Acta Materialia Transylvanica 3/2. (2020) 61–64.
DOI: hungarian: https://doi.org/10.33923/amt-2020-02-01
english: https://doi.org/10.33924/amt-2020-02-01

Adhesion Behavior of PVD-coated Cutting Tools

Enikő Réka FÁBIÁN,[1] Richard HORVÁTH[2]

Óbuda University, Donát Bánki Faculty of Mechanical and Safety Engineering. Budapest, Hungary

[1] *fabian.reka@bgk.uni-obuda.hu*

[2] *horvath.richard@bgk.uni-obuda.hu*

Abstract

Cutting with TiAlN or CrAlN tip PVD-coated tungsten carbide-based inserts manufactured by powder metallurgy, we found no significant difference in the wear behavior of inserts regardless of whether the insert was used in wet or dry conditions. We determined the adhesion properties of the coating layers with a scratch test and by Daimler–Benz test. On the tungsten-based carbide cutting tool, the thinner TiAlN coating showed slightly better adhesion than the thicker CrAlN coating.

Keywords*: TiAlN, CrAlN, adhesion test, Calo test.*

1. Introduction

Cutting tools can be classified into different groups based on their material, geometrical shape, purpose and conditions of use. Based on their field of use, there are turning, drilling, milling and other tools. A tool has to fulfil the following requirements: high-quality cutting, precision, long life, productivity, and economical use. The tool can only fulfil these requirements if it has the necessary qualities. Of these, material properties are of paramount importance. An important cause of the failure of tools is wear due to abrasive and dynamic loads. Cutting tools are often surface treated **[1–5]**, or coated **[6–9]**, so that they are more resistant to wear. The properties of coatings depend on their structure, orientation, coefficient of friction but also on how much heat treatment the metal has received **[10–11]**.

2. Previous research

According to literature sources, on tungsten-carbide tools, TiAlN suffers less wear than CrAlN coating **[10]**, while on hot-forming tool steels, CrAlN coatings exhibit better adhesion resistance than TiAlN coatings **[11]**. We performed cutting on cast state GX2CrNiMoCuN25-6-3-3 quality super duplex steel in industrial conditions for 5 minutes. Cutting speed (v_c) was 70 m/min, feed (f) was 0.175 mm, and depth of cut (a) was 1 mm. We found that the wear of the two CNMG 120408 inserts with the two different coatings (nanocrystallite TiAlN and nanocrystallite CrAlN coating) was not considerably different regardless of whether cutting was performed in dry or lubricated conditions (**Figure 1)** Wear was present in both cases.

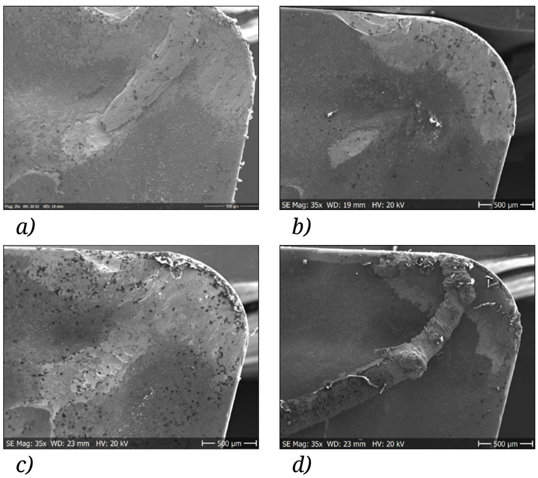

Figure 1. *Wear of coated cutting inserts. Built-up edge a) TiAlN coating + dry cutting; b) TiAlN coating + lubricated cutting; c) CrAlN coating + dry cutting; d) coating + lubricated cutting*

Figure 1 a) shows that after five minutes of dry cutting intact coating can only be found outside the "zone" of the depth of cut on the insert with the TiAlN coating. When lubricated cutting was performed, a built-up edge did not form on the rake surface up to the chip breaking groove on the TiAlN-coated insert, but the coating disappeared from the chip breaking groove and its immediate vicinity due to abrasive wear (Figure 1 b). Similarly to dry cutting, lubricated cutting also caused edge breakoff along the main cutting edge.

