

The effects of the coating stripping process on regenerated tool cutting edges

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Properties

ABSTRACT

Purpose: The cutting tools of high speed steel or cemented carbide need to be regenerated in many cases. This involves stripping the remnants of the initial coatings. The effects of chemical removal of the PVD TiN, TiAlN, TiN/(TiAlSi)N/TiN and TiZrN/10x(TiN/ZrN)/TiN coatings on some elements of geometry of cutting edges and the adhesion of subsequent coatings deposited on the cutting inserts are considered.

Design/methodology/approach: Scanning electron microscopy is used to examine the structures after the various stages of inserts regeneration: with the initial coating, after it is chemically stripped and subsequently deposited. Geometry of cutting edges, i.e. roughness, edge roundness radius and 2D and 3D geometric structure of rake and flank faces, as well as the adhesion of subsequent coatings deposited on the inserts in the regeneration process are determined.

Findings: The chemical coating stripping process did not cause unfavourable changes in the roughness parameter Ra of the rake and flank faces of cutting inserts, or in the roughness of their cutting edges. Subsequent coatings deposited on the decoated inserts had a marginally lower adhesion, but in the case of TiN coated cemented carbide, the latter coating had better adhesion than the original. Surface analyses showed that the PVD coating stripping methods were effective for TiN and TiAlN coated high speed steel HS6-5-2 inserts, as well as for TiN coated and commercially TiN/(TiAlSi)N/TiN coated cemented carbide inserts.

Research limitations/implications: The paper is concerned with geometry of cutting edge and adhesive properties of subsequent coatings. To verify fully the effectiveness of the methods described further research on different coating removal from tools made of various tool materials should be carried out.

Practical implications: The methods and chemicals used for removal of the initial PVD TiN, TiAlN and TiN/(TiAlSi)N/TiN coatings from high speed steel and cemented carbide inserts proved effective and may be used in the regeneration process of cutting tools.

Originality/value: The effects of chemical removal of mono and multilayer PVD coatings from cemented carbide and high speed steel inserts on the regenerated cutting edges quality have been determined.

Keywords: PVD; Coatings; Stripping; Roughness; Cutting edge; Coating adhesion

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1. Introduction

The majority of currently used cutting tools have their cutting edges modified with anti-wear coatings [1,2], mainly physical vapour deposited, PVD. The more expensive coated tools, e.g. cemented carbide and high speed steel hobs, are reused several times- after a regeneration process [3]. The basic regeneration process is grinding of the tool rake face; not necessarily always performed on the other tool surfaces [4]. Regarding the subsequent cutting efficiency, it is considered that, without removal of the original coatings, two is the maximum number of such operations [5]. Hobs, during use, especially by the automotive industry, are frequently refurbished to ensure their high machining efficiency. It is essential then to perform the full regeneration process, i.e. remove the coating from all the surfaces, including the flank face. This takes place up to 15 times [5].

Coating removal process is made more difficult by the variety of both substrate and coating materials. The current estimate of number of coating types is several hundred, of which, on the market in 2009 [5], there were about 70 PVD coatings with various chemical compositions. By 2011 there were new types, raising the number of commercial PVD coatings to about 100 [3]. Structure and properties of different types and PVD coatings deposited on various tool materials were presented in many publications [1,3,5-11]. The coatings efficient removal requires the retention of a proper substrate surface - using an environmentally safe method. This was a problem tackled in recent investigations of numerous substrate materials; in the case of cutting tools: high speed steels, cemented carbides, oxide and mixed ceramics - reported on e.g. in references [12-18].

PVD coated HB 10F cemented carbide hobs were investigated by Institute of Advanced of Manufacturing Technology (IAMT). These were regenerated by grinding the rake face and it was demonstrated that 4-5 coating removals were possible without resorting to chemical means [12]. Successfully studied also were TiN and (TiAl)N successively coated high speed steel hobs [19]. The most commonly-used methods of complete coating removal, however, involve "wet" chemical methods, discussed in references [12,18].

