Micro-Blasting as an Effective Pretreatment for Physical Vapor Deposition (PVD) Coating

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Abstract

One of the primary requirements of physical vapor deposition (PVD) coatings for cutting tool applications remains strong adhesion between coating and substrate. Retention of the coating during machining becomes much more challenging, particularly for difficult-to-cut workpiece materials. The current work investigates different physical and mechanical characteristics of cathodic arc evaporated AlTiN coating with and without prior substrate treatment using micro-blasting with Al_2O_3 abrasives. Microstructural analysis indicates dimple-like structure due to prior substrate deformation by micro-blasting. Grazing incidence X-ray diffraction (GIXRD) patterns reveal peak broadening and shifting of peaks towards higher angle which indicate grain refinement and stress relief due to prior micro-blasting. 17-4 PH martensitic stainless steel is considered as workpiece material and cutting force and tool wear have been given emphasis. The result clearly highlights the supremacy of AlTiN coated tool with prior micro-blasting in terms of retention of coating, a reduction of up to 10% in cutting force and 20% in average flank wear after a machining duration of 5 minutes in comparison with the same coating without any treatment. Therefore, micro-blasting as a pre-treatment technique offers enough opportunity to augment properties particularly in terms of adhesion which can significantly improve the cutting performance of PVD coated tools.

Keywords: PVD coating, Micro-blasting, Adhesion, Cutting performance, Wear.

1. Introduction

It has always been a major challenge for the manufacturing sector to maintain considerably high cutting tool life particularly during machining difficult-to-cut materials. Although coated tools have found extensive application in the industries, their performance still requires substantial enhancement if the concept of environment-friendly dry or near dry machining is to be adopted. A large amount of studies has been carried out in the last few years to improve the properties of physical vapor deposition (PVD) coated tools such as, hardness, thermal resistance, low friction coefficient and cutting performance [1]. Surface treatment prior to the deposition of coating such as micro-blasting a good promise to improve the coating properties especially of PVD coated tools [2, 3, 4].

Coating-substrate adhesion is of paramount importance for cutting tools since severe contact condition in the form of pressure, temperature and load. Improper coating adhesion would cause delamination from the substrate leading to premature failure of the cutting tool. Treatment of cemented carbide substrates with micro-abrasive particles was found to enhance the coating adhesion with the substrate [2]. Micro-blasting allows larger contacting area of substrate surfaces by removing the unwanted cobalt binder for better interlocking with the coating. Superior interlocking is due to reduced distance between the surface roughness peaks and more number of high roughness peaks. Coatings deposited on the micro-blasted and polished substrates exhibited more adhesion characteristics than that deposited on ground or polished or micro-blasted substrates. Larger removal of cobalt binder resulted in the failure of the coating in adhesive mode [2]. Increased surface energy is also a measure of the coating adhesion [5]. Substrate pre-treatment with subsequent grinding, sand blasting and polishing can lead to the increased surface energy. Lower indentation depth of the Nano-indentation tests on micro-blasted and coated surfaces showed the increased coating hardness. Higher hardness of the coating leads to good stress-strain characteristics [6]. According to Tonshoff et al [4], coarse abrasive grains cause more plastic deformation of the substrate surface while finer grains provide an abrasive effect on the surfaces. Superior adhesion also results in the reduction of the coating removal and wear. This effect has been perceived in micro-blasting of micro-peeling knives with Al_2O_3 grains where the tool life enhanced by four times compared to the unmodified CrAlN coated tools [7]. Lower roughness of the substrate surfaces after micro-blasting and coating favors for lower coefficient of friction thereby easy flow of chips over the coated tools at the time of machining [8]. The residual stress in the coating also plays an important role in the coating tribo-mechanical properties especially in machining operations. The tensile residual stress during deposition should be avoided and compressive residual stress should be introduced for the better performance of the tool [9].

