZrO_2$	multi layer	TiN + multi (Ti,Al,Si)N +TiN	2.3	PVD	40.90	76 (100)
Cermet [1)]	multi layer	TiN + multi (Ti,Al,Si)N +TiN	4.0	PVD	33.90	121 (200)
Cermet [1)]	multi layer	TiN+TiC+TiN [2)]	5.0	PVD	30.00	79 (200)
Si_3N_4	two layer	$TiN+Al_2O_3$	10.0	CVD	32.50	83 (100)
$Al_2O_3+ZrO_2$	two layer	$TiN+Al_2O_3$	6.0	CVD	34.10	73 (100)
Si_3N_4	two layer	Al_2O_3+TiN [2)]	2.6	CVD	26.25	47 (100)

[1)] Chemical composition (mass concentration 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

The micro hardness tests using the Vickers method were made on the Shimadzu DUH 202 tester (load of 70 mN).

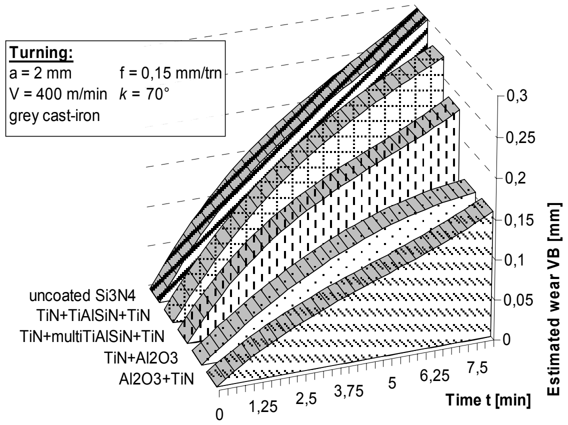
Adhesion evaluation of the coatings on the investigated inserts was made using the scratch test on the CSEM REVETEST device, by moving the diamond penetrator along the examined specimen's surface with the gradually increasing load. The tests were made with the following parameters: load range 0-200 N, load increase rate (dL/dt) 100 N/min, penetrator's travel speed (dx/dt) 10 mm/min, acoustic emission detector's sensitivity AE 1. The critical load L_c, at which coatings' adhesion is lost, was determined basing on the registered values of the acoustic emission AE.

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 tool wear of VB = 0.20 mm (for oxide ceramics, cermets) and VB=0.30 mm (for nitride ceramics) was used as the wear 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 a_p=1; 2 mm; cutting speed v_c=200; 400 m/min. Topography examinations of the worn tool surface were carried out on the JEOL SEM microscope.

3. DISCUSSION

As a result of carried out researches it was found out that the deposition of newly worked out multilayer and gradient nano-crystalline 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.

The detailed analysis was carried out of the relationships between the service properties of the investigated ceramic tool inserts 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].



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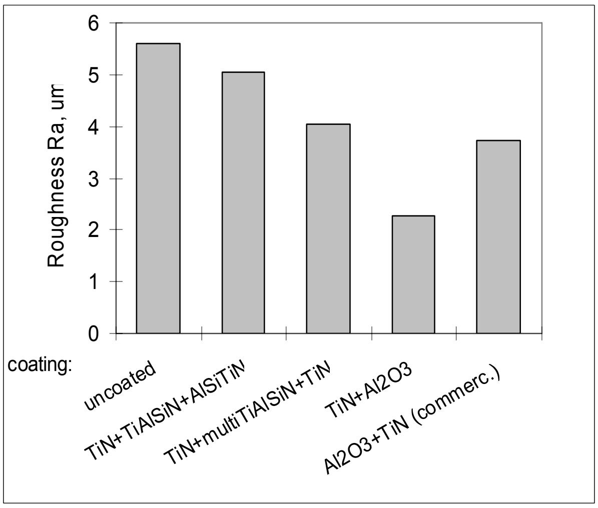

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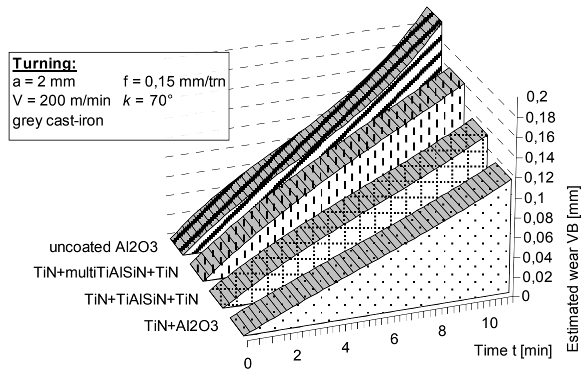
Figure 1: Comparison of the cutting characteristics of Si_3N_4 ceramics; a) tool wear VB, b) surface roughness R_a at the final machining