An efficient means of stripping requires complete coating removal without any concurrent geometric or chemical changes in the substrate material [18]. This is not easy, since the wear-resistant nitride coatings are simultaneously corrosion-resistant, more so than the substrate material. Thus the coating removal baths, in addition to the active ingredients (e.g. hydrogen peroxide, H_2O_2) which separate the coating from the substrate, must contain corrosion inhibitors (e.g. benzotriazole, imidazole, pyrazole), essential to safeguard the substrate. Commercial nitride coating stripping agents include those of Baku Chemie, Borer Chemie, „absolut Decoating Technology" and DETEC Nederland [20], which sells their chemicals only with their own stripping equipment. There is also Deconex de-coat 110 of Borer Chemie AG, for removal of AlTiN, TiAlN and ZrN coatings from surfaces of group P and K cemented carbides and high-alloy steels. "absolut Decoating Technology" has introduced for removing PVD coatings from high speed steels new assisting preparations Ferrotec® 56 and Excarbonite® 12 and for various types of coatings and substrates removing agent Uniceral® 108 [20].

This paper presents results of research on the effects of chemical removal (stripping) of the PVD TiN, TiAlN, TiN/(TiAlSi)N/TiN and TiZrN/10x(TiN/ZrN)/TiN coatings from high speed steel and cemented carbide cutting indexable inserts on some elements of geometry of cutting edges such as their roughness and edge roundness radius as well as on the adhesion of subsequent coatings deposited on the inserts in the regeneration process.

2. Experimental procedures

The specimens were PVD coated cemented carbide (HM) and high speed steel cutting tool inserts listed in Table 1. The HM inserts were produced by Baildonit (Sandvik Polska) and HSS inserts were manufactured by Ifanger.

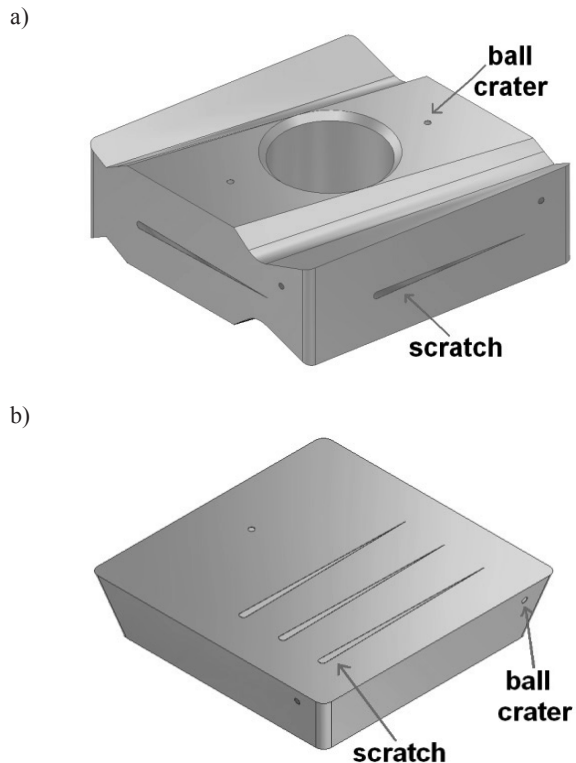


Fig. 1. Sites of coating thickness measurement on rake and flank faces (Calotest) and of adhesion (scratch test) for inserts a) high speed steel CNEG 120404 L01 b) cemented carbide SPUN 120308.

For PVD coatings removal from the Table 1 specimens the hydrogen peroxide (H_2O_2 35% water solution) was used with stabilizing and activating agents: the BAKUTRIT 50 and BAKUTRIT PL, manufactured by Baku Chemie GmbH [20]. The coating chemical stripping process parameters were determined experimentally. Effective process parameters of coatings chemical removal from high speed steel and cemented carbide inserts are given in Table 2.

Table 1.
Details of the inserts investigated

No	Insert type	Designation	Substrate	Coating
1	CNEG 120404 L01	HSS/TiN	High speed steel HSS-Co8	TiN
2	CNEG 120404 L01	HSS/TiAlN	High speed steel HSS-Co8	TiAlN
3	SPUN 120308	N335/P35	Cemented carbide P35	TiN/(TiAlSi)N/TiN
4	SPUN 120308	S20S/P20	Cemented carbide P20	TiN*
5	Specimen $\varnothing 8 \times 50$ mm***	HSS/TiN	High speed steel HS6-5-2	TiN**
6	Specimen $\varnothing 8 \times 50$ mm***	HSS/ZrN, TiN - based	High speed steel HS6-5-2	TiZrN/10x(TiN/ZrN)/TiN**

