ISSN : 0974 - 7486 Volume 12 Issue 4

Materials Science

An Indian Journal

Full Paper

MSAIJ, 12(4), 2015 [142-146]

Cathodic arc TiAlN PVD coatings for machining applications

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ABSTRACT

This paper is concerned with the variations in the specific cutting pressure with TiAlN Cathodic-arc Physical Vapor deposition (CAPVD) coated inserts while machining AISI 1040 carbon steel. To reduce the cost and to make the process environmentally safe, dry cutting is chosen. Coated and uncoated carbide tools and different cutting conditions were tested in dry condition. Cutting forces were recorded at different conditions and specific cutting pressure is calculated. The adhesion bond of the coatings is analyzed using Scanning Electron Microscopy (SEM). Comparison was made between coated and uncoated carbide tools under the same conditions of machining.

KEYWORDS

Metal matrix composites (MMC);
Hardness;
Microstructure;
Scanning electron microscopy (SEM);
Coating.

INTRODUCTION

New challenges have been evolving out to improve the quality of cutting tool materials for high speed machining which eventually increases productivity. Increasing the quality of productivity is the main challenge of any manufacturing industry. This objective requires better management of machining system corresponding to cutting tool-m/c-tool-w/p, higher productivity; lower manufacturing costs are associated with excellent surface finish[1]. The quality of cutting tool can be improved by hard coating applications and also by improving combination of coating properties as shown in Figure 1 which in turn leads to a better product.

Coating with hard substances improves cutting tool capabilities so that the tools can therefore cut at higher speeds for improved productivity with reduced power requirements. The wear resistance of the coating itself should be superior to that of the substrate material. Coating lowers the friction coefficient and thereby the contact temperature. A decrease in friction also reduces the tendency to abrasive wear. The coating acts as a heat barrier owing to lower thermal conductivity compared with that of the substrate. Thus the proportion of frictional heat, which dissipates into the substrate is reduced, which in turn lowers the substrate temperature. Cemented carbide tools are traditionally coated by two methods: Chemical vapor deposition (CVD) and plasma vapor deposition (PVD). The high hardness, wear resistance and chemical stability of these coatings offer better machining performance[2] CVD requires high temperatures that can have an annealing effect on the carbide tool[3] on the other hand PVD offers lower deposition temperature (200^0C-500^0C). PVD can be categorized into vacuum evaporation, sputter deposition and ion plating (Figure 2).

