

Study of Thin Film Coatings Deposited by Lateral Rotating Cathodes

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Abstract— The demand for high productivity and quality in machined surfaces have put a requirement on cutting tools to perform well under severe machining conditions. Application of a functional layer or coating on the cutting is reported to improve its performance in machining. The nanocomposite coatings are reported to perform well in machining compared to conventional coatings due its fine and dense grain structure. Lateral Rotating Cathodes today represent the state of art in deposition of thin film coatings on cutting tools. The main goal of this work is to investigate and compare the properties of conventional coatings Titanium Nitride, Titanium Aluminum Nitride with that of nanocomposite Aluminum Titanium Silicon Nitride. All the coatings were deposited on a cemented carbide substrate under standard conditions using the Lateral Rotating Cathodes technology. The various properties of the deposited coatings are being discussed in the present work.

Keywords— *Thin films; Lateral Rotating Cathodes; Titanium Nitride; Titanium Aluminium Nitride; nanocomposite coatings*

I. INTRODUCTION

Industries in future may have to opt for dry machining compulsorily, as laws may be enforced to protect environment. Apart from ecological protection, the need for reduced machining costs calls for the dry machining. It is reported that nearly 15% of the total machining costs account for lubricants and coolants. In either condition there is a requirement of cutting tools with high strength and performance. The coated cemented carbides suit the application most [1, 2].

Titanium Nitride (TiN) coatings is widely used to improve the properties of cutting tools in terms of their life and functionality. But TiN coatings readily oxidize at 500°C, limiting their applicability in high speed and dry machining. Addition of Al in the TiN phase leads to improvement in oxidation and wear resistance upto 800°C. However when the fine grain crystals of TiAlN or AlTiN phase are embedded in amorphous silicon nitride matrix, the nc – AlTiN /Si₃N₄ coating shows an improved hardness and oxidation resistance at high temperatures of more than 1200°C. These coatings show very apt properties to perform dry machining under high speed conditions [2 – 6].

Various techniques are available to deposit the thin films on cutting tools. The Chemical Vapor Deposition (CVD) and Physical Vapor Deposition (PVD) techniques are two broad techniques. CVD techniques possess certain problems such as

the high temperature during deposition which is nearly 1000°C. Introducing ammonia gas instead of the nitrogen increases concentration of chlorine and causes flaking of coatings. The PVD, Lateral Rotating Cathodes (LARC) technology is the most promising technique widely used in industries today. Some of the typical advantages of LARC include high degree of ionization, uniform erosion of cathodes and uniform deposition of coatings on the substrate [2, 7, 8].

The aim of present work is to investigate and compare the various properties of TiN, TiAlN and nc – AlTiN/Si₃N₄ coatings.

II. MATERIAL AND METHODS

Commercially available cemented carbide substrates with specifications TNMG 160404 were taken for the purpose of coating. The process of coating was carried out in an industrial coating unit PLATIT π – 80.

The inserts were first cleaned with deionized water and deep dried in an oven at 100°C. The coating chamber consists of two lateral rotating cathodes and carousel on which the inserts are mounted. A working pressure of 1 – 1.5 Pa was maintained in the chamber with flow Nitrogen and Argon gas. The substrate is biased with a voltage of – 70 to – 75V. The cathodes (targets) have dimensions 96 X 510 mm (D x L) and are biased with voltage of – 20 V. Current is varied between 80 – 100 amperes between both cathodes.

Prior to the deposition the arc plasma is led backwards by a magnetic system. Large particles are deposited on the wall and after the cleaning of impurities on the target without interrupting the arc the magnetic system turns the plasma towards the substrate. The target material used depends upon the type of coating being deposited. For TiN coating two blocks of Ti are used, similarly for TiAlN coating one block of Ti and other block of Al is used. For the nc- AlTiN/Si₃N₄ coating one block of TiAl and other block of AlSi is used. The schematic of the coating chamber is as shown in figure 1.

