Carbide Lubricative Coating to Withstand Aggressive Working Environment

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Abstract : Lubricative coatings are used to reduce friction between surfaces in many extreme environments including those with high/low temperature, high/low pressure, and high shaft speed where liquids and oils cannot be used. To minimize friction and abrasion resistant (to prevent seizing and galling and other physical damages), especially in high/low temperature environments where fluids may freeze or vaporize these thin films are used. In the present study our main focus is on lubricative coatings such as TiC on transition metal nitrides films CrN & TiN. This films were deposited by Cathodic Arc PVD techniques on Mirror polished stainless steel 304 & HSS coupons having dimension 22mm diameter (ϕ) and 8mm thick. These coating were deposited with highest thickness of ~3 to 4 micron. Corrosion resistance of the base stainless steel, and coatings is measured using potentiostat instrument. Wear coefficient were determined by using Calo-wear test. These special tribo-coatings exhibits excellent surface wear characteristics with optimized adhesion & corrosion resistance. Detailed study of composite coatings structures, CrN + TiC and TiN + TiC is carried out in this paper.

***Index Terms* - Lubricative coatings, Cathodic Arc PVD techniques, Tribo-coatings, Potentiostat, Corrosion resistance**

I. INTRODUCTION

lubricative coatings have been widely used in cutting tools because of the superior chemical, physical, and mechanical properties, such as high hardness, wear resistance, adhesion and corrosion resistance as well as their chemical stability[1,2]. Furthermore, friction coefficient of these coatings have been further studied because of the possible applications of these coatings in machinery industries [1, 3]. V. Derflinger et al. were deposited of a hard/lubricant coating on cutting tools to reduce the amounts of cooling emulsion in metal cutting tools [4]. These lubricating coatings are reliably protected against dust, contamination and humidity. According to C. Donnet et al. solid lubricant coatings used for a wide range of industrial applications. These coatings are now available in nano-structured and/or -composite forms to provide better performance and durability even under very severe sliding conditions [5].

A composite material is mixture of two or more micro constituents with an interface separating them. To increase performance of coated tools and to meet industrial demands of the composite hard coating-carbide tool, the development of new coatings with improve tribological performance are very much necessary to extend the useful life of components [6]. Further Multiple TiCrN + TiBC coating architectures were reviewed by V.I. Gorokovsky et al.for their ability to provide wear resistance for Pyrowear 675 and M50 steels used in aerospace bearing and gear applications. Their experimental result reflect Coating failure mechanisms and suggestted further optimization of TiCrN + TiBC coating architectures [7].

In the Neutral Buoyancy Laboratory of NASA, astronauts practice in antigravity or microgravity pools for their missions in outer space. These swimming pools are specially designed to replicate the buoyancy noticed on our body mass in near-zero gravity situations. These pools are filled with gallons of chlorinated warm water, which is a perfect recipe for degradation of metal parts on space suits and other metallic experimentation tools. The critical dependency of each component to missions like the Moon or Mars influences the way surface engineering is looked at in the context of space exploration and aerospace dynamics. High-end applications need precise surface engineering applications as these ventures calculate measures in precise numbers. Any slight miscalculation would result in catastrophic losses and failure of missions. These surface coatings need to bear high-level properties that can protect these mechanical assemblies and gadgets against the harshness of vacuum, extreme environments, and low pressures of outer space [8]. In some application, thin film coatings are applied to reduce weight and to optimize proficiency by industries like aerospace and defense. It uses materials such as carbon fiber to reduce load. The various parts of machinery are coated with titanium and chromium thin films. Lubricative coatings withstand aggressive working environment such as extreme high/low temperature and high/low pressure for high-speed machining and ultra-hard cutting tools [9]. Self-lubricating coatings include coating systems which include graphite or carbon atoms. On cutting tools, these self-lubricating coatings, as top layers on a supporting hard material layer, act as a solid lubricant [10].