TiN has been widely used as hard coating as it pro-

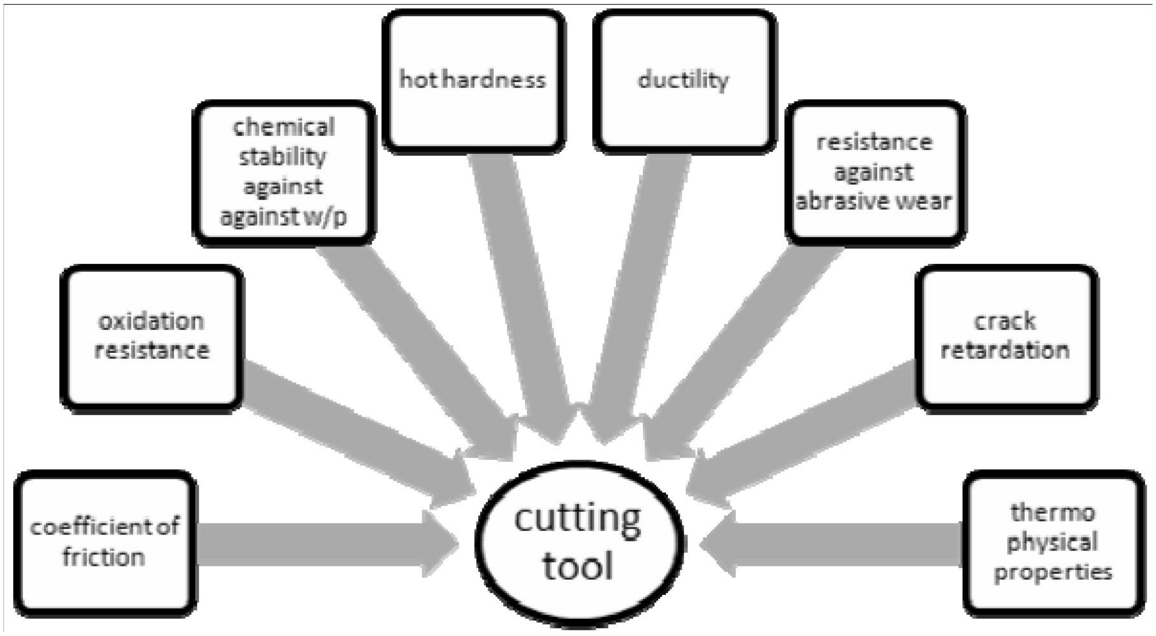

Figure 1 : Coating applications

vides dry lubrication for better chip control[4], a large improvement in the life of a cutting tool[5] TiN coatings could reduce friction in tribological contacts and increase the abrasive wear resistance[6]. Cemented carbide tools coated with TiN by CVD or PVD process can show an increase in the tool life by a factor of 10 compared to uncoated tools[7]. A major drawback of TiN is its limited resistance to oxidation at high temperatures[8] which fails the ability to increase productivity. A lot of efforts were done by alloying TiN with Al and Si for better oxidation resistance, high hardness and improved thermal stability as compared with TiN[9]. Improvements in the coatings of cutting tools have been achieved by the development of TiAlN coatings due to their advanced wear resistance and superior performance under corrosive or high temperature conditions. The tool life at cutting speeds 46 and 76 m/min for TiAlN coated tools perform better than tools with TiN coatings. The excellent crater wear resistance of TiAlN coated tools relative to TiN is also observed[10] at high cutting speeds. Studies have shown that nitride coatings with with high aluminium content such as AlCrN and AlTiN can provide better wear protection than Aluminium free nitride coatings[11] TiAlN coated tool inserts have shown greater improvements during dry turning of quenched tempered tool steel in terms of tool life, surface roughness and cutting force[12]. Most of TiAlN coatings are based on substantial lowering of operating costs by eliminating coolants, their disposal and chip cleaning. As a result, they can improve the productivity in machining applications by as much as 40%[13].

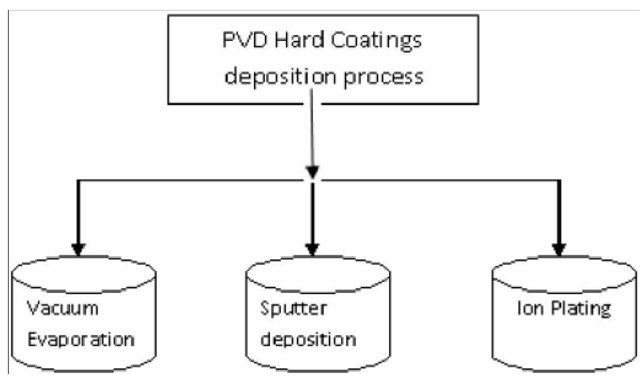

Figure 2 : Categorization of PVD depositions

Many researchers have deposited TiAlN coatings using Balzers Rapid Coating System (RCS) in a cathodic arc ion-plating mode[10,14], deposited using cathodic vacuum arc PVD process at elevated temperatures of >450^0 C in pure nitrogen atmosphere[2,11,15,17], deposited using Filtered Arc Deposition (FAD) PVD unit[16]. Based on the type of evaporation of the metallic components and based on the plasma conditions the deposition process varies. The deposits can be of a single material, layers with graded composition, multilayer coating or very thick deposits. Cathodic arc physical vapor deposition (CAPVD) method is one of the PVD process belonging to the family of vacuum evaporation in which the cathode acts as the evaporation