The carousel and the inserts are also in continuous rotation about their vertical axis with a speed of 10 rpm. The entire machine is programmed to deposit 3µm of coatings in one cycle time. The current between the two cathodes is continuously controlled in order to maintain the ratio proportion of the various elements in the coatings.

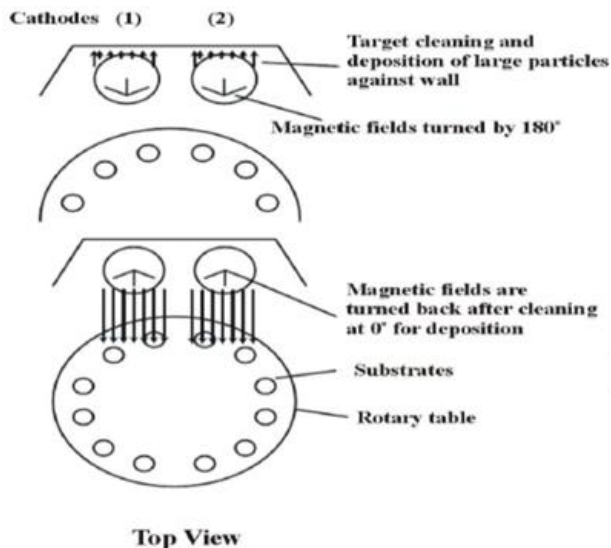


Figure 1. Schematic of the LARC process [8]

The as deposited coatings were first tested for hardness using Matsuzawa MMT – X7 microhardness tester. Microhardness is used to limit the effect of substrate in measurement of the hardness of coating. The hardness tester is equipped with automated turret system and LCD interface. The indentation left behind by the diamond pyramid type indenter is calculated and displayed on screen. The machine has a load range of 1gf – 2000gf. A load of 100gf was used on all samples with dwell time of 15 seconds. In order to study the surface structure Scanning Electron Microscopy (SEM) images of the samples were captured. Phenom desktop scanning electron microscope was used to capture the images. Further, to conform the surface roughness of the coatings and elemental phases present atomic force microscopy (AFM) and x-ray diffraction studies (XRD) were performed. Bruker's Dimension V scanning probe microscopy was used to study AFM and Bruker's D8 advance x – ray diffractometer was used for XRD studies.

III. RESULTS AND DISCUSSIONS

A. Hardness Test

The hardness of all the three coatings is as shown in table 1. The hardness of nc – AlTiN/Si₃N₄ was higher than TiN and TiAlN coatings. The possible increase in hardness is due to the fine grain structure and self-strengthening spinodal phase segregation mechanism. The relation between hardness and grain size is well realized by “Hall – Petch” model wherein the hardness increases with decrease in grain size down to tens of nanometers. Addition of silicon improves the density of grain structure. The strong interfacial bond between the amorphous and crystalline phases causes enhancement in strength and further prevents the movement of dislocation causing increase in oxidation and wear resistance [2 – 4, 8, 9]. The hardness obtained in the present work is comparable with ref. [10]. However, the values did not reach the super hardness state as in [2 – 4].

Table 1. Hardness values of as deposited coatings

Type of Coating	Colour	Hardness (HV0.1)
TiN	Golden yellow	1835.42
TiAlN	Dark grey	2345.26
nc- AlTiN/Si ₃ N ₄	Blue – grey	2855.10

B. Scanning Electron Microscopy and X – ray diffraction

The following images show the SEM images of all the three coatings. TiN and nc – AlTiN/Si₃N₄ coating almost show a smooth morphology. TiN coating shows the presence of a small hair line crack. These cracks do not propagate during machining and is called “gargling effect” [11]. Some porous areas are also visible. Some micro particles can be observed on TiAlN and nc – AlTiN/Si₃N₄ coating which could have resulted from Ti micro particles dropping out after deposition process [12,13].