When it comes to cutting fluid technology, supplying tools with tiny amounts of coolant drives for a reduced state of friction and further reduces the process of adhesion between the substrate to be working on, the chip, and the tool. Mostly, emulsions, oils, or water are the types of coolants used and only the smallest quantity makes it through for use. To adjudge the smallest amounts, a pump and a small pipe attached to it are used. The purpose of reducing friction is to reduce the frictional heat that is caused in the interim and other processes, including deposition. In the case of an external supply, the use of an aerosol is most frequent. The aerosol is sprayed onto the tool externally with either one or several nozzles [11]. This type of coolant application finds itself in use in cases of tools used for sawing, shaft, and knife head face milling. In the case of internal machining, considering processes like drilling, reaming, or tapping, having an external supply of oiling is not highly practical and works only for a smaller surface or interface. Considering the instance of grinding cemented carbide most often creates large amounts of mist and dust particles, which contain harmful metal compositions that are dispersed in the air. Grinding with coolants also causes environmental problems and overheating an oil base is inflammatory. Then again, considering the instances of brazing cemented

carbide tools at extremely high temperatures against achieving the melting point of brazing materials can initiate loosening or breakage of the tool itself.
Such cases allow us to venture and look out for alternative, environment-friendly media that will help fulfill all the various functions expected from traditionally used cutting fluids. Using a thin film of lubricative coating aids in such scenarios and is particularly suitable for different applications that are subjected to UV or X-rays and vacuum [12]. Such coatings also help in cases where aggressive media is involved including high and low temperatures. Returning to the issue of environmental safety and sustainable manufacturing, the reduction in the use of such cutting fluids/oils/emulsions can effectively reduce environmental problems like fumes, toxic waste (disposal), and pollution. On the other hand, the proven use of coated tools supports dry machining and minimum quantity lubrication machining. Hence, an environmental-friendly and sustainable situation appears. In addition, the cooling lubricant, its cleaning and disposal will prove to be cost-effective.

II. Experimental process

In Manufacturing and Production industries, there are machines that facilitate activities like threading, gauging, clamping, and milling. This stands true for textile industries, feed mills, chemical industries, and many more industries. These large-scale industries operate on a 24/7 basis, making it absolutely imperative for the equipment and tooling to have carefully designed and engineered surface technology applied to their coatings. With near-zero maintenance requirements or supply and inadequate downtime for repair or replacement, the surface coatings used need to be stay resistant to extremely high temperatures and a very low coefficient of friction among other properties. These properties help prevent adhesive materials from sticking to machine parts. With a dry-lubricated surface, corrosion and wear can be inhibited and performance, durability, and longevity can be enhanced. Corrosion is a concern in chemical industries as there are a variety of chemical reactions taking place, which might interfere with the tooling metals. With such a contamination of the metal, protecting them can increase productivity and performance and maintenance costs can be curbed as per compliance rules and standards.

When it comes to the formation of sheet metals, the desired form is usually achieved through the means of elastic deformation and milling. However, these processes produce a lot of stresses and strains on the milling and deforming machinery. Different types of stresses include the duration of checking the tensile strength of metals, bending, compressing, and even shearing. Metal die stamping too produces much stress on the tools and equipment used across the industry and its various procedures. Through these study, It is found found that cemented carbides have a different thermal expansion coefficient when applied with steel and ferrous materials.

The phenomena at the interface involve the effects of all the components on the sliding friction, wear rate, hardness, surface roughness, and elastic/plastic deformation. Industrial tooling and components are frequently subjected to severe conditions of load and heat, widely used for mechanical working operations such as hot forging and extrusion, thereby limiting the life of the parts. By analyzing the applications of these industrial tools, the strength of the tool must exceed that of the workpiece, therefore making it mandatory for the coating to maintain its durability and functionality for a long time. The performance requirement must be resistant to the high levels of mechanical shear found in various industrial systems. When considered as design elements of a system, lubricants stand as a significant factor in a range of automotive and industrial equipment

