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SIGNIFICANCE OF SURFACE PRE-TREATMENT FOR DIFFERENT CUTTING TOOLS COTED BY CA-PHYSICAL VAPOUR DEPOSITION

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ABSTRACT: With the advent of new materials with high performance to meet the current applications has increased the complexity in machining because of their high strength, hardness, toughness. Two widely accepted solutions are there to overcome this problem which is hard metals and surface coatings. In coatings physical vapour deposition technology and chemical vapour deposition technology had used on cutting tools to machine these types of materials. Even though there are some problems like rapid tool wear and/or abnormal tool failure occurred because of poor adhesion, high surface roughness value and sharp cutting edges of the cutting tools. To eliminate these difficulties, pre-treatment technique is one of the viable solution and also to enhance the tool life further. Micro-blasting on PVD films has been documented, among others, as an efficient method for inducingcompressive stresses, thus for increasing the coating hardness and potentially tool life of coated tools. Sincecontradictory results have been registered concerning the efficiency of wet micro-blasting on coated tools forimproving the wearbehavior, the paper aims at explaining how this process can be successfully applied forpost-treatment of PVD films. In this context, the employed conditions such as pressure and grain size affectsignificantly the wear resistance of the micro-blasted coated tools.

1. INTRODUCTION

Now a days machining is one of the major operation which is widely caring out in many industries such as automobile, aerospace, locomotive, marine, etc. The main objective in the machining operations like drilling, boring, milling, reaming, turning, etc. is to transvers a raw material into specific desired shape. While in the transformation cutting tool had a prominent role. Therefore, tool life is the main criterion which decides productivity of machining operation. But there are many changes had occurred in materials to suit with current applications. Traditional materials would not suitable for this purpose so, now a days industries using advanced exotic materials like composites, hard powder metals, bimetals, high strength alloys, Inconel, carbon fiber reinforced plastic, etc. Despite to the advancement in materials, the machining operation had become very difficult and simultaneously tool life was also decreases rapidly. Because, while performing the machining operations there would be a chance of high temperature, stresses and forces generation at contact point between the cutting tool and material and also rapid tool wear was taking place.

So, surface treatment technique had a possible solution to avoid these difficulties. This can be done by applying a layer of film or coating onto the existing surface to create a new surface with altering the base material properties. Chemical Vapour Deposition (CVD) and Physical Vapour Deposition (PVD) are the two most prominent coating process treatments. PVD process had been widely using coating treatment than CVD.

Despite to this process treatment rapid tool wear and failure are still major problems in all machining processes. Tool wear such as flank wear, corner wear and built up edge could effects hole quality and surface finish of the product. Thus, besides the coating material properties and specifications a large number of further parameters affect the coating performance in cutting tool applications. So, along with the coating technique, cutting edge geometry and surface pre-treatment technique had also placed a vital role in hard machining and high speed machining.

2. TWIST DRILL BIT GEOMETRY

Drilling is one of the most commonly used machining processes. A typical drill has several design parameters such as tip angle, chisel edge angle, chisel edge length, cutting lip length and helix angle. It is known that a drill consists of two main cutting edges, namely; the chisel edge and the cutting lips. The Chisel edge extrudes into the work piece material and contributes substantially to the thrust force. The cutting lips cut out the material and produce the majority of the drilling torque. [1]. The drill geometry influences the cutting force effects on the tool and additionally material properties of tool and workpiece along with machining conditions also influences the cutting forces.

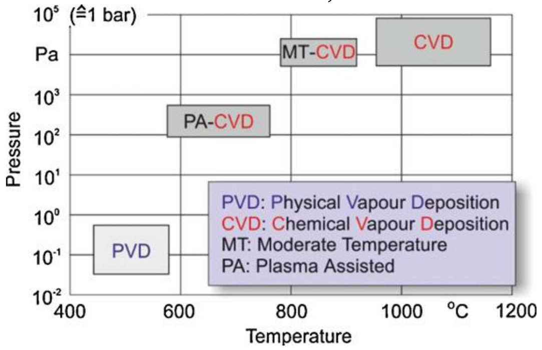
Twist drills: In the case of drilling, the new developments are mainly relates to

- Drill point geometry has to be improved for better results.
- Materials and coatings are used to improve the performance and tool life.