Machining tests of turning the grey cast iron with the Si_3N_4 ceramics revealed the clear wear resistance effect of the presence of the Al_2O_3+TiN and TiN+Al_2O_3 coatings combinations on the inserts' tool life. In case of inserts with the PVD coatings based on the TiN and TiAlSiN layers no tool life extension was observed, as flank failure occurs at the same time as for the uncoated insert. This is probably, caused by a weak adhesion of these coatings to the substrate, albeit their hardness, *e.g.,* of the TiN+ multi (Ti,Al,Si)N+TiN coating, exceeds significantly hardness of other deposited coatings, table 1. On the other hand, it was noticed that among the CVD-coated inserts, the longest tool life during continuous turning corresponds to the Si_3N_4 with the TiN+Al_2O_3 coating, for which the tool wear reaches the value of VB=0.16 mm after 8 min., Figure 1a.

It was found out, basing on the technological turning test of grey cast iron with the Al_2O_3+ZrO_2 ceramics, that the tool reaches the VB = 0,20 mm wear criterion after t = 11 min of cutting time. Time of t = 11 min was assumed as the comparative criterion for measurement of the tool wear for all specimens (inserts) with the Al_2O_3+ZrO_2 substrate. After the assumed machining test duration the smallest cutting tool wear of VB = 0.11 mm was revealed in case of the TiN+Al_2O_3 coating, Figure 2a.



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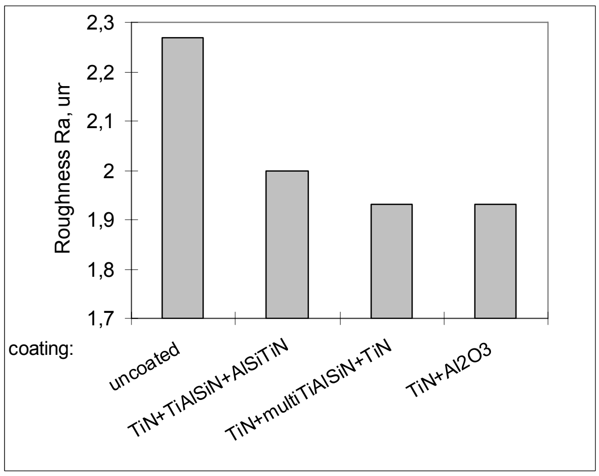

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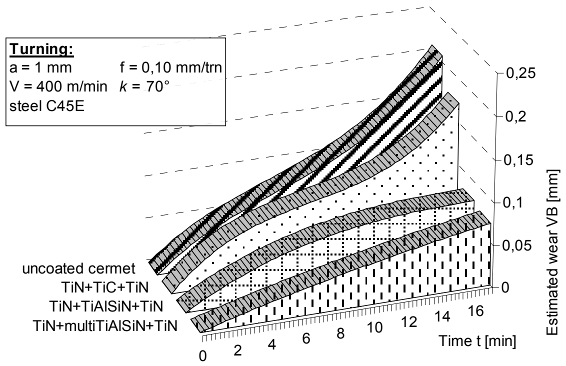
Figure 2: Comparison of the cutting characteristics of Al_2O_3+ZrO_2 ceramics; a) tool wear VB, b) surface roughness R_a values at the final machining

Depositing the wear resistance gradient and multi TiN+(Ti,Al,Si)N+TiN coatings on tool cermets results in increase of their wear resistance, which immediately causes, among others, increasing the tool life.

It was found out, basing on the turning test of C45E steel with the uncoated cermets, that the tool reaches the VB = 0,20 mm wear criterion after t = 17 min cutting time. Time of t = 17 min was assumed as the comparative criterion for measurement of the tool wear VB for all specimens (inserts) with the tool cermets substrate. After the assumed machining test duration the smallest cutting tool wear of VB = 0.07 mm was revealed in case of the TiN + multi (Ti,Al,Si)N + TiN coating (Figure 3a).



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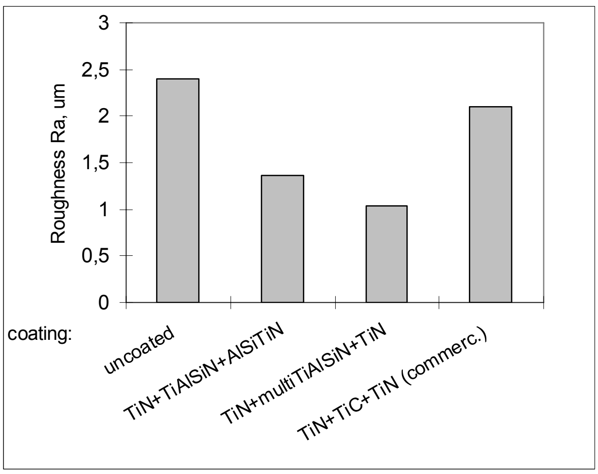
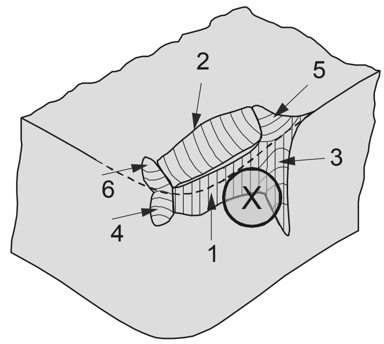


b)

