Analysis And Tribological Behaviour of Tin-Cr Based Hard Coating Material's and Experimental Study

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Abstract— The progress in cutting tool materials, coating techniques, and machine tools has satisfied the way for machining of materials higher cutting speeds, higher feed rates or in hardened state. The requirement of tool has to be ductile to prevent fracture and hard to decrease tool wear.[1] TiAlN has been one of the most significantly investigated hard coatings in real life applications. A new tri-nitride AlCrN with high percentage of aluminum and superior properties has become increasing interest. As per the research, Compared to the TiAlN coating, the AlCrN coating presented better characteristics against the anti-oxidation, and removing debris from the contact interface. It was found that the AlCrN coating with good wear resistance probably has a most possible tribological applications than the TiAlN coating under the condition of sliding wear. [2].

Key words: EDM, PVD, CVD

I. Introduction

Machining has become main shaping process used in manufacturing of engineering components throughout history. In any manufacturing technology, there is a most requirement for the tools durability. Operate smoothly, and ensure the requested quality of the product. Thus cutting tools are important in any manufacturing operation. Due to high comparators, manufacturers are required to increase tool life, productivity, product quality, and to decrease lubricant consumption. These goals can be achieved by modified its tool geometry, machining parameters, or tool material improvements. It has quite strong limitations. Namely, the tool has to be ductile to prevent fracture and hard to decrease tool wear. However, high ductility and high hardness are basically conflicting demands – a material is either hard and with poor ductility, or vice versa. A solution of this problem is to protect the tool made of ductile material with hard coating. The former ensures resistance to fracture, while hard coating protects the cutting edge against abrasive and mild adhesive wear. Hard coating also reduces the tool temperature by reducing the friction between chip and rake face of a tool. Additionally a relatively low chemical reactivity of coating with workpiece materials ensures protection against welding and thus reduces the adhesive wear. The result of all these effects is that coated tool can operate at higher cutting speed and higher feed rate. Thus hard coating expands the safe zone of cutting tools by minimizing the buildup edge formation and crater wear. Hard protective coatings with high hardness, good resistance to wear, and oxidation, are principally transition-metal nitrides with a coating thickness of a few micrometers. Hard protective coatings, deposited by physical vapor deposition (PVD) and chemical vapor deposition (CVD).[1] The progress in cutting tool materials, coating techniques, and machine tools has efficient the way for machining of materials at higher cutting speeds, higher feed rates or in hardened state. Hard machining operations have capacity to be an alternative to grinding and electrical discharge method (EDM) due to their high productivity and flexibility and low environmental waste formation. It is essential that a workpiece material has good machinability.[1,6] A workpiece material with high machinability would be described by its low cutting forces, high material removal rate, good surface integrity, precise workpiece dimensions, and low tool wear rate. Hard coatings enhance improvement of these characteristics of machinability. A method to improve machinability of hard to cut materials is surface coatings deposited on the cutting tool. An effective technique is hard physical vapor deposited (PVD) coatings. Nowadays, the TiAlN family of PVD coatings are popular for hard to cut materials. Hard PVD coatings for machining of aerospace materials should address the following issues: resistance to heavy load/high temperature operating conditions, resistance to chemical (diffusion wear) and reduction of attrition wear intensity. The aluminum-rich TiAlN PVD coatings show improved tool life under conditions of machining of aerospace alloys. The aluminum-rich hard TiAlN coatings have a number of beneficial characteristics. Firstly, they have a favorable combination of hardness and oxidation stability at elevated temperatures. Furthermore, these coatings have improved plas- ticity and fatigue fracture resistance. Thus during plastic deformation the coating has the ability to dissipate energy during friction. As a result, less energy is present to cause crack initiation and the probability of surface damage is reduced. This is very beneficial for reduction of attrition wear intensity. These coatings also typically have low thermal conductivity, which protects the tool surface from heat transfer.[6] In the past years, TiAlN coatings obtained by physical vapor deposition (PVD) techniques were widely applied to improve the lifetime and performance of a wide variety of tool materials for their attractive properties such as high hardness, good wear and chemical stability. Recently, a new ternary nitride AlCrN with higher percentage of aluminum has become the subject of ever-increasing interest coating for their excellent properties particularly under the high temperature condition.[2]

II. Experimental

As per the previous research on tribological behaviors of TiN–, CrN– and MoN–Cu nanocomposite coatings the following experiments was performed, The Me–N–Cu (Me: Ti, Mo, Cr) films were produced by a hybrid cathodic arc+magnetron sputtering physical vapor deposition technique. The schematic diagram of the specific system used during deposition is shown in Fig. 1. Me component of the hard coatings were evaporated by a cathodic arc source while Cu is sputtered from a d.c. magnetron source. The reactive gas (i.e., pure nitrogen (99.999%)) was introduced into the system using a flowmeter at flow rates sufficient to result in nearly stoichiometric TiN, MoN, and CrN phases. Hardened high-speed steel (HSS) was used as a substrate material and polished to a surface roughness of Rap0.09 mm. After the polishing process, samples were ultrasonically cleaned in a series of hot alkaline cleaning baths for 5 min, then soaked in trichloroethylene and dried.[3]

A. Wear tests

The tribological properties of hard coatings were evaluated in a pin on disk tribotester and a reciprocating wear test machine (Plint & Partners, Model TE70). The unidirectional tests (ball on disc tests) were performed under a normal load of 5N and a sliding velocity 0.2 m/s in open air of 4573% relative humidity. The counter face material was 10mm diameter alumina balls.