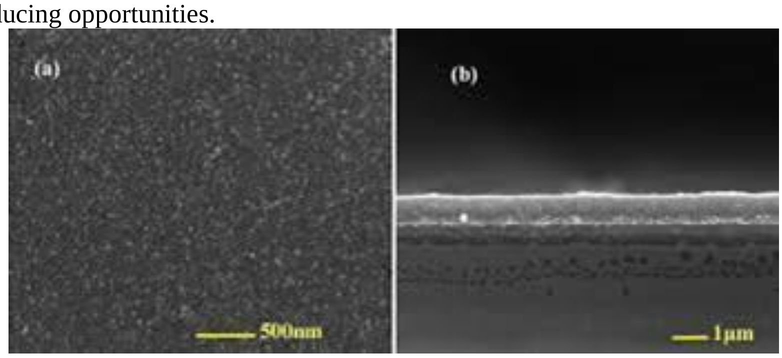
3. THIN FILM DEPOSITION

Surface engineering involves changing the properties of the surface and near surface region in a desirable way. Surface engineering involves an overlay process or surface modification process. In overlay process a material is added to the surface and the underlying material is covered and not detectable on the surface. This process changes the properties of the substrate but the surface material is still present on the surface.

Physical Vapour Deposition (PVD) is one of the most prominent processes which were used in the thin film deposition techniques. PVD processes are atomistic deposition processes in which material is vaporized from a solid or liquid source in the form of atoms or molecules and transported in the form of a vapour through vacuum or low pressure gaseous environment to the substrate, where it condenses [2].

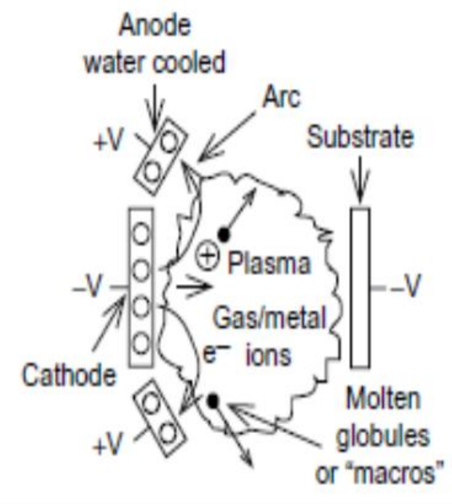


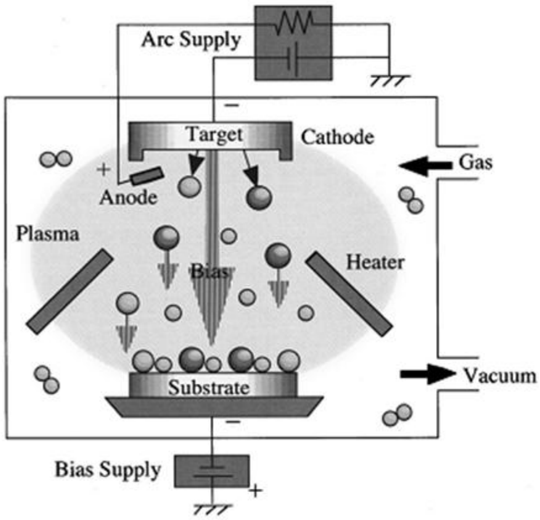
CVD coatings were already commercialized for carbide inserts in the 1960s. PVD was developed almost 20 years later and today both CVD and PVD are sharing the coating market of cutting tools. PVD coatings for cutting tools can be deposited at temperatures lying in the range of 450^{0}C to 550^{0}C, which allows the film deposition on high speed steel tools. Moreover the ability to control thickness on the edges, when PVD is employed, guarantees a sharp coated edge. PVD films can be produced without any chemical interaction with the substrate. CVD coatings easily interact with the substrates, occasionally producing brittle carbides at the interfaces. The ease of decoating and resharpening of PVD coated tools opened a large industrial market highly sensitive to cost reducing opportunities.



3.1 CATHODIC ARC

Cathodic arc deposition or Arc-PVD is a physical vapor deposition technique in which an electric arc is used to vaporize material from a cathode target. The vaporized material then made to condense on a substrate to form a film. In this method, a small limited area (few microns) is evaporated with a very high-energy arc that quickly moves over the metal surface to be evaporated. The plasma generated consists of highly ionized metal vapor (approx. 50 – 100%). The ionization rate is considerably greater than any other process of PVD. The energy associated with the evaporated species during the deposition of coating depends on the bias voltage given to the substrate (the component on which one is interested to coat), which is also responsible for control of momentum transfer. The amount of momentum transfer is highest in the case of the cathodic arc deposition process. This leads to high deposition energy, and a dense coating [2].