On the CrAlN-coated tool there were no shavings or built-up edge in the chip breaking zone of the rake surface, but the continuous wear of the chips completely wore off the coating (Figure 1 c). During lubricated cutting, there was no edge breakoff on the CrAlN-coated tool, but many built-up edges of the duplex steel can be seen along the edge. On this tool, the built-up edge from the duplex steel can be found on the rake surface, over a long distance, even in the chip breaking zone (Figure 1 d).

The test results were somewhat surprising because according to the distributor, the coefficient of friction of CrAlN is lower (0.4) than that of the TiAlN coating (0.6); the hardness of the TiAlN coating is 3200 HV, while that of the CrAlN coating is 3300 HV.

To find out why the coated inserts behaved as they did, we examined the actual thickness of the coating and its adhesion with various methods.

3. Materials and methods

The CNMG120408 inserts were manufactured by powder metallurgy. They were coated in conventional industrial conditions. Since not only the coating but the inserts are very hard too, the measurement of layer thickness with metallographic methods is very complicated; a coating is likely to break off, even when cut with a diamond disk. The hardness of the material makes conventional metallographic sanding complicated too, therefore we measured layer thickness with the Calo test [12–14] using a 30 mm diameter Al_2O_3 abrasion ball. The test is based on the wear between two surfaces based on abrasion. In the test, a Ø30 mm ball was coated with a suspension containing abrasive particles. The ball was then rotated through friction drive and pushed against the surface to be tested.

For the adhesion test, we used scratch test with MST[3] equipment, [15], and Daimler–Benz test [16].

4. Results

During the Calo test, the abrasion ball with the abrasive suspension creates a crater, with the shape of a spherical cap (Figure 2). The wear mark is measured under a microscope and the layer thicknesses are calculated [14].

Layer thickness (T) is calculated as follows:

$$T = \frac{X \cdot Y}{D};\ \mu m \tag{1}$$

Notation can be found in Figure 2.

On the coated inserts, the thickness of the different coatings is different. (Figure 3).

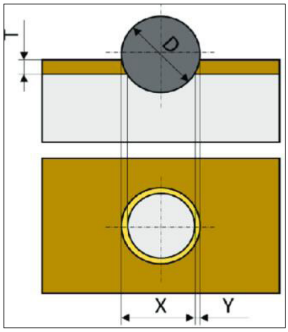

Figure 2. *Notation for calculating layer thickness.*

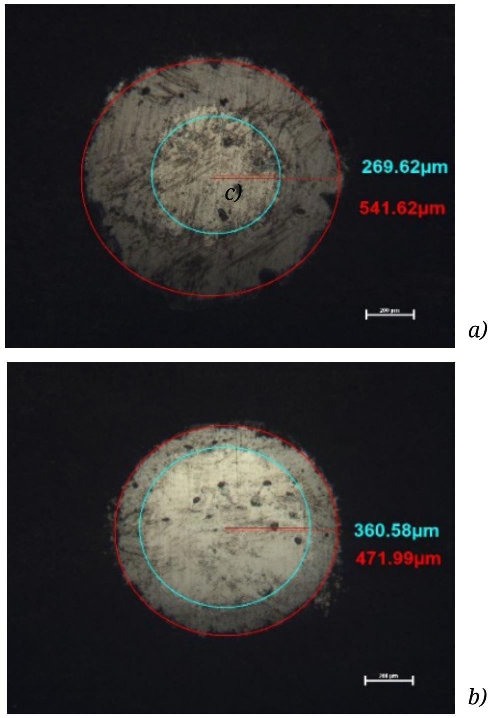

Figure 3. *Images of measuring the thickness of coating layers on CNMG120408 inserts a) TiAlN coating b) CrAlN coating.*

After the Calo test, we measured the circles around the spherical caps with an optical microscope and calculated the layer thicknesses. The thickness of the TiAlN layer was 6.2–7.4 μm on average, while the CrAlN layer just exceeded 3 μm (3.3 μm on average).