Figure 3: Comparison of the cutting characteristics of cermets;
a) tool wear VB, b) surface roughness R_a at the final machining

Therefore, the real life tests confirm the quality of the 3rd generation of the coatings: 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. Wear characteristics of investigated cermets and ceramics are compatible with wear models, Figure 5 [11].



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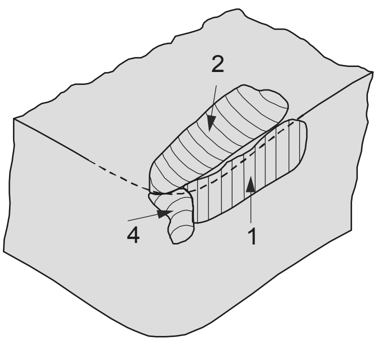
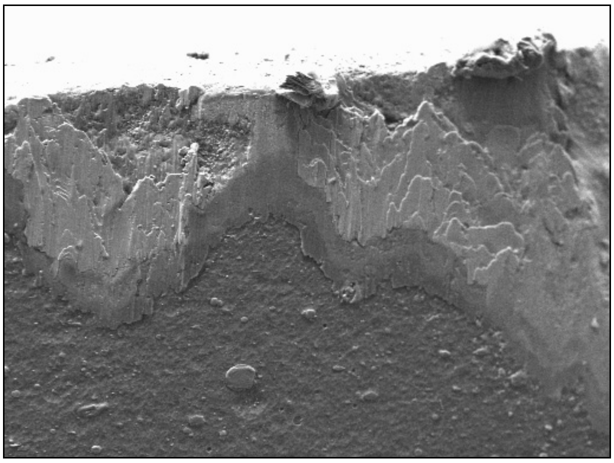


b)

Figure 4: Tool wear models for different cutting materials: a) cermets, b) ceramics: 1 – wear of flank face, 2 – crater on rake face, 3 – notch on major flank face, 4 – notch on minor flank face, 5, 6 - notches on rake face

Basing on the surface roughness tests, depending on the cutting period, it was found out that depositing the PVD and CVD coatings onto the investigated substrates results in decrease of the machined material roughness and – the same – improvement of its quality, especially at the final machining process.



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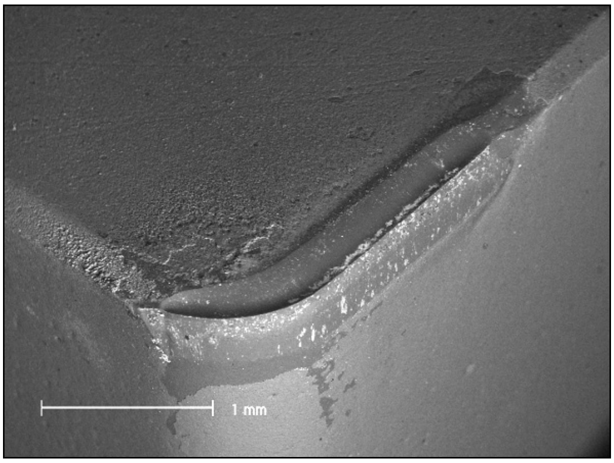

b)

Figure 5: Characteristic wear of different cutting materials coated with TiN+TiAlSiN+TiN a) cermet (X-area from Fig. 4a), b) Si_3N_4 ceramic

For cermets tools, the minimum surface roughness of R_a = 0.92 μm, at the final machining, was revealed in case of the TiN+ multi TiAlSiN+ TiN coating, Figure 1b. For nitride ceramics tools, the minimum surface roughness of R_a = 2.3 μm obtained in case of the TiN+Al_2O_3 coating, Figure 2b. Whereas, for the oxide ceramics tools, the minimum surface roughness of R_a = 1.5 μm obtained in case of the TiN+ multi TiAlSiN+ TiN coating, Figure 3b.

4. CONCLUSIONS

Employment of the hard anti-wear coatings deposited onto the sintered ceramic tool inserts 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 inserts 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 inserts, as well as of cermets with the complex nano-crystalline 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.

ACKNOWLEDGMENTS

Research was carried out within the CEEPUS Network No PL-013/2004-05, and financed partially by the Ministry of Education, Science and Sports Republic of Slovenia, and partially within the framework of the Polish State Committee for Scientific Research Project KBN PBZ-100/4/T08/2004 headed by Prof. L.A. Dobrzański.

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