4. TYPE OF COATINGS

4.1 TiN, the first universal coating

A number of different hard coatings, binary, ternary and quarternarycompositions were deposited by CVAE in the former Soviet Union [4,5,6], but in the West mostly TiN coatings have been deposited using different PVD techniques. Therefore it is no surprise, that we can find successful TiN coatings in all fields of applications. However, for most applications we can also choose another coating which is similar or better performance than TiN. It is interesting to report the results on tools for sewing needle manufacture and the sewing needles themselves which are coated at 200^0C. Replacing hard chrome with TiN significantly increases the lifetime of the needles.

4.2 CrN, the second universal coating

The fine grained coating combines low brittleness and sufficient hardness with good oxidation resistance and chemical inertness. Industrial experience shows that the CrN coatings can perform better in metal forming that the CVD TiC/TiN coating. The lifetime of CrN tools increased by a factor greater than 30. CrN coatings also show very good results in manufacturing copper materials both forming and cutting and when cutting turbine blade materials (Inconel) as well as in glass forming. Moulds for parts made of elastomers, thermoplastics and phenol plastics have been coated successfully for many years. It was also found that CrN coatings increase the lifetime of mould broaches in die casting of aluminium in the range of a factor of 2-15.

4.3 (Al, Ti)N, a high oxidation resistant coating

It is well known that higher cutting speeds as well as"bad" lubrication conditions are connected with thegeneration of high temperatures. (A1,Ti)N coatings witha high Al-content (metal content [Al]/[Ti]> 1) are themost oxidation resistant coatings deposited by the CVAEprocess onto tools [7]. So this coating is the bestcandidate to meet the conditions of highcuttingspeedsand "unlubricated" operation. However, it was reportedthat (Ti,A1)N coatings (metal content [A1]/[-Ti]=I)deposited by magnetron sputtering are not suitable formilling operations [8]. AlTiNcoatingsdeposited by CVAE can increase significantly theperformance of milling tools. Excellent results wereobtained in the cutting of high nickel-alloyed materialsand of grey cast iron. It was also reported that for theforming of non-ferrous materials such as high-nickelalloys or titanium alloys, A1TiN coatings can performbetter than the other coatings.

4.4 Other coatings

It is possible to increase the hardness or the oxidation resistance of titanium-basedcoatings by alloying withZr, Nb, Hf, V, W and B [5,10,6,7,10.11]. Thesecoatings have application niches where they show betterperformance than the other coatings. CrCN coatings aresuccessfully applied for plastic tools and different cutting operations.

4.5 Combined coatings

For some applications, combination coatings are moreeffective than PVD coatings alone. In the specific caseof tribological systems with corrosive action, the combinationof an electroless nickel layer with a PVD coatingshould be applied. Another important variant is thecombination of nitriding treatment with the depositionof a hard coating. This allows the load-bearing capacityof the composite to be raised and also gives a wearreserve. Initially, results of coating CVD-coated hardmetal inserts with PVD coatings showed the possibilityof an increase in lifetime [7].

5. SIGNIFICANCE OF PRE-TREATMENT

As per the literature review, pre-treatment for different cutting tools before coating would affect the tool performance. Previous researchers explained the significance of different surface pre-treatment, post-treatment for different type of coatings and also explained the effects of it.