The results of the scratch tests performed with the MST^3 device are shown in **Figure 4.**

During the scratch test of the inserts, the flaking of the CrAlN layer has already started at a force of 4.03 N, while the TiAlN coating did not exhibit characteristic chipping at a fine scale low load even at the maximum load of 30 N that can be applied by the device. However, acoustic signals were detected even at very small loads.

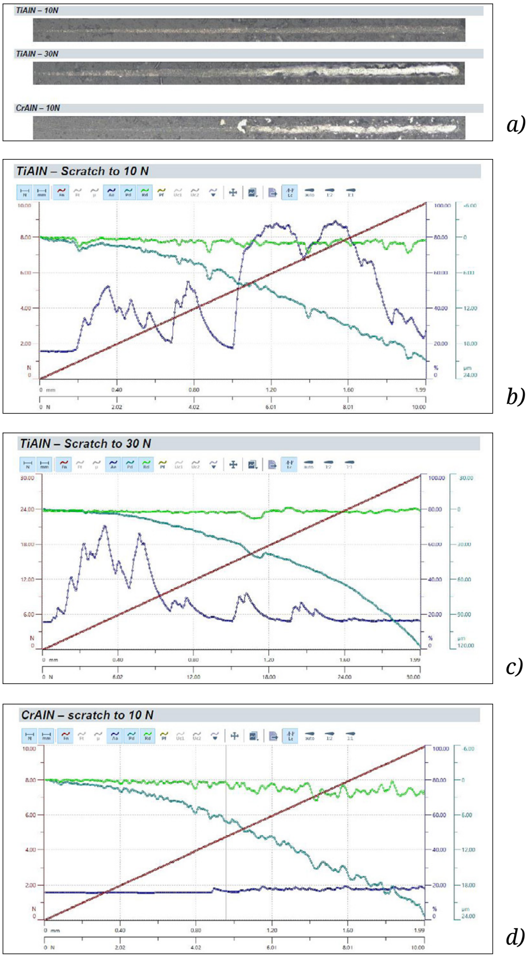

Figure 4. *The results of the scratch test*
a) the optical representation of scratches on the CNMG 120408 coated inserts
b) TiAlN coating, max load 10 N
c) TiAlN coating, max load 300 N
d) CrAlN coating, max load 10 N

For the Daimler–Benz test, a Rockwell hardness tester with a diamond cone indenter and a load of 1470 N was used.

Daimler–Benz test was evaluated using an optical microscope as can be seen at **Figures 5.** The imprints were classified from HF1 to HF6 conforming to VDI 3198 **[16]**. The adhesion of the CrAlN layer (produced by PVD) on the CNMG 120408 inserts shows rather poor adhesion (H5/H6 based on the series of images), while the TiAlN layers have somewhat better adhesion, they receive a classification of H3/H4 based on the Daimler–Benz test, as **Figure 5** indicates.

5. Conclusions

The adhesion tests explain the relatively fast wear of the coating during cutting both in dry and lubricated conditions. The tests show that the relatively thick TiAlN coating produces acceptable adhesion on the CNMG120408 inserts, which are produced by powder metallurgy and have a relatively rough surface. On the other hand, the CrAlN coating breaks up as a result of even a small force and is classified as rather bad by the Daimler–Benz test.

Acknowledgements

The authors wish to express their thanks for the financial support in the framework of the EFOP-3.6.1-16-2016-00010 project to the Hungarian State and the European Union.

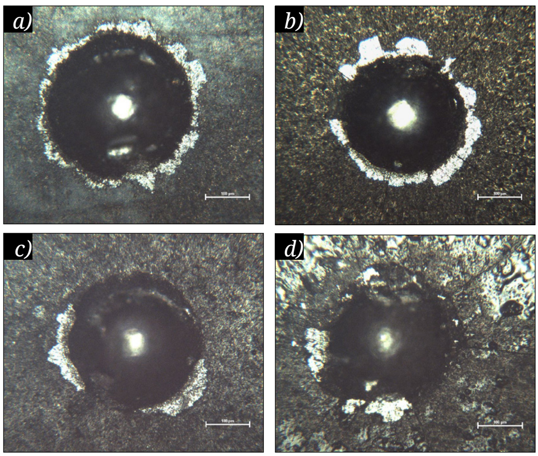

Figure 5. *The results of the Daimler–Benz tests at CNMG 120408 coated inserts*
a) TiAlN coating on insert 1
b) TiAlN coating on insert 2
c) CrAlN coating on insert 1
d) CrAlN coating on insert 2