The pre-treated tool also showed better performance in drilling and milling compared to unmodified tools. AlTiSiN coated tools with prior drag grinding operation had performed better than tools undergone micro-blasting and coating [8]. The better performance of TiAlN coated drill bit with prior micro-blasted or water peened tools also observed by Tonshoff et al [4]. Bouzakis et al [2, 6, 9] claimed the advantages of micro-blasting as a pre-treatment on different milling tools. Improved coating adhesion and increased edge radius due to micro-blasting was responsible for superior cutting performance.

From the literature review it is evident that different properties of PVD coated tools can be improved with the help of micro-blasting prior to coating deposition. Effect of micro-blasting on cutting performance is relatively scares. Few studies concentrated on milling operations, while there is hardly any information during turning operation. The current study therefore investigates the role of micro-blasting prior to deposition of AlTiN coating by cathodic arc evaporation technique. Effect of micro-blasting is studied morphology, micro-structure, chemical composition, crystallographic orientation and hardness of AlTiN coating. Particular emphasis is also provided in understanding the role of micro-blasting on cutting performance during dry turning of 17-4 PH martensitic stainless steel.

2. Experimental Details

Cemented carbide substrates of ISO K-grade were considered for the substrate to be coated. The samples were coated with AlTiN coating using cathodic arc evaporation (CAE) in an industrial scale 8-target PVD coating system at Oerlikon Balzers Coating India Limited under fixed deposition condition. In order to study the influence of micro-blasting as pre-treatment technique, the results of different tests then compared with the untreated counterpart.

The substrate micro-blasting was carried out with Al_2O_3 grains of 50 µm size for 15 s at a process pressure of 0.6 MPa.

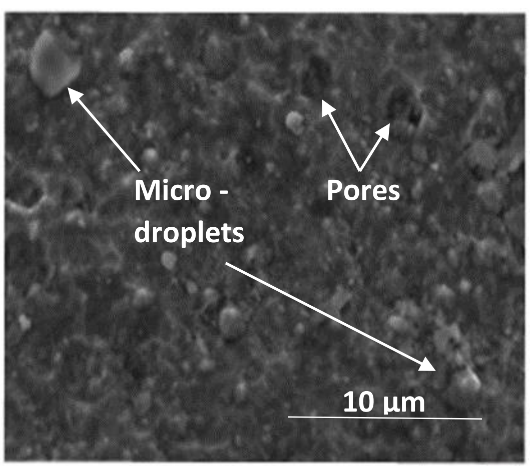
Surface morphology and fractured cross-section of the coating was analyzed using field electron scanning electron microscopy (FESEM) using NOVA NANO SEM 450 machine. Energy dispersive spectroscopy (EDS) through X-ray was carried out along with SEM to analyze the variation of elemental composition of the coating due to prior treatment. Grazing incidence X-ray diffraction (GIXRD) was carried out using RIGAKU ULTIMA MODEL IV in the 2θ range of 10-900 in the voltage of 40 kV. Grazing incidence angle of 2° and Cu-kα radiation were used for this purpose.

LECO LM 700 Vickers microhardness tester was used to find out the composite hardness of untreated and pre-treated coated samples. Performance evaluation of AlTiN coated tools with and without treatment was carried out during dry turning of 17-4 PH martensitic stainless steel. Dry turning experiments were conducted on a heavy duty lathe machine (NH-26, Make: HMT, India) under varying cutting speeds of 80, 120 and 150 m/min. along with constant feed of 0.2 mm/rev and depth of cut of 1 mm. Cutting force was measured using a 4-channel piezoelectric dynamometer (Model: 9257B, Make: Kistler, Switzerland) in combination with a charge amplifier which was connected to data acquisition system (National Instruments, India). Tool wear was measured using stereo zoom microscope (Radical Instruments, India).