Preparation of Thin Film Using the Advanced Cathodic Arc Deposition Process

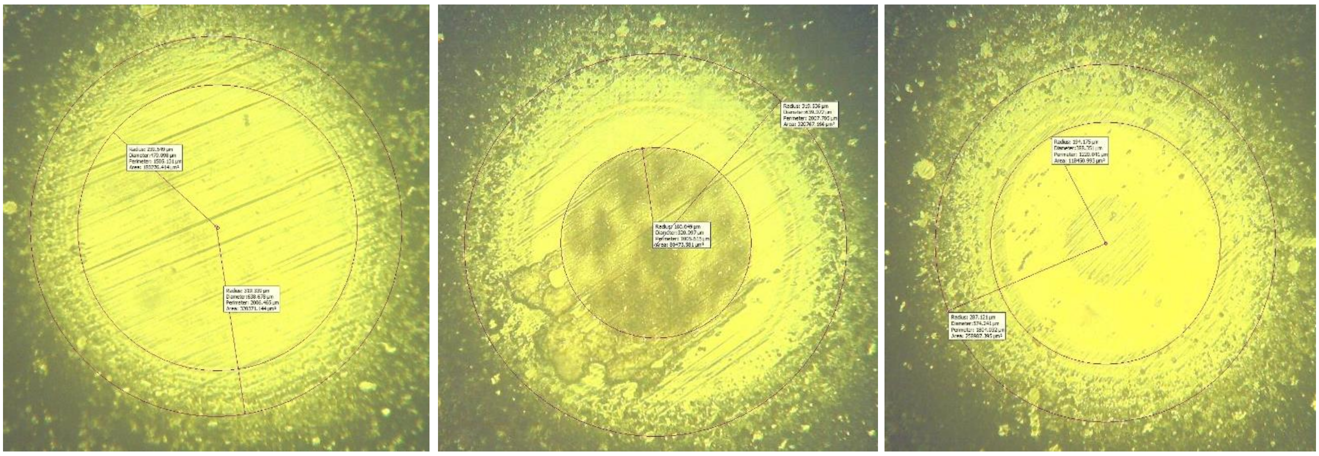
In the current investigation, an advance cathodic arc system deposits monolayer, and bilayer coatings on various substrates such as OHNS, HSS, and mirror-polished stainless-steel (SS 304) coupons and silicon wafer substrate. Much of this research concentrates on the use of advanced cathodic arc deposition for improving the performance of industrial tooling and cutting or milling operations. The thin films deposits use reactive advanced cathodic arc evaporation process. In these cases, low-pressure reactive gas, such as Argon (99.99%), Nitrogen (99.99%) or Acetylene (98.99%), usually introduce itself between the cathode and substrate into the system to deposit nitrides and carbides coatings. Prior to deposition the samples were polished and ultrasonically cleaned by organic solvents. They were mounted to a rotatable holder, to permit a homogeneous coating. The reaction takes place at the cathode target and the surface of the substrate to form of metal nitrides or carbides coatings.

Coating properties were characterized by a variety of methods, coating thickness was measured using Ball crater, Coating Wear Measurement was done by Calotest, Roughness Measurements by Mitutoyo profilometer Roughness tester, Mercedes test using Rockwell C Hardness instrument, and corrosion resistance measurement by potentiostat.

III. RESULTS AND DISCUSSION

The mechanical and tribological properties of coating materials affects the effective transitioning taking place with the tool substrate. Gauging the suitability for each type of substrate material accurately makes the perfectly coated tool for complete applicability and sustainability. For example, with regard to the tribological and mechanical properties and in a bid to enhance these properties, an adhesion layer of TiN or CrN, followed by a TiC transition layer can work wonders as a top-coat. This understanding stems from a close study of the low friction coefficient and wear loss properties of the TiN/TiC coatings. This bilayer coating also produced an elevated level of toughness and microhardness, making it possible to achieve the tenacity required for the substrate to work as intended. This would mean that the gradual build-up and layering of these surface coatings give the stiffness that avoids the accumulation of sharp and intense interfaced and gives a good chemical continuity on the surface, exercising the optimum load support for the top layer of the coat. In the case of the TiN/TiC coating on a substrate material, the presence of equiaxed grain shapes, grain boundaries having high angles, and the prevalent low surface energy facilitates the sliding of the grain boundary. Clubbing all these properties onto a materials coating effectively prevents any dislocation of the layers or the presence of movement across the interface where the TiC and TiN layers meet.