References

[1] Bitay E.: *Bevonatolt gyorsacélok kopásállósága/ Coated HS Steels Wear Resistance.* XVIII. FMTÜ, EME, Kolozsvár, Románia 2013, 73–76. https://doi.org/10.36243/fmtu-2013.10

[2] Kovács T. A., Umesh Mhatre, Nyikes Z., Bitay E.: *Surface Modification Innovation for Wear Resistance Increasing*. In: IOP Conf. Series: Materials Science and Engineering. vol. 613. (2019). 5th International Conference on Competitive Materials and Technology Processes 8–12 October 2018, Miskolc-Lillafüred, Hungary. https://doi.org/10.1088/1757-899X/613/1/012039

[3] Fábián E. R, Furkó M., Vehoczki B.: *Különböző típusú elektrokémiai bevonatok tulajdonságai.* In: Fiatal Műszakiak Tudományos Ülésszaka, 19. (2014) 145–148. https://doi.org/10.36243/fmtu-2014.029

[4] Kovács-Coskun T., Bitay E.: *The hardness control in the coated surface layer.* Materials Science Forum, 729. (2013) 415–418. https://doi.org/10.4028/www.scientific.net/MSF.729.415

[5] Bitay E., Kovács T.: *The effect of the laser surface treatments on the wear resistance*. Materials Science Forum, 649. (2010) 107–112. https://doi.org/10.4028/www.scientific.net/MSF.649.107

[6] Bitay E.: *Lézeres felületkezelés és modellezés.* Műszaki Tudományos Füzetek 4., EME, Kolozsvár, 2007. https://doi.org/10.36242/mtf-04

[7] Bagyinszky Gy., Bitay E.: *Kopásálló felületkezelt rétegek minősítése/Characterization of surface treated, wear resistant layers*. In: Fiatal Műszakiak Tudományos Ülésszaka, 14. (2009) 13–16. https://doi.org/10.36243/fmtu-2009.08

[8] Bitay E.: *Lézeresen kezelt felületek kopásállósága.* In: Fiatal Műszakiak Tudományos Ülésszaka, 6. (2001) 111–118. https://doi.org/10.36243/fmtu-2001.23

[9] Sebestyén A., Nagyné Halász E., Bagyinszky Gy., Bitay E.: *Felületmódosítási eljárások hatása acélok kopásállóságára.* In: Fiatal Műszakiak Tudományos Ülésszaka, 12. (2007) 161–169. https://doi.org/10.36243/fmtu-2007.4

[10] Liu Aihua, Deng Jianxin, Cui Haibing, Chen Yangyang, Zhao Jun: *Friction and wear properties of TiN, TiAlN, AlTiN and CrAlN PVD nitride coatings.* Int. Journal of Refractory Metals and Hard Materials, 31. (2012) 82–88.

[11] Tillmann W., Grisales D., Stangier D., Butzke T.: *Tribomechanical behaviour of TiAlN and CrAlN coating deposited onto AISI H11 with different heat treatments*. Coating, 9/519. (2019) 2–21.

[12] Rupetsov V., Minchev R.: *Experimental calo tester for the coating thickness measurement.* 15th International Scientific Conference Smolyan, Bulgaria, 2016. 188–191.

[13] Tribotechnik: *Kemény bevonati rétegek vastagságmérése Calo-teszttel* https://www.tribotechnic.com/en/products/calotest/

[14] PVD-bevonatok vastagságmérése https://www.pvd-coatings.co.uk/Ph.D.-coating-technology/testing-equipment/coating-thickness-tester

[15] Bevonatok tapadásvizsgálata karcteszteléssel https://www.anton-paar.com/corp-en/products/details/micro-scratch-tester-mst3

[16] Verein-Deutscher-Ingenieure 1992 Daimler Benz Adhesion Test VDI 3198. Dusseldorf, VDI-Verlag 7.