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Technical Paper

# Influence of surface preparation on the tool life of cathodic arc PVD coated twist drills

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ABSTRACT

Cutting tool micro-geometry and surface integrity have been critical aspects to be considered for successful application of PVD thin films for cutting tool life enhancement. The present study examines in detail the role of pre-coating surface preparation (micro-blasting and drag finishing) on the tool life of coated cutting tools. TiN coating was deposited on different kinds of pre-treated (Micro blasting, Edge rounding and a combination of both) HSS and WC drills using cylindrical cathodic arc deposition method. They were subsequently characterized for surface roughness ($R_a$), adhesion strength and machining performance on EN 24 material. Pre-coating surface roughness (developed due to pretreatment) has a major influence on the adhesion strength of the coating. A lower pre-coating surface roughness with optimized edge rounding led to higher adhesion and edge strength which in turn resulted in a notable increase in tool life. Further underlining the importance of the present study, commercial TiN coatings deposited on HSS substrates were tested. The tool life obtained in the current study prolonged the tool life by a factor of 3 in comparison to the commercially available tools in the present day market.


## 1. Introduction

The development of cutting tools to provide a viable solution to the burgeoning need for high speed machining (aggressive machining) with minimum quantity lubrication (MQL) has been gaining interest in the recent years. By adapting to these needs a steep decrease in tool life is expected. Among the various material removal processes being used currently, drilling along with allied operations like micro-drilling, reaming, boring, trepanning etc. encompasses approximately 30% of all metal cutting operations [1]. Several attempts have been made to enhance the tool life of materials such as employment of hard materials like cemented carbides, cermets and other super hard materials. Alternatively the application of coatings to cutting tool materials has also been well known and industrially practiced to increase tool life. The coating industry has been thriving with the development of chemical vapor deposition (CVD) and physical vapor deposition (PVD) based coatings [2]. Among the family of PVD techniques, cathodic arc based PVD (CAPVD) coatings have superior properties, i.e. excellent adhesion (due to high ionization) and high deposition rate over other PVD techniques like magnetron sputter deposition and ion plating. Therefore this technique has garnered widespread interest and industrial viability [3–6]. Cathodic arc deposited hard metal nitride coatings like titanium nitride (TiN) and chromium nitride (CrN) have been well researched/documented universally since decades and employed for cutting tools due to their excellent wear and oxidation resistance [7–10]. These coatings endure temperatures ranging from 550 °C to 700 °C [11] which is insufficient during high speed machining. Therefore, the relatively lower thermal stability has been the primary driving force behind the addition of aluminum (Al), silicon (Si) or both Al and Si to these materials via TiAlN, CrAlN, TiN/$Si_3N_4$, CrN/$Si_3N_4$, TiAlN/$Si_3N_4$ and CrAlN/$Si_3N_4$ coatings [12–15]. All these coatings have emerged as a better option than simple TiN coated tools [16,17].

In general, as developed drill bits have sharp cutting edges with high surface roughness (machining scars). Sharp cutting tool tips and edges are the source for excessive stress and higher impact loads. Cathodic arc deposition being a potential based process and uses substrate bias to enhance adhesion strength; these sharp edges hinder uniform deposition leading to poor tool life. Also, due to the high surface roughness of the drill bit the substrate-coating adhesion is very poor [18,19]. Therefore uniform deposition and maximizing adhesion strength is of prime importance in improving the wear resistance of coated tools which is majorly influenced by

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the sharp edges and surface roughness of the substrate [20] and hence suitable methods need to be employed.

Different methods have been adopted for this purpose as pre or post coating operations [21–23]. Some of the commonly used pre/post treatment methods are grinding [24], micro abrasive blasting (micro-blasting (wet/dry)) [25–27], drag finishing [28–30], magnetic polishing [31], abrasive water jet blasting [32] and laser texturing [33–35]. These methods result in either improving the surface integrity or modifying the tool geometry (cutting edge, corner in case of drill bits). Among all the available techniques, micro-blasting (micro abrasive blasting) and drag finishing are two such durable and cost effective methods resorted to increase tool life. Micro-blasting and drag finishing are known to reduce the mechanical and thermal loads subsequently providing an effective surface finish and edge stability.

In view of the above, the aim of the current investigation was to study in detail the effect of surface roughness (of the substrate) on the substrate-coating adhesion and correlating the same with the observed tool (HSS and WC twist drills) life by evaluating their machining performance.

## 2. Experimental details

The substrates used in this study are $12.5 \times 12.5 \times 5\,mm^3$ high speed steel (HSS) and tungsten carbide (WC) flat coupons, 6 mm M2-HSS (Addison make) and 5 mm carbide drill bits (Miranda make). Prior to the coating, the drill bits and coupons were prepared to achieve different surface finish using micro-blasting and drag finishing techniques. Micro-blasting was carried out in a micro-blasting unit (Guyson Euroblast 2SF system) at a pressure of 4 bar under a 10 mm diameter blasting gun. To study the effect of particle morphology and size, two grades of angular alumina ($Al_2O_3$): 50 μm, 15 μm and spherical zirconium dioxide ($ZrO_2$: 50 μm) powders were used as micro-blasting mediums. The SEM images shown in Fig. 1(a–c) indicate the powder morphology. Hereafter, MB1, MB2 and MB3 are used to denote the HSS substrates which have been micro-blasted with 50 μm $Al_2O_3$, 15 μm $Al_2O_3$ and 50 μm $ZrO_2$ respectively. The micro-blasting process was optimized to obtain the lowest possible surface roughness achievable by each medium. The optimized blasting time durations are: 4 s, 30 s and 50 s for MB1, MB2 and MB3 respectively. Similarly, the WC substrates are also micro-blasted for an optimized duration of 20 s with 15 μm $Al_2O_3$ and 50 μm $Al_2O_3$. The surface finished WC substrates are represented as MB4 (15 μm) and MB5 (50 μm). Edge rounding studies were carried out in a drag finishing machine (Otec DF-4) in 100 μm $SiO_2$ medium (Fig. 2). The drag finishing parameters were set at a fixed spindle speed of 50 rpm and the edge rounding duration was varied between 05 and 20 min. ER1, ER2, ER3 and ER4 denote the HSS drill bits and ER5, ER6, ER7 and ER8 denote the WC drill bits which have been drag finished for 5, 10, 15, 20 and 5, 10, 15, 60 min respectively. Also MB + ER is used to denote the HSS drill bits which have been micro-blasted followed by drag finishing.