B. Micro-Hardness Measurements

Hardness measurements were carried out with an ultra-micro-hardness tester (Fischercope) 20mN load was applied in steps of 0.2mN so that the Vickers pyramid indenter penetrates to the one tenth of coating thickness. [3]

C. PVD Coating

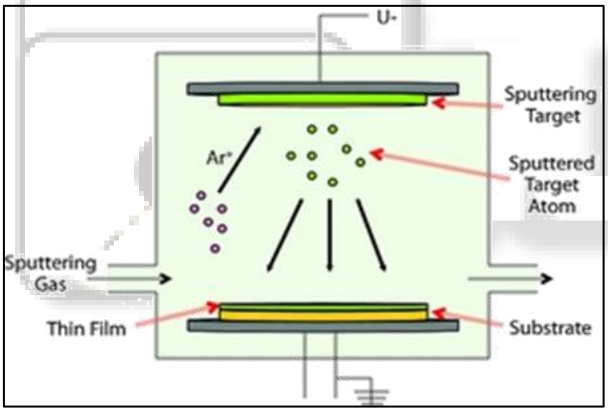

Fig. 1: Schematics of the PVD

As per above experiment conducted for checking the tribological behavior of the coating material results are follows

D. Properties of the Coatings

EDS analyses indicated that the hard coatings produced on HSS substrates contained 5.5–14.0 at% copper depending on coating process parameters. The thickness of the coatings (as determined by a calotest method and further verified by cross section SEM investigations) varied between 1.8 and 3.8 mm. The hardness of the TiN and CrN coatings decreased slightly with the addition of the copper, but such a decrease was not observed for the MoN coatings perhaps due to somewhat lower copper content of these coatings compared to CrN and TiN. A gradual decrease in hardness is generally observed in the MeN–X type nanocomposite coatings with the increase of copper contents over 2–3 at%. However, it is reported in the literature that hardness decrease was not observed when a high bias voltage was applied during the coating process. For the coatings used in this study, the application of a high bias voltage (_100 to _150 V) during the production might be the explanation for retaining of the hardness of the coatings with copper contents well above 2–3%[3]The test is conducted for the checking tribological behaviours of AlCrN and TiAlN coatings—Deposited by physical vapor deposition,

E. Specimens Preparation

Cemented carbide with microhardness of HV50g 1350 was used as the substrate material. The flat specimens were machined to the size of 10mm×10mm×20mm for reciprocating sliding test, and Ø 25mm×3mm discs for ball-on-disc test. Prior to the coating deposition, the specimens were polished to a surface roughness of approximately 0.04_m. Two types of the commercially available coatings (AlCrN and TiAlN), deposited using a commercial arc PVD equipment and provided by Zigong Cemented Carbide (Chengdu tool department) Corp.,Ltd., were investigated in this paper. Customized Al70Cr30 and Al67Ti33 targets in a reactive nitrogen atmosphere were used to obtain stoichiometric AlCrN and TiAlN coatings. Both of these coatings are monolayered with a cubic structure. The thickness of the AlCrN and TiAlN coatings were around 1±0.2 and 2±0.1_m, corresponding to the deposition time of 90 and 150 min, respectively. The temperature of the specimens during deposition was held at approximately 500 ◦C for the AlCrN coating, and at 600 ◦C for the TiAlN coating. For both coatings, the DC-substrate bias voltage was in the range of −50 to −150V.[2]

III. TRIBOLOGICAL TESTS

The CETR UMT-2 micro-tribometer was a singlemeasuring system with multi-motion tribo-metrology. The rotational motion (ball-on-disc), reciprocating motion and horizontal rotation motion were able to achieve on this system. The upper specimens can be motorized by a vertical positioning system with a position encoder and a lateral positioning system with another position encoder. On this microtribometer, an actual dynamic friction force was truly able to obtain as function of the testing time by its servo-controlled normal load. The tribological properties of two types of sliding wear (reciprocating sliding and ball-on-disc) for the two coatings were evaluated on the UMT-2 test system under the temperature of 20–25 ◦C, the relative humidity of 50–60% and an unlubricated ambient atmospheric condition. Si3N4 balls with diameter of 4mm and hardness of HV50g1600 were chosen as the spherical specimens to avoid additional chemical reactions. For the reciprocating sliding tests, the experimental parameters were as follows: the normal load of 5N, the sliding displacement amplitude of 2mmat the constant speed of 8 mm/s and the total testing time of 30 min. The same normal load was used for the pin-on disc tests. The other testing parameters of the ball-on-disc tests were as follows: the rotational speed of 318 rpm (10 m/min), the wear track nominal diameter of 10mm and the total testing time of 30 min.[2]