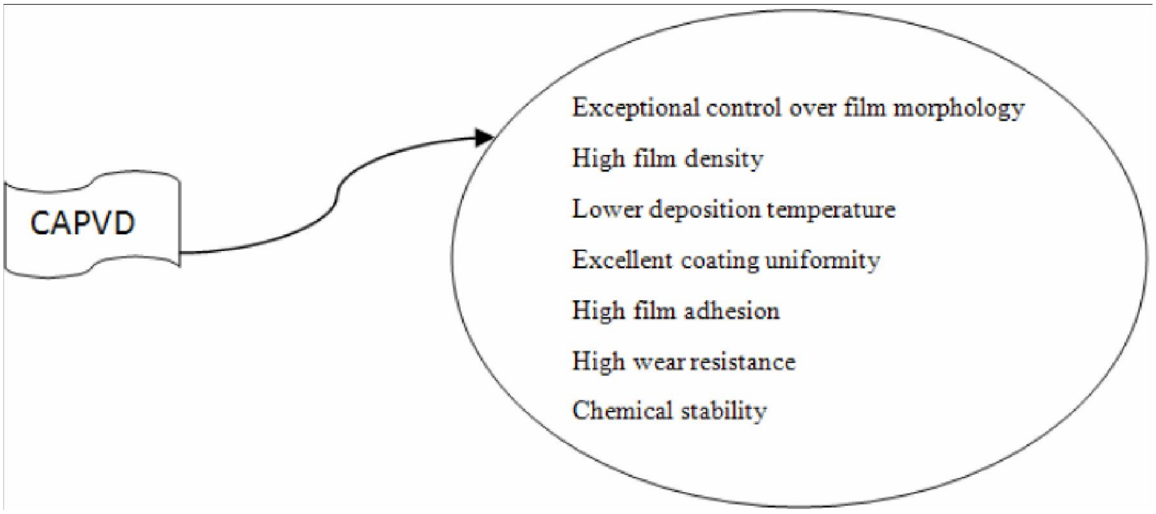

Figure 3 : Advantages of CAPVD

source for deposition of thin film material[18]. Cathodic arc physical vapor deposition (CAPVD) method has received considerable attention for the production of hard metallic coatings which are wear and corrosion resistant[13,17]. This technique offers advantages over other PVD processes as listed in the Figure 3.

This technique uses high current, low negative voltage arc to vaporize a cathodic electrode and deposit the vaporized material on a substrate. The vaporized material is ionized in a vacuum chamber and the substrates are biased so as to accelerate the ions to the substrate surface. Figure 4 shows a schematic diagram of the deposition process. CAPVD provides dense film with excellent adhesion to the substrate and this technique is used to deposit on cutting tools such as end mills, drills, inserts, plastics, metal molds and high wear resistance tribology components. The only drawback with this technique is that it produces unwanted micro particles (droplets). More is the droplet formation higher is the residual stress.

In the present study new advanced coating system like PLATIT π^{300} (Figure 5) is used in which asymmetric arrangement of the cathodes with respect to the samples to be coated enables pre- cleaning of the cathodes by means of a virtual shutter that effectively reduces the emission of droplets and significantly improves the performance of the coatings[19].

TABLE 1: Chemical composition of Carbide tool (%wt)