*/ TiN coating of Baildonit specimens was by cathodic arc PVD method effected elsewhere

**/ Coatings were deposited by cathodic arc PVD method at IAMT; sequence of the layers starting from a substrate

***/ Specimens used only for some trials of coating removal

Table 2.
Process conditions of coating removal from high speed steel HSS and cemented carbide (HM) inserts and specimens

Insert Designation	Coating	Thickness, μm	Substrate	Removal process temperature, $^{\circ}\text{C}$	Time, min	Coating removal bath composition
HSS/TiN	TiN	2-3.5	HSS	90-95	60-120	H ₂ O ₂ (35%) and BAKUTRIT 50 water solution
HSS/TiAlN	TiAlN	2-3.5	HSS			
HSS/ZrN, TiN - based	TiZrN/10x(TiN/ZrN)/TiN	4.5-5.5	HSS	90-95	195	H ₂ O ₂ (35%) and BAKUTRIT PL, Aktivator I and II water solution
N335/P35	TiN/(TiAlSi)N/TiN	3-4.5	HM	25-30	300-350	
S20S/P20	TiN	2.5-3.5	HM			

The surfaces of coated and de-coated specimens as well as structures on the metallographic cross-sections were observed using a scanning electron microscope JSM-6460LV (JEOL). The energy dispersive spectroscopy (EDS) was applied to determine possible changes in chemical compositions of the substrates after chemical coating removal.

After effective initial coatings removal from HSS and HM indexable inserts, the subsequent PVD coatings were deposited.

Calotest, according to the standard PN-EN 1071-2:2004, was used to determine coating thickness on both the rake and flank faces, as shown schematically in Fig.1. A profilometer TOPO 01P with appropriate attachment for measuring the geometric structure of the surface and the edge was employed to measure roughness, on 4mm trajectory. The edge rounding radius was measured using a diamond blade with a 2 μm tip radius. The adhesion of deposited PVD coatings, first and subsequent (after chemical removal of the previous), was measured by the scratch test, standard PN-EN 1071-3-2007, on a CSM Revetest Scratch Tester (at the Koszalin University of Technology). For high speed steel inserts the measurements were performed on the flank face, as it proved impossible to use the rake face for CNEG inserts (Fig. 1a). For cemented carbide inserts the measurements were made on the rake face (Fig. 1b).

3. Results

In case of PVD TiN, TiAlN on HSS substrates and TiN, TiAlSiN on HM substrates, the chemical stripping effected in a complete coating removal without any special damage to the de-coated surfaces. The examples of specimens with completely removed coatings are given in Figs. 2 and 4. The chemical composition measurement by EDS of the specimen surfaces also proved that they were free of coating remnants.

But the PVD TiZrN/10x(TiN/ZrN)/TiN coating was not completely removed from the HS6-5-2 substrate (Fig. 5). The removal of this complex multilayer coatings needs some further investigation.

The results of thicknesses of initial and subsequent coating measurements of HSS and HM inserts are given in Table 3.

Figs. 5 and 6 present examples of the determination of rounding radii of the cutting edges for high speed steel CNEG 120404 L01 inserts and cemented carbide inserts SPUN 120308, respectively after successive stages of regenerations.

After coating removal, the cutting edge roughness parameters (Ra, Rz, Rt, etc) were lower than for inserts with the first or subsequent coating (Tables 4 and 5).