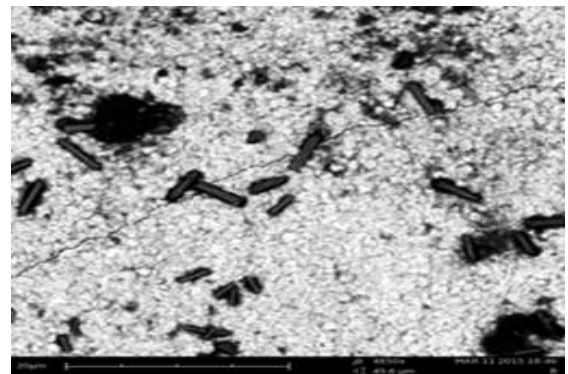


Figure 2. SEM image of TiN coating

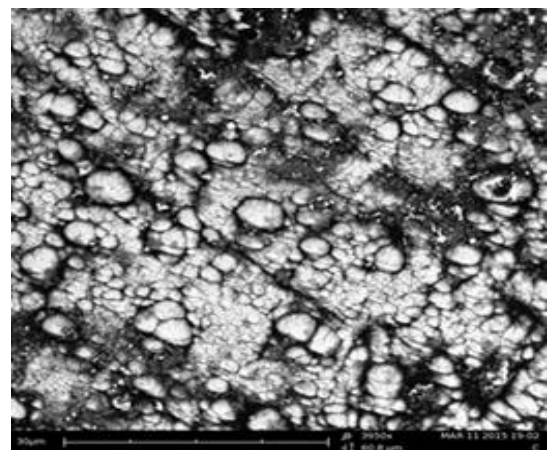


Figure 3. SEM image of TiAlN coating

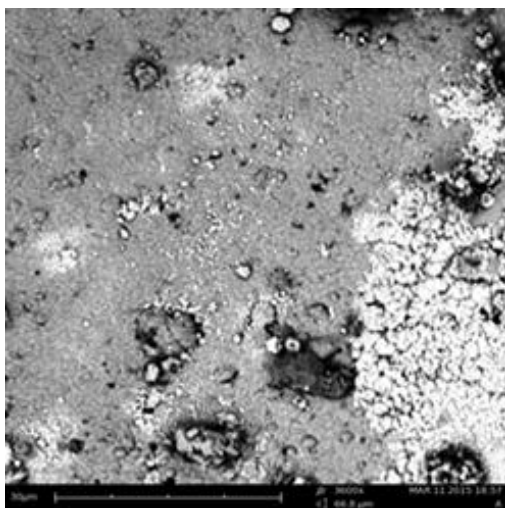


Figure 4. SEM image of nc-AlTiN/Si₃N₄ coating

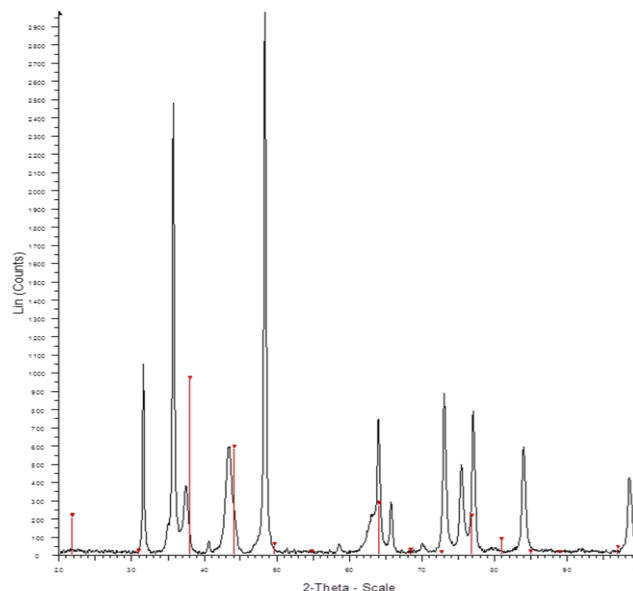


Figure 6. XRD patterns of fcc – TiAlN phase in TiAlN coating

C. X- ray diffraction and Atomic force microscopy

XRD studies showed that all coatings have FCC structure. TiN coating showed fcc – TiN phase with an orientation along (111) and (200) plane. The intensity of (111) peak is higher than that of (200) plane. However with addition of Aluminum in TiAlN, the coating showed the presence of fcc- TiAlN. The peak intensities for c –TiN phase was very low. This suggests that Al had