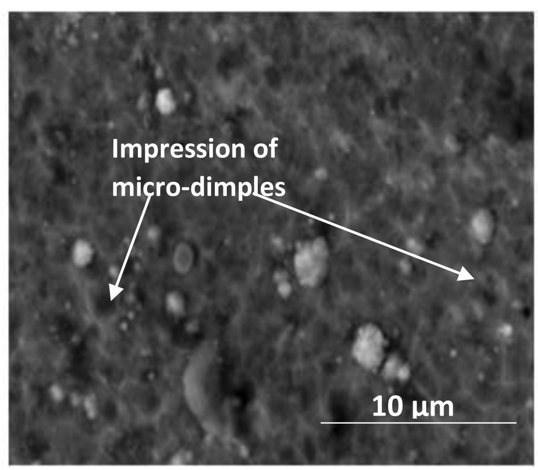
3. Results and Discussion

3.1 Surface Morphology

Top surface morphology of the as-deposited and prior micro-blasted AlTiN coating is shown in Figure I. As-deposited coating (C) exhibits rougher surface morphology with larger micro-droplets and more number of micro-voids. On the other hand, smooth morphology with less number of pores can be visible on the coated surface with prior micro-blasting (M+C). Even the dimple-like structure is detected which is possibly the result of substrate deformation due to prior micro-blasting pre-treatment (M+C). Coating grows over these defect sites and follows the same texture.



(a)

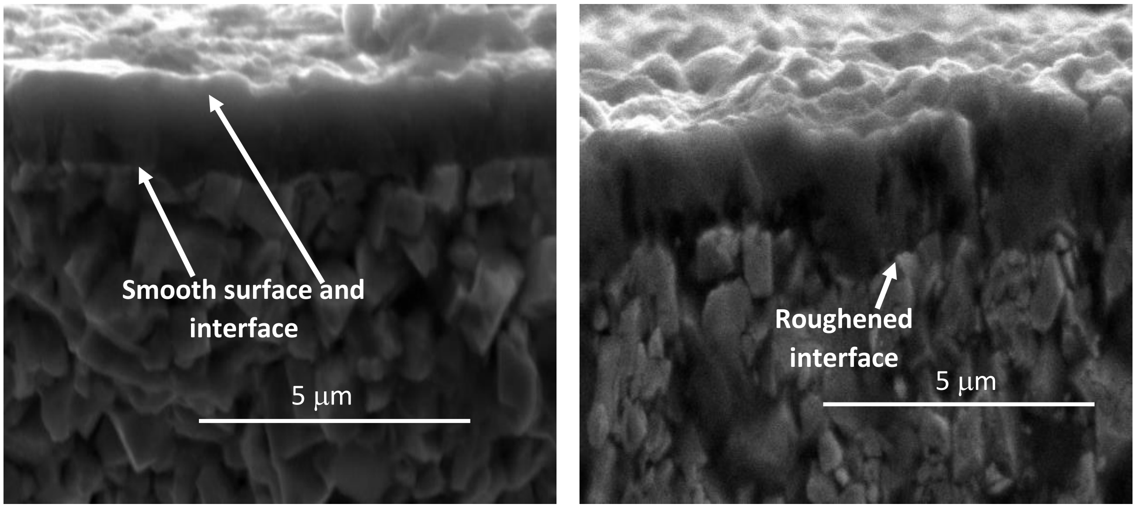


(b)

Figure I Top surface morphology of (a) as-deposited; (b) prior micro-blasted coatings configurations.

3.2 Fractured Cross Section

Fractured cross-section of AlTiN coatings with or without prior micro-blasting is depicted in Figure II. While as-deposited coating (C) does not reveal any roughening of either interface or coated surface, the sample with prior micro-blasting (M+C) clearly demonstrated engineered interface of coating and substrate which is typically responsible for improved coating adhesion. For further understanding the effect of micro-structural alternation, coating-substrate adhesion and hardness of the coating is required.