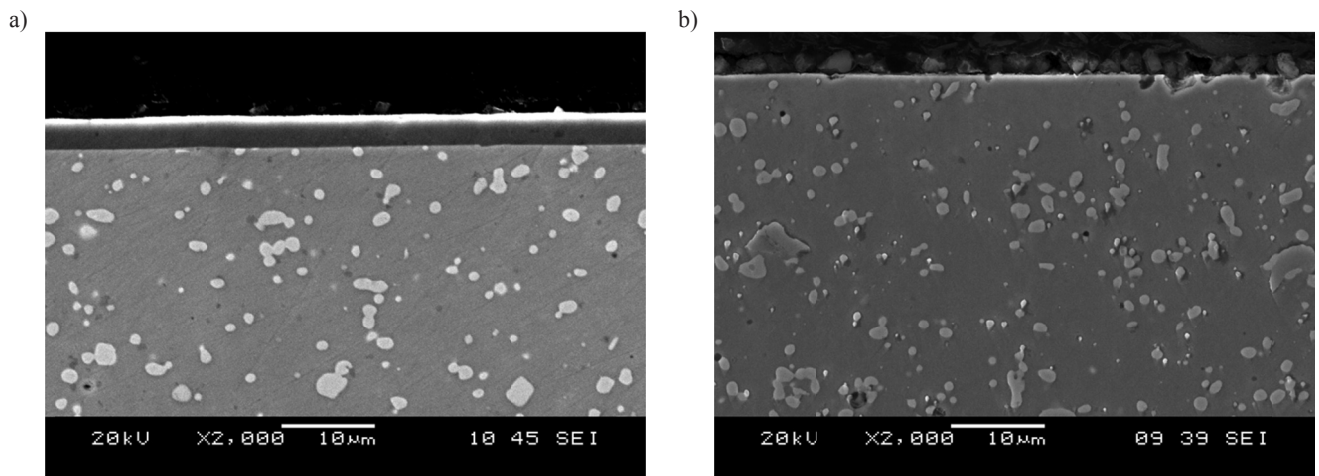


Fig. 2. SEM images of HS6-5-2 structure on the cross section a) PVD TiN coated, b) after removal of the coating

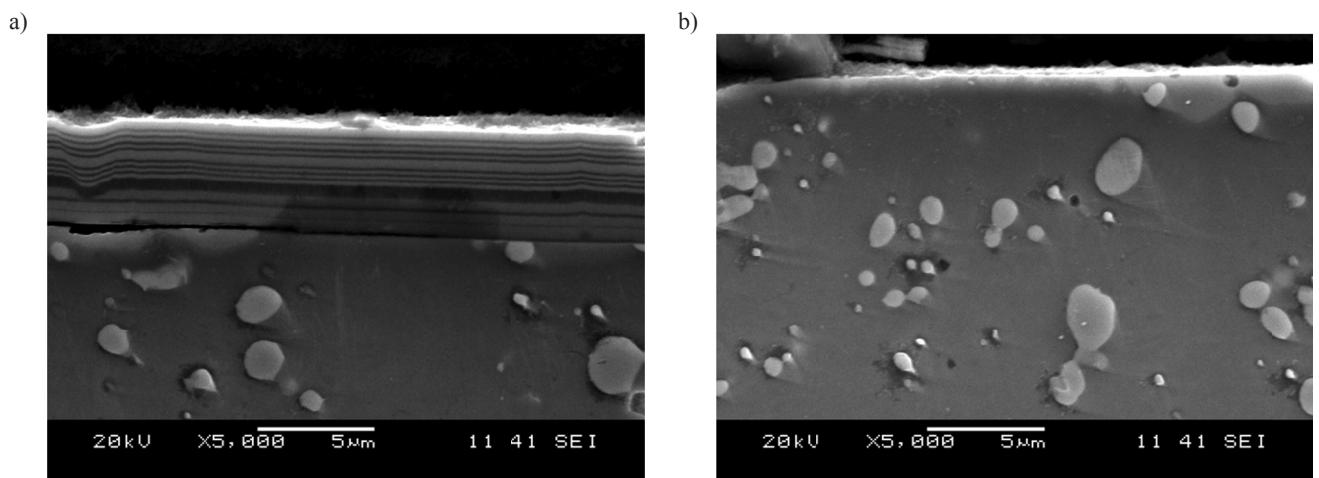


Fig. 3. SEM images of HS6-5-2 structure on the cross section a) PVD TiZrN/10x(TiN/ZrN)/TiN coated, b) after removal of the coating

