Surface & Coatings Technology 205 (2011) S128–S132

Contents lists available at ScienceDirect

Surface & Coatings Technology

journal homepage: www.elsevier.com/locate/surfcoat

# Effect of PVD films wet micro-blasting by various $Al_2O_3$ grain sizes on the wear behaviour of coated tools

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A R T I C L E I N F O

Available online 31 March 2011

*Keywords:*
PVD coatings
Wet micro-blasting
Hardness
Residual stresses
Cutting edge radius
Wear

A B S T R A C T

Micro-blasting on PVD films has been documented, among others, as an efficient method for inducing compressive stresses, thus for increasing the coating hardness and potentially tool life of coated tools. Since contradictory results have been registered concerning the efficiency of wet micro-blasting on coated tools for improving the wear behaviour, the paper aims at explaining how this process can be successfully applied for post-treatment of PVD films. In this context, the employed conditions such as pressure and grain size affect significantly the wear resistance of the micro-blasted coated tools.

In the described investigations, TiAlN coatings were post-treated through wet micro-blasting by $Al_2O_3$ abrasives of various grains' diameter. Abrasion mechanisms after micro-blasting were investigated by roughness measurements. Nanoindentations on micro-blasted film surfaces at various pressures revealed the influence of this process on coating superficial hardness. The related residual stress changes were estimated considering the film yield stress alterations, which were analytically determined, based on nanoindentation results. Nano-impact tests were conducted for investigating the effect of the developed film compressive stresses at certain micro-blasting pressures and grain sizes on the film's brittleness. To monitor film thickness and cutting edge radius changes of coatings subjected to micro-blasting, ball cratering tests and white light scans were carried out respectively. In this way, micro-blasting conditions for improving the film hardness, without revealing the substrate in the cutting edge region, were detected. Finally, the wear behaviour of coated and variously wet micro-blasted tools was investigated in milling of hardened steel.



## 1. Introduction

The post-treatment of PVD coated tools by micro-blasting is applied in the industry, as an efficient method for improving the performance of coated tools and machine elements [1–5]. By this process, among others, coating surfaces with enhanced tribological characteristics can be attained [5]. Moreover, residual compressive stresses are induced into the film structure, thus leading to coating hardness and strength properties improvement [6–8]. Micro-blasting parameters such as pressure and time have a pivotal effect on the coated tool cutting performance [2,3].

The present paper investigates the potential for increasing the wear resistance of PVD TiAlN coated cemented carbide tools through wet micro-blasting by $Al_2O_3$ abrasive grains of different diameters. The grain size is pivotal for the developed hardness and residual stresses close to the film surface and for the cutting edge integrity as well. Herewith, the wear resistance of coated tools can be significantly improved.

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doi:10.1016/j.surfcoat.2011.03.046

## 2. Experimental details

Fig. 1 illustrates the working principle of the applied water micro-blasting procedure. In this operation, water with abrasive grains is guided into the blasting nozzle, where an incoming air flow of adjustable pressure, accelerates the mixture and generates the water jet. In the described investigations sharp-edged $Al_2O_3$ abrasives with average grain diameters of 10 µm and of 100 µm were used for conducting wet micro-blasting on TiAlN films. The water micro-blasting treatments were conducted by a NP10 machine of WIWOX GmbH Surface Systems. The $Al_2O_3$ material concentration was approximately 10 gr/L and 6 gr/L in the cases of 10 µm and of 100 µm grains' diameter respectively. These values correspond to water $Al_2O_3$-grains mixtures, streaming out from the blasting nozzle at a pressure of 0.3 MPa. Considering previous micro-blasting investigations published in Refs. [2–4], the distance between the nozzle and substrate was set to 100 mm and the process duration at 4 s. The air pressure was varied from 0.2 MPa up to 0.4 MPa, in steps of 0.1 MPa. The tool rake and flank were treated in separate micro-blasting procedures.

TiAlN films, with an Al/Ti ratio of 54/46 were deposited by a CEMECON C900 coating machine [9] on SPGN120308 cemented carbide inserts of

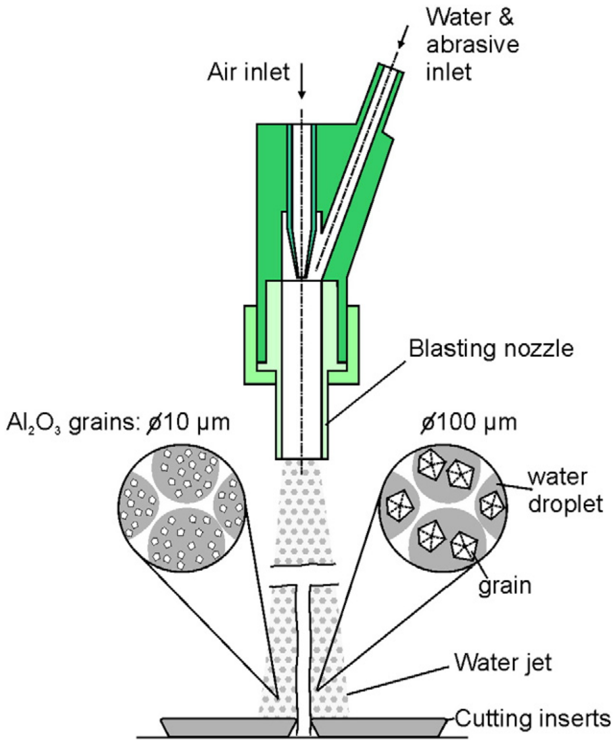


**Fig. 1.** Working principle of water micro-blasting.

HW-K05/K20 ISO specifications. The film thickness on the tool rake was approximately 3.5 µm. A PVD process technology with high ionization sputtering and pulsing (HIS and HIP) was applied, leading to nano-structured, nano-laminated and nano-dispersed coating systems [9]. The deposition temperature was 450 °C, the total gas pressure 570 mPa and the Ar and $N_2$ partial pressure amounted to 450 mPa and 120 mPa respectively. The developed residual stress in the films at an information depth of 1 µm, in both of parallel and perpendicular directions to the cutting edge, are less than 1 GPa, according to X-ray diffraction measurements by the $\sin^2\psi$ method [10]. The used device was a SEIFERT XRD 3000 unit, equipped with a 4-circle goniometer [3]. The residual stress changes after micro-blasting were estimated, taking into account, that the coating yield stress changes after micro-blasting correspond to the equivalent residual stress alterations, as described in Ref. [11].