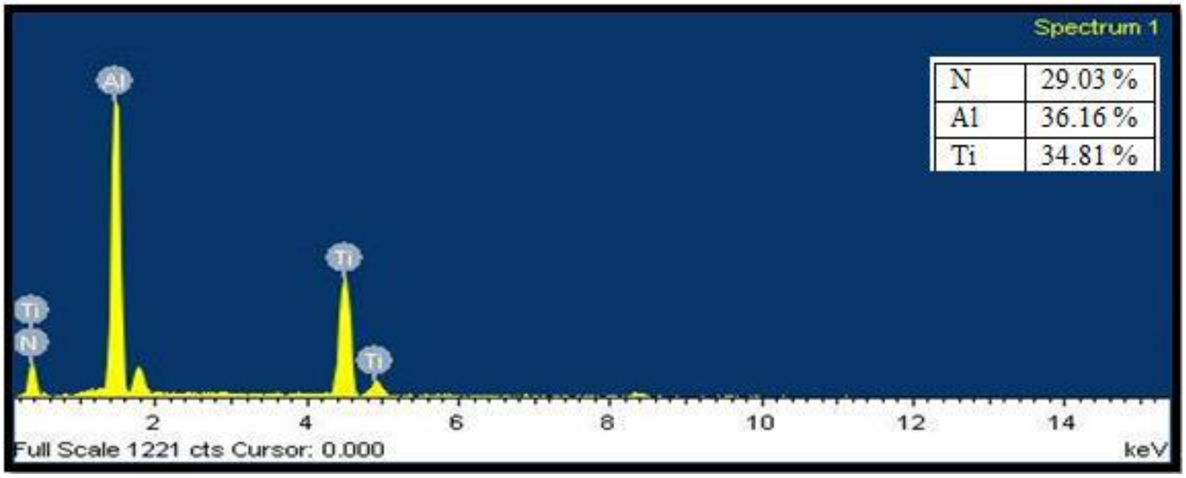


(a) (b)

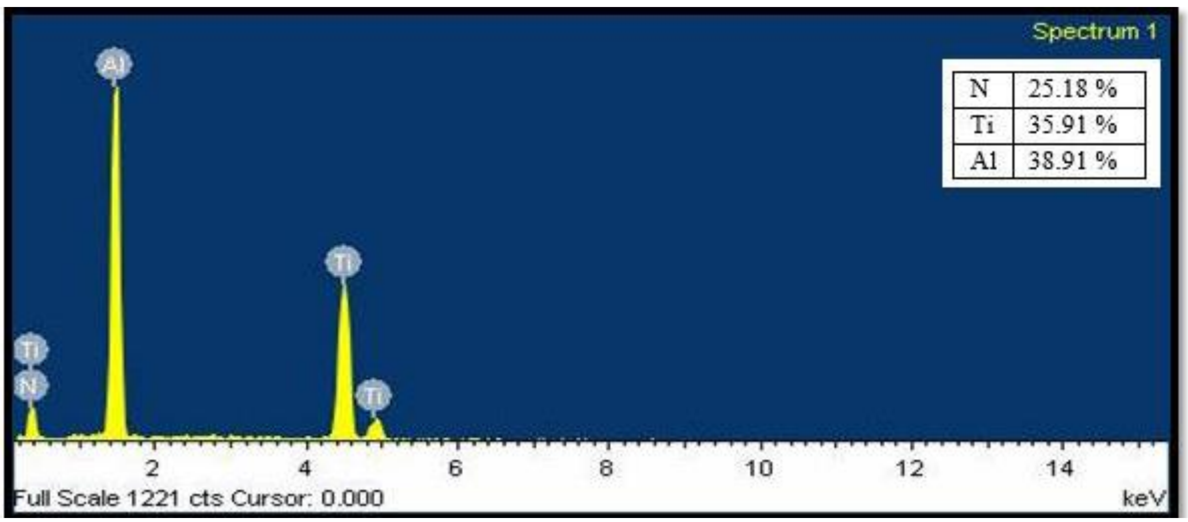
Figure II Fractured cross-section of the (a) as-deposited and (a) prior micro-blasted coating

3.3 Chemical Composition

Influence of micro-blasting both as pre-treatment techniques has been investigated on chemical composition of coating using EDS and detailed results have been provided in Figure III including spectra as well as composition. Little consideration will indicate that as-deposited coating (C) approximately conforms to the formation of $Al_{0.54}Ti_{0.46}N$, while relative atomic percentage changes due to micro-blasting. For pre-treated specimen, high atomic percentage of N_2 might be explained by the preferential nitriding of activated nucleation sites due to substrate micro-blasting. However, any significant alternation in Al/Ti ratio may hardly be observed.