In the present study, Coating thickness is measured using Ball crater which shows 2.18 µm, 3.60 µm and 3.97 µm for TiC, CrN+TiC & TiN+TiC coatings respectively [Fig.1]. Calo-wear test has been carried out to evaluate Wear coefficient of the TiC, CrN+TiC & TiN+TiC coating was 5.83 X 10^{-14} m^2/N, 5.17 X 10^{-14} m^2/N and 4.09 X 10^{-14} m^2/N respectively.



(a) TiC (b) CrN+TiC (c) TiN+TiC

FIGURE 1. Ball crater images using Calotest for (a) TiC, (b) CrN+TiC and (c) TiN+TiC

The potentiodynamic polarization scans were utilized to compare the corrosion rate of these coatings based on the quantitative measurements achieved. In the potentiodynamic polarization graph, the values obtained from the corrosion potential (Ecorr) revealed the susceptibility of a material to corrosion. The corrosion current density value (Icorr) determined the corrosion of the material from a kinetic viewpoint. The value Ecorr is the potential at which the anodic current density is equal to the cathodic current density. One Molar HCl solution is used to calculate corrosion resistance & it is measured using potentiostat instrument of TiC, CrN+TiC & TiN+TiC coating was 5.123 X 10^{-1} mm/yr, 8.560 X 10^{-2} mm/yr and 5.608 X 10^{-2} mm/yr respectively [Fig.2].On the other hand, the corrosion rate of substrate SS304 measured as 7.371 x 10^{-1} mm/yr.

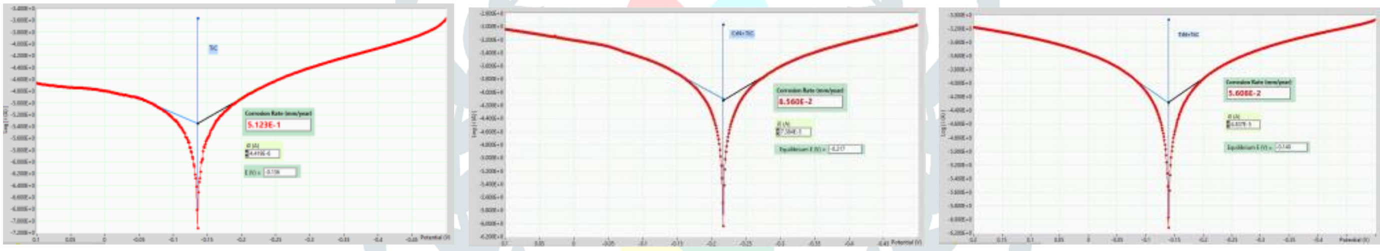
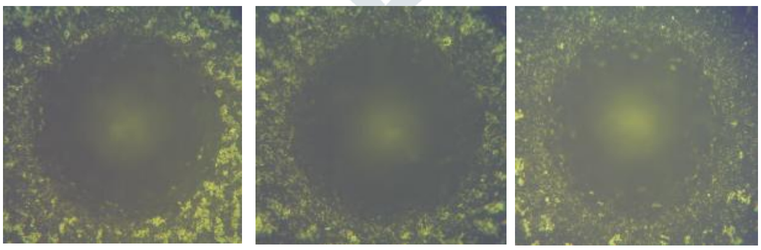


FIGURE 2. Corrosion resistance by potentiostat of (a) TiC, (b) CrN+TiC and (c) TiN+TiC

Mercedes test using Rockwell Hardness C instrument with the load of 150N shows no coating peel-off in either coating systems indicates good adhesion between the base and coating[Fig.3]. The deposition with good adhesion is highly important as it improves the tribological properties of the surface coating and promotes strong bonding between the substrate and the coating. Sufficient adhesion must be developed between the coating and tool for controlling deformation of the edges, as soft or malleable films may not withstand the force of piercing during indentation. Therefore, the adhesion test of the deposited thin film stands as a crucial element in studying tribological properties of the coating.



(a) TiC (b) CrN+TiC (c) TiN+TiC

FIGURE 3. Rockwell C indentation of (a) TiC, (b) CrN+TiC and (c) TiN+TiC

Coating surface roughness was measured by Mitutoyo profilometer for TiC, CrN+TiC & TiN+TiC coating was having average roughness (Ra) of 0.455 µm, 0.564 µm and 0.643 µm respectively[Fig.4].