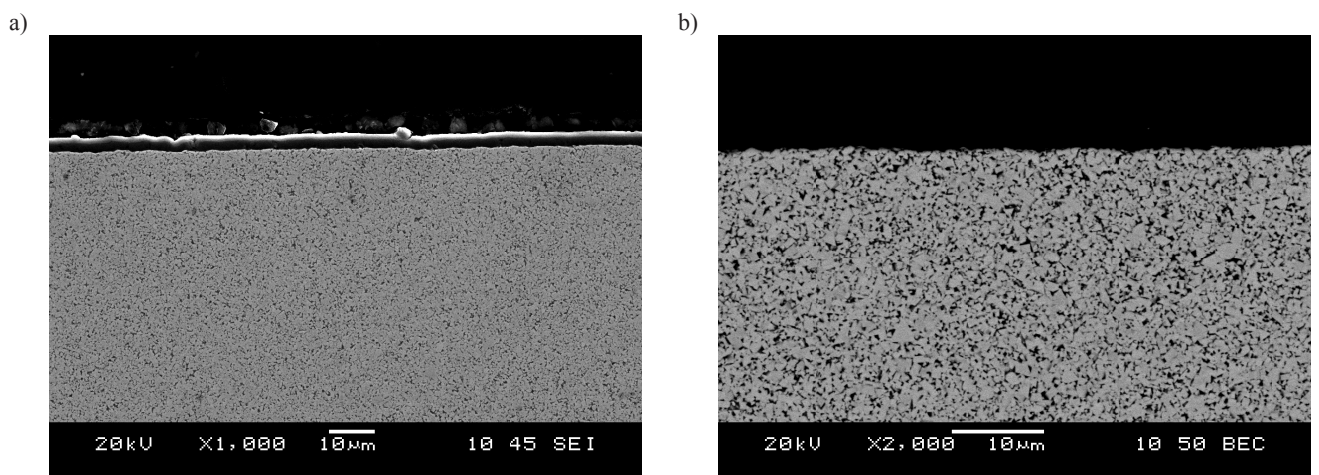


Fig. 4. SEM images of cemented carbide structure on the cross section a) PVD TiN/(TiAlSi)N/TiN coated, b) after removal of the coating

Table 3.
Coating thicknesses on the rake and flank faces of high speed steel (HSS) and cemented carbide (HM) inserts

Insert type		Coating thickness, μm							
		HSS/TiN		HSS/TiAlN		HM - N335		HM - S20S	
		Initial coating TiN	Subsequent coating TiN	Initial coating TiAlN	Subsequent coating TiN	Initial coating TiN/(TiAlSi)N/TiN	Subsequent Coating TiN	Initial coating TiN	Subsequent coating TiN
rake	Mean ¹	1.7	1.8	1.8	2.5	4.6	3.6	2.6	2.5
flank	Mean ²	3.2	2.5	3.5	3.1	3.0	2.0	2.0	2.2

^{1/} number of measurements $n=2$, ^{2/} number of measurements $n=4$

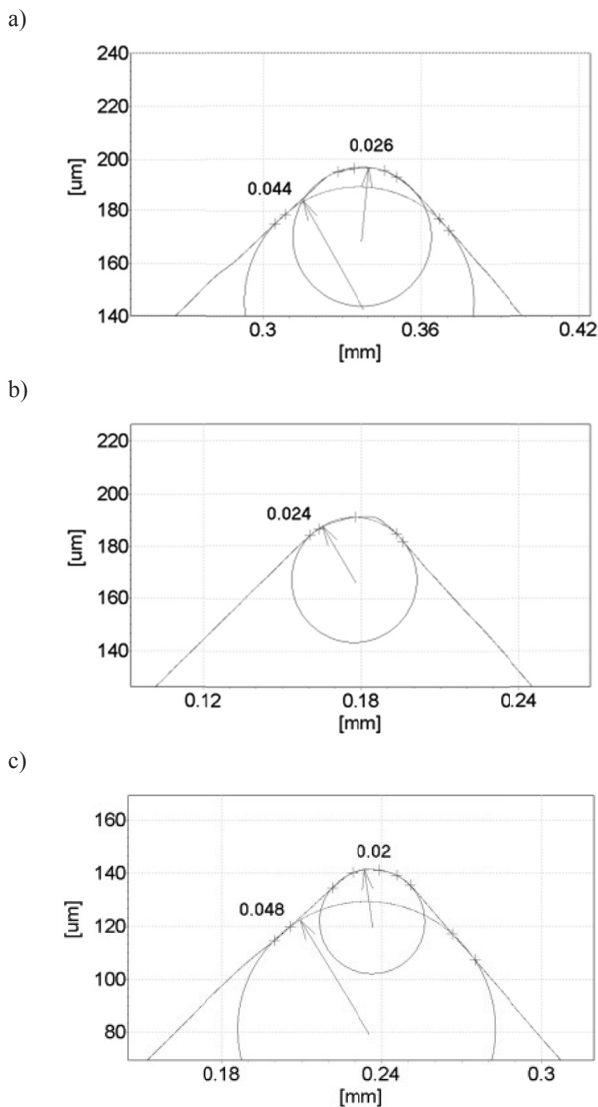


Fig. 5. Examples of measurement of cutting edge rounding radii of CNEG 120404 L01 HSS/TiN inserts after various regeneration stages: a) with initial TiN coating, b) after chemical removal of the TiN coating c) with subsequent TiN coating.