(a)



(b)

Figure III EDS results of the (a) untreated and (b) prior micro-blasted AlTiN coated tools

3.4 Crystalline Phase

Influence of micro-blasting prior to deposition of AlTiN coating has been studied using GIXRD technique. The patterns clearly indicate the formation of crystalline phases consisting of cubic TiN and AlN phases as indicated in Figure IV. In addition to this, peak broadening and shifting of peaks to lower angle for micro-blasted specimens in comparison with untreated (C) AlTiN coated tool has been noted. This observation is indicative of introduction of compressive residual stress and grain refinement due to micro-blasting.

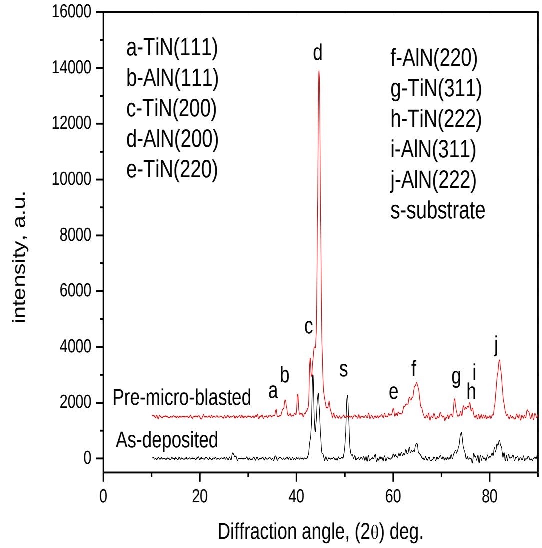


Figure IV GIXRD patterns for untreated and prior micro-blasted AlTiN coatings

3.5 Coating Micro-Hardness

Coating hardness for different samples as obtained from Nano-indentation has been plotted in Figure V. It may be noted that substrate micro-blasting could not improve the hardness whereas that of AlTiN coating significantly increased to about 27 GPa. Both the untreated and prior micro-blasted AlTiN coated tools showed the same hardness behavior.

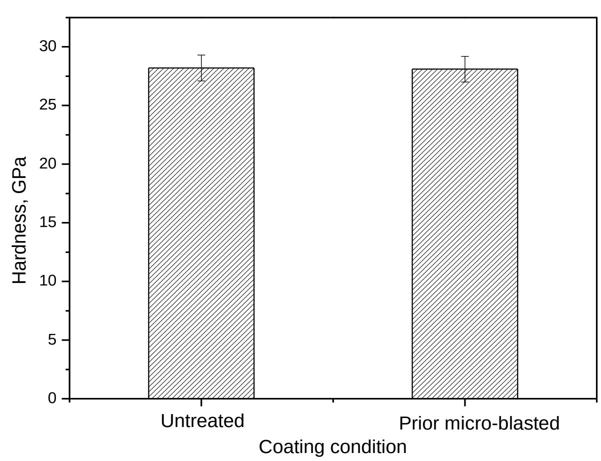


Figure V Hardness of untreated and prior micro-blasted AlTiN coatings

3.6 Cutting Performance

One of the major objectives of the current work is to study influence of micro-blasting as pre-treatment methodology on machining performance of cathodic arc evaporated AlTiN coated tools. Machining performance has been primarily carried out in terms of cutting force and tool wear of coated tool. Figure VI shows variation of main cutting force while machining with and without treated coated tools under three different cutting speeds. There was a clear decreasing trend of main cutting force with cutting speed. The lower cutting force for prior micro-blasted coated tool is obtained at 80 m/min after 60 s of machining. After 480 s of machining, a marginal reduction in cutting force in prior micro-blasted coatings observed as compared to the untreated coated tool.