The nanoindentations were carried out by a FISCHERSCOPE H100 device. The roughness $R_t$ of the coated specimens amounted approximately to 0.5 µm. For excluding the specimen roughness effect on the nanoindentation results accuracy, 30 measurements per nanoindentation were conducted for stabilizing the moving average of the indentation depth versus the indentation force [12]. To capture cutting edge radius and coating thickness distributions, white light scanning by a 3D confocal system µSURF of NANOFOCUS AG was employed. The nano-impact tests were conducted via a Micro Materials Ltd device at loads of 10, 20 and 30 mN, at a frequency of 1 Hz [13]. The milling investigations were carried out by a three-axis numerically controlled milling centre using the steel 42CrMo4 QT, hardened at approximately 300 HV (≈30 HRC).

## 3. Results and discussion

### *3.1. Abrasion mechanisms in wet micro-blasting and developed film hardness and residual stress changes*

Fig. 2 explains schematically the effect of wet blasting by fine $Al_2O_3$ grains of an average diameter of approximately 10 µm and by ten times larger in diameter $Al_2O_3$ grains as well, on the coated tools' surface integrity. Numerous fine abrasive grains are guided by the water droplets at high density on small areas of the coated tool's surface. These can cause for the same treatment duration, more intense coating material removal through micro-chippings, compared to micro-blasting by coarse and less numerous grains per water droplet. On one hand, this happens, since the numerous small grains are dragged easier by the flowing water along the film surface, thus deteriorating intensively its roughness. On the other hand, the coarse grains are less affected by the flowing water and mainly deform the coating material. In this way, a larger portion of the initial grain kinetic energy of the coarse grains is consumed to deform plastically the coating, compared to the small ones. Thus, coatings subjected to wet micro-blasting by fine $Al_2O_3$ grains are expected to possess higher roughness and smaller nanohardness, compared to the corresponding ones, micro-blasted by coarser grains under the same conditions.

The aforementioned assumptions can be validated taking into account the demonstrated results in Fig. 3. The more intense abrasion in wet micro-blasting, when fine $Al_2O_3$ grains instead of coarse ones are applied, leads to increased roughness on the tool surface (see Fig. 3a) as well as near the cutting edge. This is clearly visible in the displayed surface topomorphies before and after micro-blasting by various grain sizes at 0.4 MPa. In this way, it can be concluded that although the average coating's thickness remains practically invariable by blasting procedures at low pressures and process durations [2], the actual film thickness in individual micro-regions on rake and flank depends strongly on the developed integrity after micro-blasting. Thus, the augmentation of micro-blasting pressure and duration may result in significant local coating thickness reductions, which may affect the micro-blasted coated tool's cutting performance.

Nanoindentations at a maximum load of 15 mN were conducted on coated inserts, wet micro-blasted by fine ($\overline{d}_g \approx 10$ µm), or coarse ($\overline{d}_g \approx 100$ µm) $Al_2O_3$ grains at various pressures. The corresponding courses of the maximum indentation depth versus the micro-blasting pressure are presented in Fig. 3b. By increasing the micro-blasting pressure in the case of coarse $Al_2O_3$ grains, a diminution of the maximum indentation depth develops, thus improving the film hardness. Similar

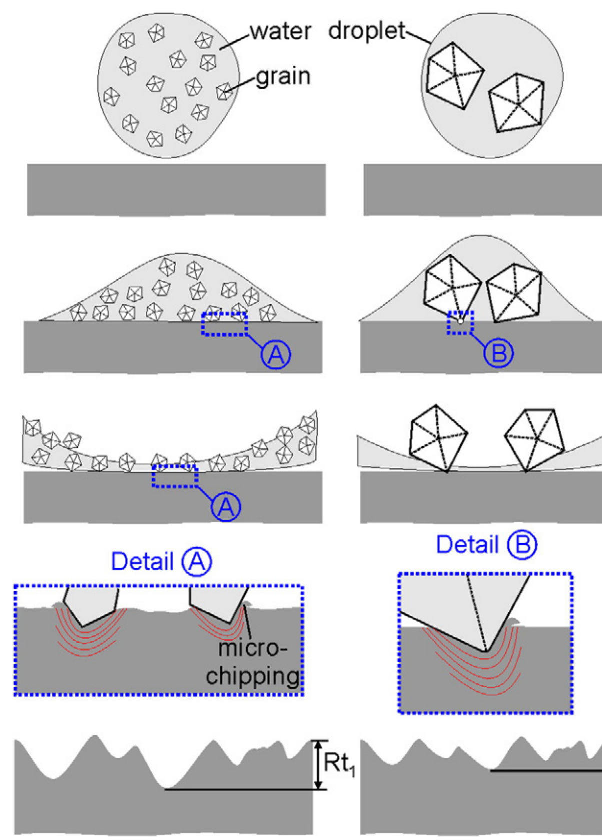


**Fig. 2.** Effect of abrasive grains' size on the surface roughness in wet micro-blasting.