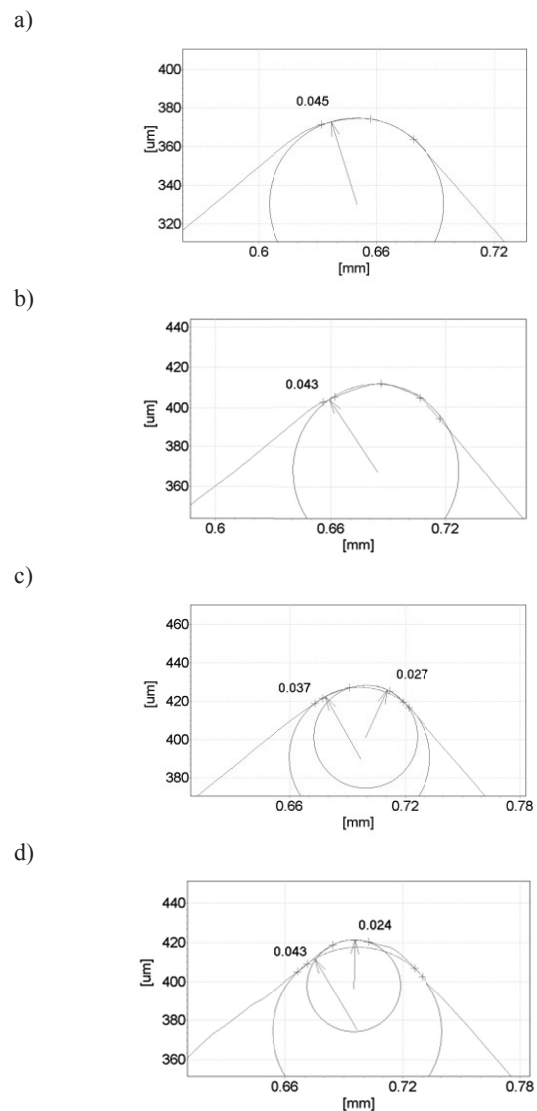


Fig. 6. Examples of measurement of cutting edge rounding radii of SPUN 120308 HM/TiN inserts after various regeneration stages: a) without coating b) with initial TiN coating, c) after chemical removal of the TiN coating d) with subsequent TiN coating

Table 4.
Mean roughness parameters of cutting edge of TiN coated high speed steel inserts CNEG 120404 L01 after successive regeneration stages.

Parameter, μm	Inserts			
	With initial coating		Coating stripped	Subsequent coating
Ra	0.90	0.93	0.51	0.75
Rz	5.38	5.10	3.38	5.18
Rt	7.49	7.06	5.41	9.04
Rp	2.71	2.43	1.50	2.41
Rv	2.67	2.67	1.88	2.77

Remark: Results for 2 specimens

Table 5.
Mean roughness parameters of cutting edge of TiN coated cemented carbide inserts SPUN 120308 after successive regeneration stages

Parameter, μm	Inserts					
	No coating			With initial coating	Coating stripped	With subsequent coating
Ra	0.27	0.28	0.22	0.55	0.22	1.77
Rz	1.57	1.86	1.27	3.09	1.44	9.38
Rt	2.82	2.94	1.79	4.06	2.62	13.29
Rp	0.68	1.01	0.60	1.59	0.60	4.99
Rv	0.89	0.85	0.67	1.49	0.84	4.39

Remark: Results for 3 specimens

Table 6.
Adhesion of PVD coated inserts on the rake (rf) and flank (ff) faces for high speed steel and cemented carbide inserts.