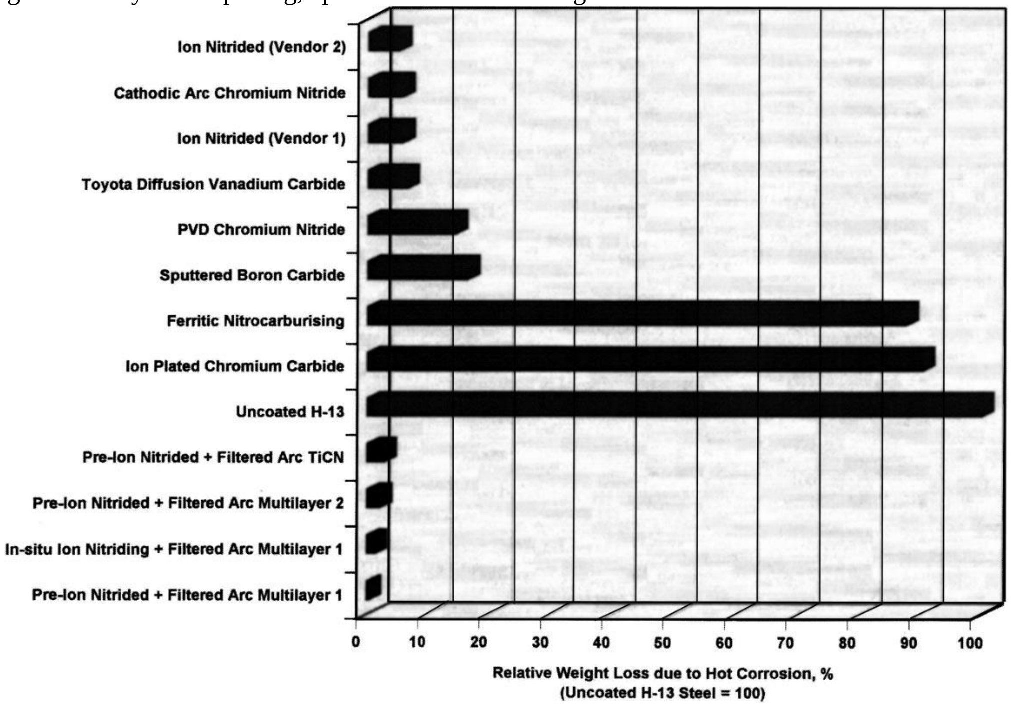
- **C. Subramanian et al.** 2μm thick TiN coatings were deposited on M2 HSS twist drills, coated and uncoated bits were tested and SEM studies carried out to explain the possible wear mechanism. Was able to estimate, Compared to bare TiN performs 4 times better
- **R. Buhl et al.** studied in detail the PVD deposited TiN for microstructure, adhesion and machining properties. Also gave a 4 times higher life to TiN coated tools when compared to bare
- **W. D Sproul et al.** compared PVD coated and sputtered TiN bits with and without coolant, finally giving a life 20-30 times more than bare bit
- **S.G Harris et al.** influence of chromium content was studied in TiAlN coatings. An improvement in tool life was observed based on Cr addition.
- **K.-D. Bouzakis et al.** Micro blasting on pvd films has been documented as a potentially efficient method for improving the cutting performance of coated tools. This process induces residual compressive stresses into the film structure, thus increasing the coating hardness but its brittleness too. Micro blasting parameters pressure and time have crucial effect on the coated tools cutting performance. Along with this Bouzakis also investigated 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.
- **Knotek et al.** state that coating adhesion increases with improved surface quality and surfaces with low roughness values offer more favorable growth conditions for hard PVD films, increasing micro-hardness and coating rate (speed of growth of the coating thickness during the PVD process)
- **S.G Harris et al.** influence of chromium content was studied in TiAlN coatings. An improvement in tool life was observed based on Cr addition.
- **Bouzakis et al.** applied micro-blasting to cemented tungsten carbide inserts and observed that Co is removed from the surface to be coated. Moreover, high roughness peaks are reduced due to the removal of carbide grains and numerous new smaller peaks are revealed, thus contributing to the enhancement of substrate–coating adhesion. The increased coating adhesion occurs due to the better mechanical binding of the deposited coating on the substrate surface through small roughness peaks.
- **B. Denkena et al** Coating adhesion is dependent on the surface roughness of the prepared inserts and on the difference between residual stresses in the coating and in the substrate near the interface. Higher compressive residual stresses on the substrate after coating contribute to the decrease of tool wear, since the rupture of the insert material is hindered. Since the coating is rapidly removed, the properties of the substrate have a great influence on insert performance.

6. EMERGING APPLICATIONS

As mentioned earlier, the major commercial applicationfor cathodic arc technology is in the enhancementof useful life for cutting tools w97x. This is likely thecase because major benefits in tool life were achieveddespite the presence of macroparticles in the coatings.With the advent of commercially available arc filters,we expect to see new applications which depend onbeing able to produce macroparticle-free coatings.While many of these applications are still tightly protectedtrade secrets, we have listed some examplesbelow which have been reported in the open literature.

6.1 Example: corrosion protection of dies

Figure shows a comparison of the corrosion behaviorof some die pins which have been given a variety ofdifferent surface treatments and subsequently exposedto molten aluminum. The sample which was pre-nitridedand subsequently coated with a TiN/TiBCNmultilayer coating prepared in the filtered cathodic arc system, showed virtually no corrosion in this hostile environment [24]. Once again, this application requiresfiltering of the arc since macroparticles in thecoating would provide a path for the corrosive mediumto gain access to the underlying part. The demonstratedsuccess of filtered arc multilayer coatings forcorrosion protection suggests additional applicationsmay become practical such as the replacement ofchromium coatings currently generated by electroplating,a process which is causing environmental concern.



Comparison of corrosion resistance of die pins treated with various surface treatments, the most successful being a duplex coating with afiltered-arc-produced TiNrTiBCN multilayer coating [24]. Courtesy of D. Bhat.