Co	Cr_3C_2	Wc
6.0	0.5	93.5

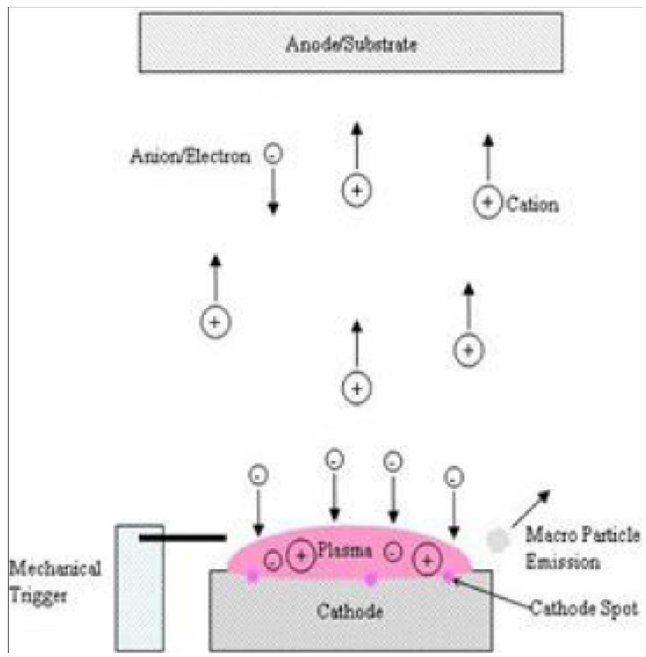

Figure 4 : Deposition process

EXPERIMENTAL DETAILS

Materials

In the present study, AISI 1040 carbon steel was considered as a work piece material and cemented carbide with TiAlN coated and uncoated as cutting tool inserts.

Coating deposition

The coating deposition was conducted in the pure nitrogen atmosphere. DC current is applied the rotating cathodes Ti and Al. Prior to the deposition the

TABLE 2 : Technological Parameters for deposition

Coating	Substrate	Thickness µm	Substrate temperature ^{0}C	N_2 Pressure Pa	Accelerating Voltage V	Coil Current A	Time of Deposition min	Temp ^{0}C
TiAlN	Cemented Carbide	3	410	3	23	20	30	410

TABLE 3: Cutting Conditions for turning

Work piece	Cutting speed	Feed rate	Depth of cut
1040 AISI steel(HB 200)	208 m/min	0.05-0.4 mm/rev	1.5mm

substrates were cleaned in Thermovide V300 Pre-cleaning unit by argon –ion-etching process. The pre cleaned mirror polished substrates were mounted on a carousel substrate holder. The chemical composition of the cutting tools is presented in TABLE 1. The thin TiAlN coating was deposited onto the cutting tool substrate by CAPVD method. The technological parameters of the used procedure are given in TABLE 2.

Hardness test

The microhardness of CAPVD TiAlN coatings were measured using Vickers type indentor. The load applied was 60N.

Machining test

The machining tests were carried out on 250mm long and 80mm diameter cylindrical bars without coolant with the constant cutting speed and depth of cut. The work piece material and cutting conditions used in the experiment are listed in TABLE 3. The machining tests were conducted on a HMT Lathe.

For each cutting, the cutting forces are recorded. The specific cutting pressure (K_c) was estimated from the mean cutting values calculated using the following equation.

$$K_c = \frac{F_c}{A} = \frac{F_c}{f_b} \quad (1)$$

where F_c is the cutting force, A is the undeformed chip cross-sectional area, which is the product of feed rate (f) and depth of cut (b) and K_c in N/mm^2.