substituted TiN phase. No wurtzite phases were found indicating, that excess of Al was not present. In case of nc – AlTiN/Si₃N₄ both crystalline and amorphous phases were detected. The coating mainly consisted of fcc- AlTiN phases with some hexagonal AlN phases present. Some peaks for TiSi were also observed indicating interfacial bond formed between crystalline and amorphous phase. Traces of oxygen were found in TiN and nc – AlTiN/Si₃N₄ coatings, which could have possibly led to decrease in hardness [2 – 5, 14, 15].

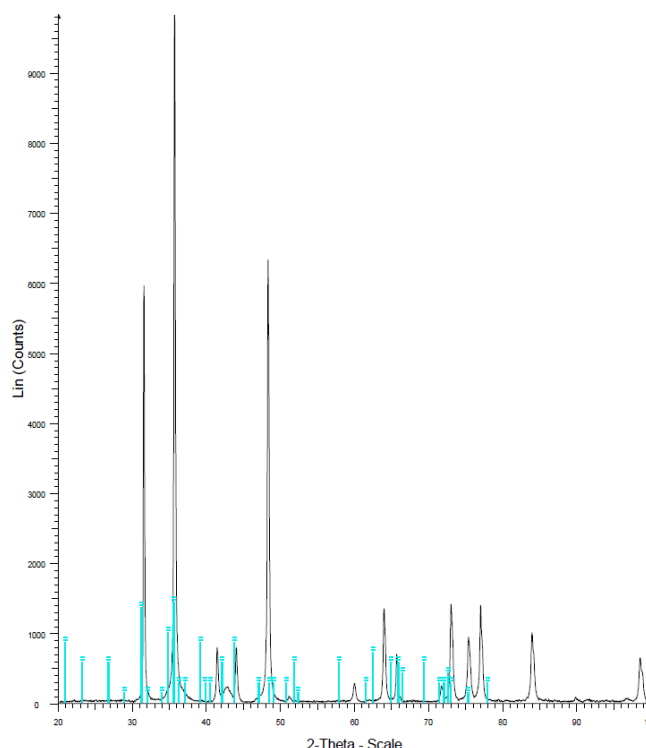


Figure 7. XRD showing Si₃N₄ phase in nc coatings

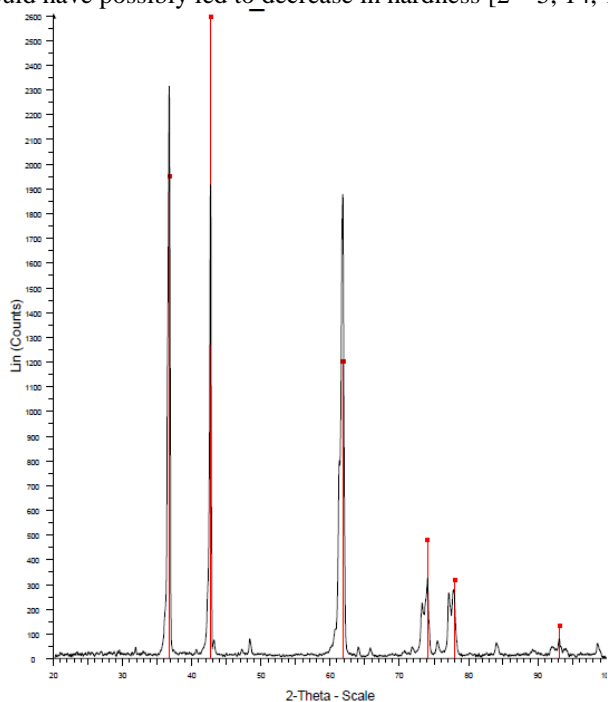


Figure 5. XRD pattern of fcc – TiN phase in TiN coating
XRD patterns for other two coatings are shown in figure 6 and 7.