An industrial scale ultrasonic cleaner (TermoVide) with a means for ultrasonic cleaning, rinsing with steam and vacuum drying was used to clean all the substrates and drill bits. TiN coatings were deposited on all the pretreated and cleaned substrates (drill bits and coupons) using a cylindrical cathodic arc physical vapor deposition system (π 300, PLATIT) with a 99.99% pure Ti cylindrical cathode. The cathode current and substrate bias were kept constant at 175 A and −50 V. The nitrogen partial pressure and substrate temperature was maintained at $3 \times 10^{-2}$ mbar and 400 °C respectively.

The HSS coupons were characterized for thickness, hardness and modulus and surface roughness ($R_a$). To cross verify the thickness deposited on the drill bit, it was sectioned very close to the cutting edge and observed using a scanning electron microscope (SEM, Hitachi S-3400N). The hardness and modulus were measured using a table top nano-indentation machine (CSM, NHT) at a load of 50 mN in sinus mode (10 Hz). An average of 15 indents was taken to measure the hardness and modulus of the TiN coated sample. The adhesion strength of the coatings were characterized using a scratch tester (Revetest CSM) at a progressive load ranging from 0.9 to 150 N and a scratch length of 8 mm. Surface roughness ($R_a$, μm) of the coupons was measured using an optical profilometer (Zygo NewView 6200) at a magnification of 20 X. Averages of 15 readings were taken on each sample to measure the surface roughness. The cutting edge radius was measured using a scanning electron microscope by sectioning it very close to the cutting edge. A perfect circle is fit on this fabricated edge using the utility options present in SEM

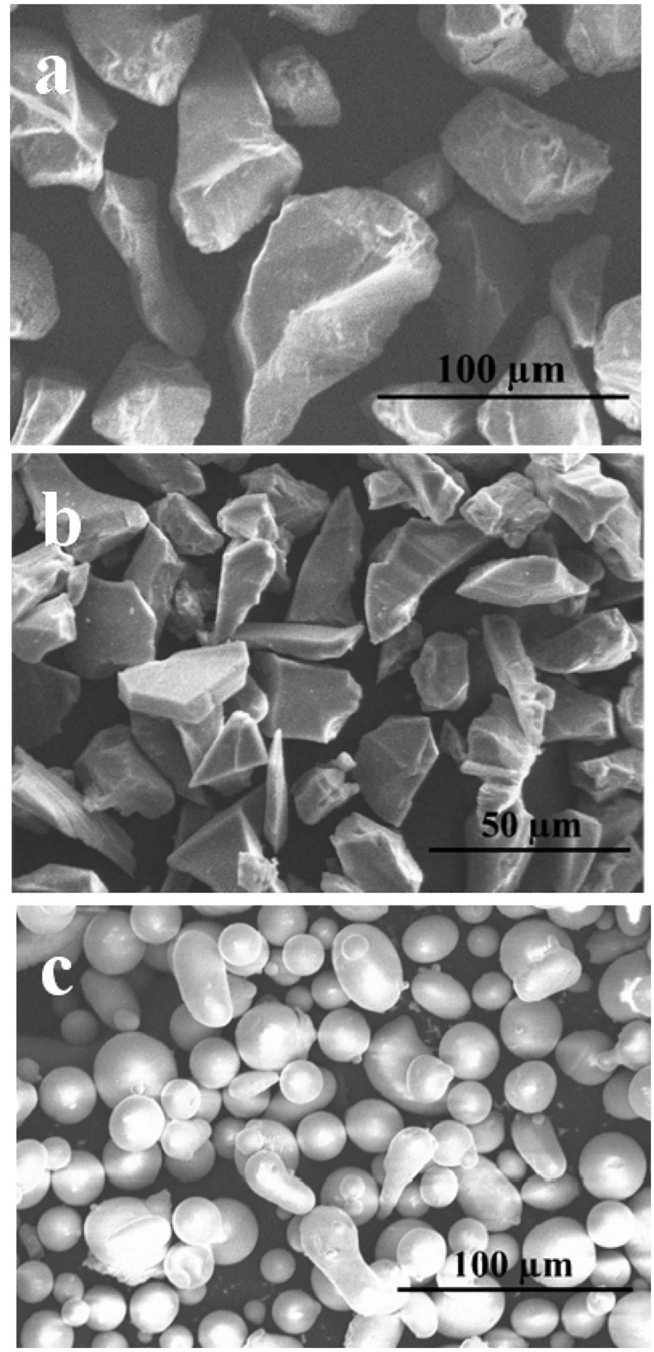


**Fig. 1.** SEM image of different powders (a) 50 μm $Al_2O_3$ (b) 50 μm $ZrO_2$ (c) 15 μm $Al_2O_3$.