Insert	Substrate	Face	Coating	Normal force to detach the coating, N		
				Mean	S.D.	Confidence interval for α=0.10
HSS/TiN	HSS-Co8	ff	Initial coating TiN	48.1	0.8	±1.4
	HSS-Co8	ff	Subsequent coating TiN	46.0	0	±0
HSS/TiAlN	HSS-Co8	ff	Initial coating TiAlN	52.2	0.6	±1.0
	HSS-Co8	ff	Subsequent coating TiN	47.5	2.4	±4.1
N335	N335/P35	rf	Initial coating TiN/(TiAlSi)N/TiN	69.2	1.4	±2.4
	N335/P35	rf	Subsequent coating TiN	58.5	0.7	±1.2
S20S	S20S/P20	rf	Initial coating TiN	57.3	3.3	±5.6
	S20S/P20	rf	Subsequent coating TiN	64.3	2.3	±3.9

After coating removal, the cutting edge roughness parameters (Ra, Rz, Rt, etc) were lower than for inserts with the first or subsequent coating (Tables 4 and 5).

For high speed steel (HSS) inserts the cutting edge rounding radius after coating chemical removal was 0.024-0.028 mm with a regular contour (Fig. 5b). For TiN coating of high speed steels the contour of edge roundness was irregular, both for initial (Fig. 5a) and subsequent (Fig. 5b) coatings.

As-received cemented carbide inserts had radii in the range 0.044-0.058 μm and regular contours (Fig. 6a). After the first and subsequent coatings, the edge contours became irregular and the radii were on the same level. After chemical removal of the coating, the rounding radii were somewhat smaller, 0.031-0.048 μm, but the contours irregular (Fig. 6c).

Figs. 7 and 8 present examples of the determination of 3-D surface roughness parameters of CNEG 120404 L01 high speed

steel inserts and SPUN 120308 cemented carbide inserts, respectively after successive stages of regenerations. The coating removal process did not cause unfavourable changes in the roughness parameter Ra, or increase the roughness of the rake faces.

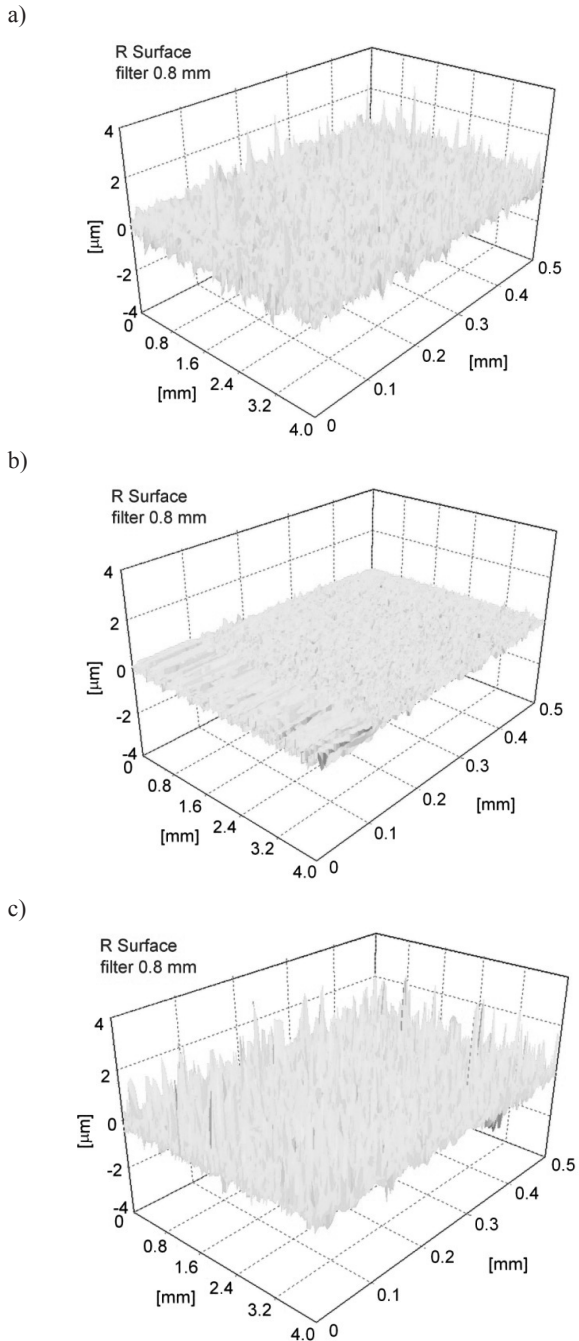


Fig. 7. 3-D surface roughness parameters of the rake faces of CNEG 120404 L01 HSS/TiN inserts after various regeneration stages: a) with initial TiN coating, b) after chemical removal of the TiN coating c) with subsequent TiN coating