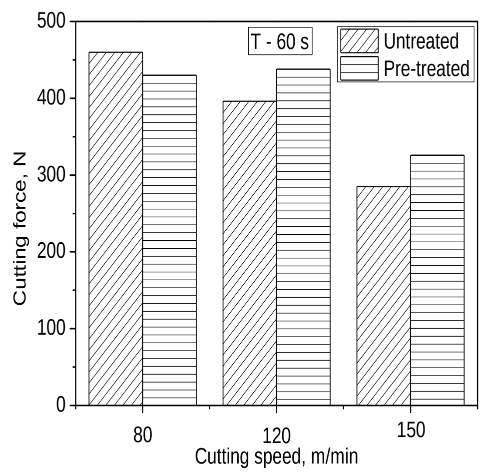


Figure VI Comparison of cutting force for as-deposited and prior micro-blasted coatings after 60 s of machining

Although coating adhesion is typically assessed with the help of scratch or indentation test, more practical way of evaluating interfacial strength is possibly machining test itself in which the coated tool encounters more severe contact condition in terms of stress and temperature. Therefore, to further ascertain the mechanism of substrate treatment (pre-treatment), wear of coated tool both at rake and flank faces has been investigated and shown in Table I. It is evident the gradual progression tool wear along with significant coating delamination for untreated coated tool. This is more prominent for higher cutting speed (150 m/min.) with presence of nose wear as indicated in Table I. Interestingly, both coating delamination and protection of rake, nose and flank could be remarkably improved with the help of micro-blasting pre-treatment technique due to enhancement of coating-substrate adhesion.

4. Conclusion

The present work aims at studying the influence of micro-blasting as surface treatment technique prior to deposition of AlTiN coating. The study resulted in the following major conclusions.

1. Micro-blasting of substrate resulted in substrate micro-deformation. As a result, micro-roughening of interface took place leading to better mechanical interlocking.
2. Prior micro-blasting resulted in more nucleation sites which causes the more weight percentage of N_2 in the composition.
3. Substrate micro-blasting does not have significant effect on the coating hardness.
4. Micro-blasted tool caused reduction in cutting force for machining 17-4 PH stainless steel.
5. Significant coating delamination along with severe nose damage of could be observed in as-deposited coated tool at cutting speed of 150 m/min. On the other hand, prior micro-blasting provided remarkable resistance to flaking of coating along with tool wear and did not fail after 480 s of machining.

Table I Condition of as-deposited and prior micro-blasted AlTiN coated tool after 480 s of machining at 120 and 150 m/min cutting speeds

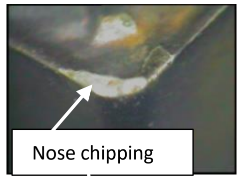
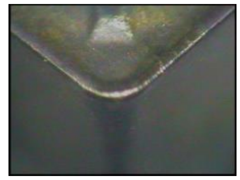
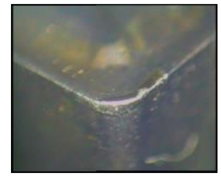
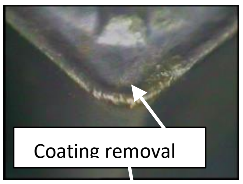
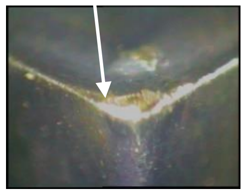
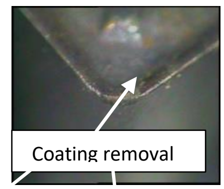
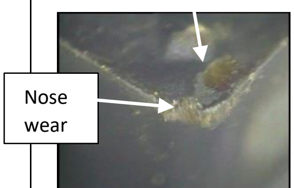
Machining duration	As-deposited coating		Prior micro-blasted coating	
(s)	At 120 m/min.	At 150 m/min.	At 120 m/min.	At 150 m/min.
60				
240				
480		Tool failed		

Figure I Top surface morphology of (a) as-deposited; (b) prior micro-blasted coatings configurations.

Figure II Fractured cross-section of the (a) as-deposited and (a) prior micro-blasted coating

Figure III EDS results of the (a) untreated and (b) prior micro-blasted AlTiN coated tools

Figure IV GIXRD patterns for untreated and prior micro-blasted AlTiN coatings

Figure V Hardness of untreated and prior micro-blasted AlTiN coatings

Figure VI Comparison of cutting force for as-deposited and prior micro-blasted coatings after 60 s of machining

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