The roughness (Ra) of all the coatings was found to be in the range 0.122 – 0.124 μm. TiN and nc – AlTiN/Si₃N₄ showed a roughness of 0.122μm while TiAlN showed a roughness value of 0.124μm. The roughness values obtained in the present work is much less than the values in [11]. Nearly 50% reduction in the roughness of the coating is observed. The smooth texture of coatings is due to LARC technology method [16].

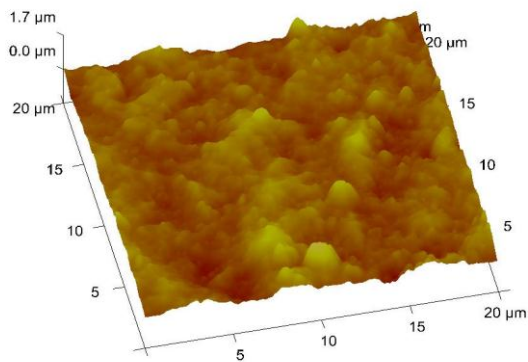
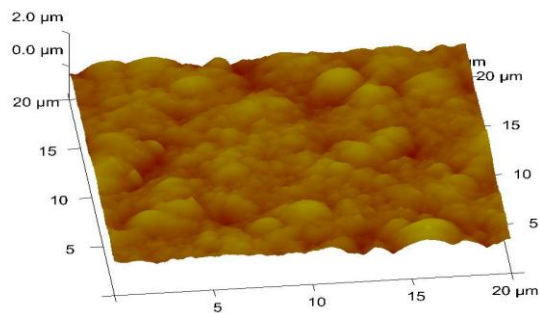
Figure 8. 3D – Profile of AFM for nc – AlTiN/Si₃N₄ coating

Figure 9. 3D AFM profile of TiAlN coating

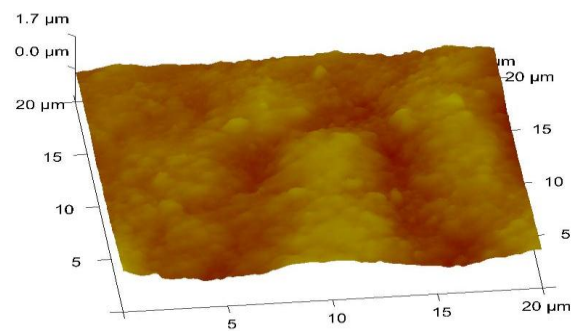


Figure 10. 3D AFM profile of TiN coating

IV. CONCLUSIONS

All the coatings were characterized for their surface morphology and mechanical properties. It was observed that nc – AlTiN /Si₃N₄ showed higher hardness than the other two coatings. The higher hardness of the nanocomposite coatings can be attributed the spinodal phase segregation process which occurs during the deposition process. Addition of silicon densifies the grain structure. Also the three dimensional amorphous silicon nitride matrix forms a strong interfacial bond crystalline phase, thus blocking the dislocations that arise. All the coatings show a smooth texture with roughness value between 0.122μm – 0.124μm which is mainly because of the optimized LARC process. Smoother coatings have less co-efficient of friction and thus contributing to better tool life. All the three types of coatings have the potential to be used in dry machining applications. However, the nanocomposite

coating is expected to perform better than the other two even under higher speeds and feed rates due its high hardness and ability to form dense film of aluminum oxide at high temperatures. Better optimization of cutting tool design and process parameters can open further advancements for the better performance of this coating.

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