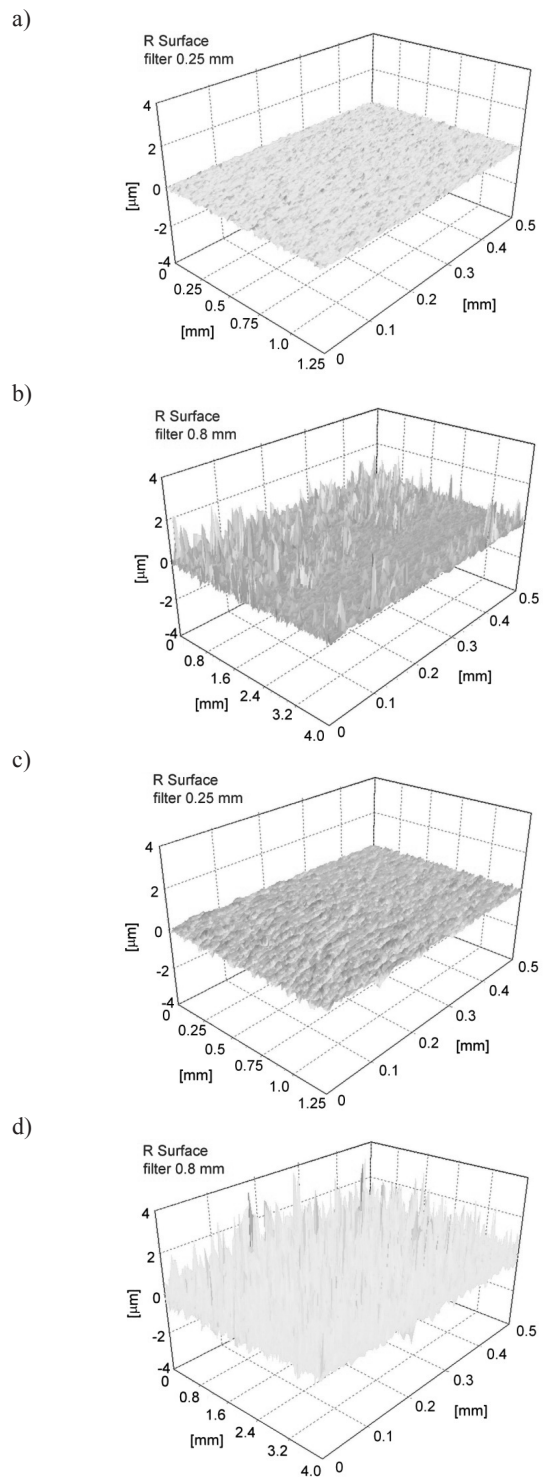


Fig. 8. 3-D surface roughness parameters of the rake faces of SPUN 120308 HM/TiN inserts after various regeneration stages: a) insert prior initial coating deposition, b) with initial TiN coating, b) after chemical removal of the TiN coating, c) with subsequent TiN coating

Table 5 lists the adhesion results for both substrates and the first and subsequent coatings. Critical loads tend to be marginally lower for subsequent coatings. In the case of S20S cemented carbide inserts with the TiN coating, however, the situation is reversed. It should be stressed that in this case the first and subsequent coatings were both of TiN, deposited with the same PVD method and processing parameters. This indicates that there was no deleterious effect of chemical coating removal on adhesion of the subsequent coating.

4. Conclusions

The methods and chemicals used for removal of the initial PVD TiN, TiAlN and TiN/(TiAlSiN)/TiN coatings from high speed steel and cemented carbide inserts proved effective. The stripping process did not cause unfavourable changes in the roughness parameter Ra, or increase the roughness of the cutting edge. Subsequent coatings had similar, or a little lower, thicknesses than the original, and somewhat higher roughness. Subsequent coats had a marginally lower adhesion, but in the case of TiN coated S20S cemented carbide, the latter coating had even slightly better adhesion than the original. Surface analyses showed that the PVD coating stripping methods were effective for TiN and TiAlN coated high speed steel HS6-5-2 and commercially TiN/(TiAlSiN)/TiN coated cemented carbide.

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