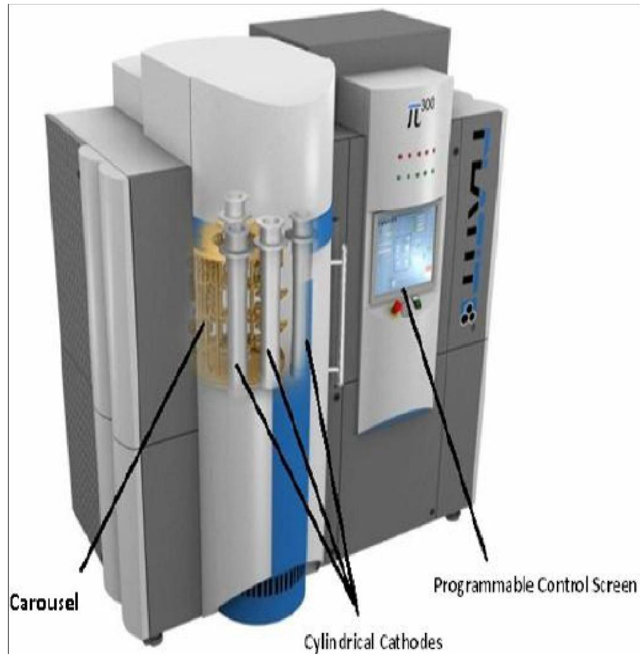

Figure 5 : PLATIT π^{300} coating system

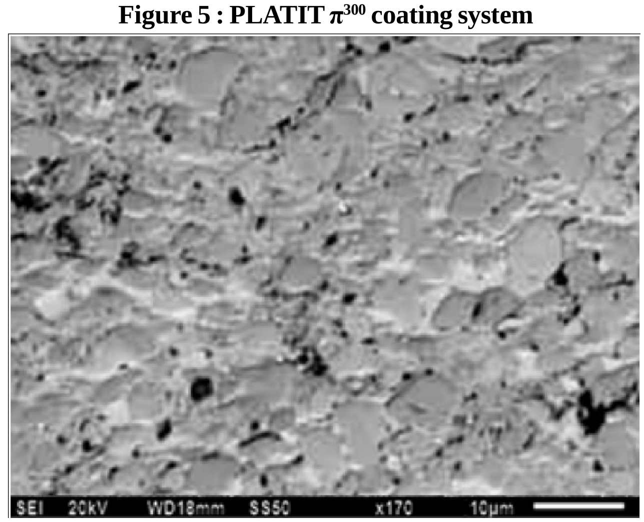

Figure 6 : SEM micrograph of TiAlN coated carbide tool

Microstructural characterization

The microstructure of the coated carbide tool was examined using JSM-6610LV scanning electron microscope equipped with energy dispersive X-ray analyzer

TABLE 4 : Coating Characterization data

Substrate	Coating	Chemical composition, at %	Al/Ti ratio	Properties	
				Thickness (µm)	Microhardness (GPa)
Uncoated carbide tool	--	--	--	--	18
Coated carbide tool	TiAlN	$Ti_{0.25}Al_{0.22}N0.53$	1.0	3.0	30

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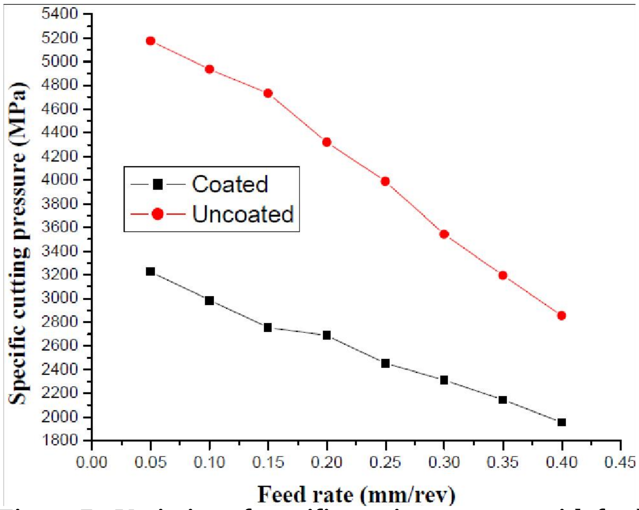

Figure 7 : Variation of specific cutting pressure with feed rate

(EDX).

RESULTS AND DISCUSSIONS

SEM micrograph of TiAlN coating on carbide tool is shown in Figure 6. It is evident that the adhesion of the coatings to the hard substrate was good and no flaking was observed. The micro hardness gain due to the coating is clearly understood from TABLE 3.

Figure 7 shows values of the specific cutting pressure obtained from the experiments. It is seen that there is a decrease in K_c when machined with the coated carbide tool when compared with uncoated one. It is evident that higher feed rate corresponds to low K_c value. Hence it is understood that coating exerts significant influence on the specific cutting pressure when turning with higher feed rate. It is also understood that K_c can be maintained and influenced by coating properties.

CONCLUSION

High hardness of TiAlN coatings significantly enhanced the machining productivity. Coated inserts have shown a much greater performance improvements than uncoated tool inserts during dry turning. Reduction of machining cost and elimination of cutting fluids is also achieved in machining. Thermal aspects can be taken into consideration for future research.

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