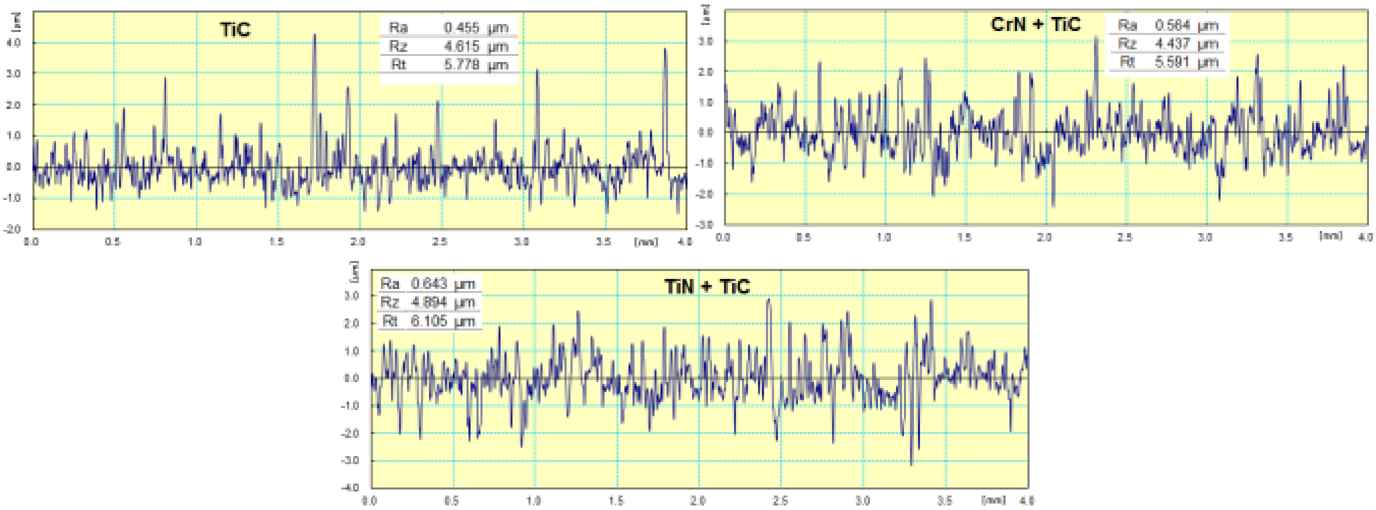


FIGURE 4. Surface roughness by Mitutoya profilometer of (a) TiC, (b) CrN+TiC and (c) TiN+TiC

To fulfil industrial demands, hard and wear resistant thin lubricative coatings have been deposited on industrial tools. lubricative Coating is applied on smallest fasteners, pastes and greases to massive industrial components that require reduce friction. These coatings are particularly suitable for applications involving extremely high or low temperatures, in contact with aggressive media, subject to UV or x-rays and vacuum applications.

IV. CONCLUSION

The aim of this research as well, and efforts are focused on developing and understanding highly engineered surfaces by changing the surface properties of a the components and thus improve its function without compromising its bulk properties. Solid lubricant architectures involves the production of coatings which significantly enhance adhesion, and thus improves their wear properties. This consideration will ensure the sustenance of high its high levels of strength even at elevated temperatures and in a corrosive gas environment. It will further ensure excellent toughness and resistance to cracking and delamination, reduced wear mechanisms—including abrasive wear—which occur at the tool surface during machining, and improved friction. This coating will self-lubricate during the tool's functions by forming oxides at appropriate temperatures, which facilitates the cutting edge of the workpiece in dry conditions

Finally, in conclusion,Extensive characterization of these coatings showed improved corrosion resistance as well as wear resistance compared to steel by nearly one order of magnitude. Present study showed duplex coating system consisting of TiN/CrN and TiC thin film have superior tribological properties, as compared to TiC alone. TiN+TiC Bilayer films has low wear resistance then others. We conclude that the TiN+TiC Bilayer coatings has of high surface roughness and good adhesion then TiC & CrN+TiC. Though this roughness appears to be very high when used in working conditions roughness will reduced and results in low friction coefficient.

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