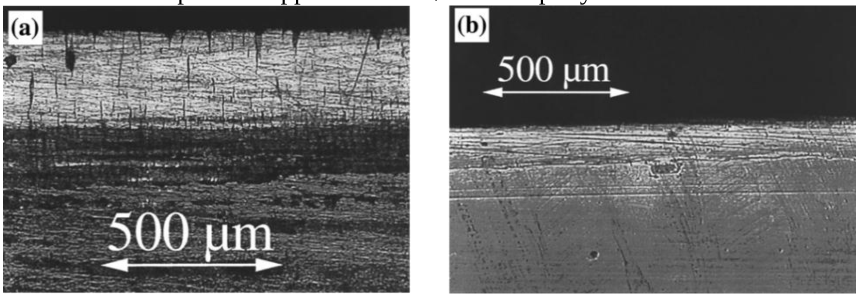
6.2 Example: hard carbon films

As discussed earlier, cathodic arc deposited carbon isa particularly interesting system because of the widevariety of coating structures and morphologies whichcan be generated. Potential applications for coatingsproduced by a filtered arc abound. It has been suggestedthat they may have value in protecting knifeedges and surgical blades since extremely hard smoothcoatings are possible. They may prove useful for bearingsurfaces in high precision machine tools for thesame reason [25,26]. Electron emissive carbon coatings [27]suitable for flat panel displays have been demonstrated [28,29], and electron emission from vacuum-arc a-C coated nanotubes is being investigated [30].

Cathodic arc systems with advanced filters suchas the Twist Filter may represent a possible avenuefor synthesizing ultrathin films having the requiredfeatures. However, pulsed-arc synthesizedcarbon films can be very hard and elastic even whensp^2 bonds dominate, provided the graphene sheets arecurved [31]. The range of carbon-based materials isstill growing and we should be prepared to see moreinteresting properties discovered in this field.

6.3 Example: nitrides, oxides, carbides and other coatings

Unfiltered cathodic arc deposition of TiN coatings is a well-established technology[33,34] which supportstens of millions of dollars of business annually worldwidein coating equipment sales and hundreds of millionsof dollars annually for the coatings generated by that equipment [32]. Most of the arc-TiN coatings aredecorative and protective coatings on plumbing fixtures,door knobs and lamp reflectors. Welty estimates that the value of cathodic-arc-coated productsapproaches US$1 billion per year.



Comparison of thermal fatigue behavior of coated and un-coated H13 steel die pins (a) Optical micrograph of an uncoated pin; (b) TiN/TiBCN multilayer-coated pin. The multilayer produced inthe filtered cathodic arc system prevents surface cracking that is found in the uncoated part. Courtesy of D. Bhat.

The reason that theindustry can use the reactive arc deposition process forthese applications is the technologists have learned todiminish the quantity of macroparticles by making thinnercoatings, using appropriate side shielding and magneticfields.

7. SUMMARY AND OUTLOOK

Although cathodic arc deposition is one of the earliestplasma technologies, its commercial use has beenlargely limited to applications where some number ofmacroparticles can be tolerated such as lifetime extensionof machine tools and decorative applications suchplumbing fixtures, and door knobs. Recent progress inthe development of macroparticle filters is likely toextend this list of applications. The driving force topursue arc technology, as opposed to evaporation andsputtering technologies are the often outstandingproperties of the films deposited, and the wider processwindow (range of partial pressure) in reactive plasmadeposition. Film properties can be readily tuned andtailored because cathodic arc plasmas are fully ionized.With the introductionof the improved ability to control the arc trajectory andplasma trajectory, it is likely a larger range of applicationswill bepursued.The productivity increase demands in cutting processes can beaddressed, among others, through the application of coated tools.The paper deals at first with current trends of coated toolsmanufacturing, providing an overview on the evolution of filmdeposition technologies, coating materials and adhesive interlayers.Moreover, coated tools wear mechanisms were explainedby innovative methods for characterizing film material, functionaland dimensional properties. These issues are supported bysophisticated computational procedures, which contribute inobtaining a thorough understanding of the tool wear mechanismstaking place during cutting with coated tools. The describedprocedures allow the prediction of coated tool cutting performanceand the effective adaption of the cutting conditions to the filmproperties, thus restricting the related experimental cost. Appropriatesubstrate and coatingthermal as well as mechanicaltreatments improving the tool wear behavior, were also introduced.The potential of applying coated cutting tools in difficult-tocutmaterials was exhibited in characteristic workpiece materialcases. Finally, the possibility of reconditioning worn coated solidcutting tools and its effect on the mechanical properties, thecutting edge sharpness and performance was highlighted.

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