IV. RESULTS AND DISCUSSION

A. Coefficients of Friction

In the reciprocating sliding tests, the COF of the AlCrN coating was lower than that of the TiAlN coating, It took about 60 cycles for the COF of the TiAlN coating to reach its peak value of approximately 0.7, while over 2000 cycles for the COF of the AlCrN coating to reach a lower peak value of about 0.55. The AlCrN coating presented a better antiwear properties with lower COF value than that of the TiAlN coating. The COF of the TiAlN coating reached the steady stage within much less cycles due to the rapid increase of the wear rate. Moreover, it decreased and fluctuated during the steady wear stage, which was attributed to an accumulation of wear products (debris) in the contact zone. The debris behaviours and degradation of the two coatings would be discussed in the following sections in detail. The COF of the AlCrN coating was lower than that of the TiAlN coating throughout the whole ball-on-disc tests. After an initial stage of about 5m in sliding distance, the COF of the AlCrN and TiAlN coatings reached its stable values of approximately 0.75 and 0.85, respectively, Both the COF of two coatings presented a descended tendency probably due to the tribo-chemical reaction and debris behaviours. The COF of the TiAlN coating presented more unstable than that of the AlCrN coating due to the different debris behaviours and tribo-chemical properties.[2]

B. Wear Rate

The coatings after reciprocating sliding and ball-on-disc wear tests, respectively. It can be observed that the wear scars of the AlCrN coating were shallower and smoother than those of the TiAlN coating. The wear rate (mm3/N m) of the coatings against sliding distances was calculated by the formulae used in literatures. The results shown indicated that the wear rate of the TiAlN coating was about twice over that of the AlCrN coating in the two sliding modes. A good consistency exhibited confirmed that the AlCrN coating presented a better wear resistance than the TiAlN coating in both types of the wear tests. Similar results were reported for their wear performances in cutting tests.[2,3]

Specific wear rates values were obtained according to

$$k = \frac{V}{w * L}$$

where k is the specific wear rate [m3/Nm], V is thewearvolume [m3], W is the normal load [N] and L is the sliding distance [m]. [6,7]

C. Pin-on Disc Wear Tests

The results of tribological tests have further confirmed that the friction and wear coefficients of un-doped coatings were rather high for TiN but somewhat lower for both CrN and MoN. In other studies too researchers have often reported very high friction for TiN and relatively low friction for CrN and MoN coatings. The exact mechanisms that control friction and wear behavior of these coatings are not well-understood, but certain investigators have attributed high friction of TiN to the formation of TiOx while the relatively low friction of CrN and MoN was also attributed to the oxygen-rich tribofilms forming on their sliding surfaces. Apparently, compared to TiOx, the oxides of Mo and Cr have lower shear strength and hence capable of providing lower friction, especially at elevated temperatures Certain TiOx films (especially the ones with Magnelli type phases) are also known to possess easy shear character and hence low friction However, based on our limited surface analytical and structural work in this study, we could not verify the presence and/or absence of such phases within the tribofilms.[2,3]

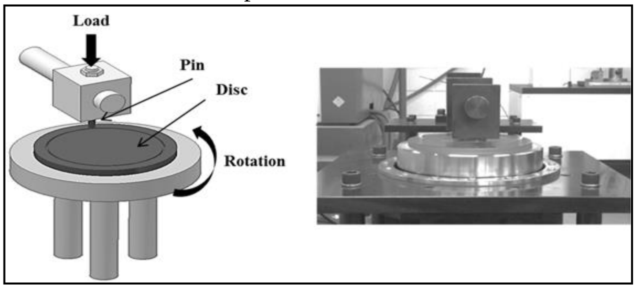

Fig. 2: Schematic of the test system Pin-on disc

V. TRIBOLOGICAL BEHAVIOUR OF PVD HARD COATINGS

It is well known that binary nitride coatings such as TiN and CrN deposited on various tools and machine parts by physical vapor deposition technique can significantly improve the perfor- mance and lifetime of these products [1]. However, nowadays binary hard coatings are unable to meet the increased require- ment from the developing industry, and alloying with another metal to form multi-component coatings has been explored to further improve the general performance of the PVD hard coatings. It has been well established that TiN alloying with aluminum would show significant increase in hardness, wear resistance and high temperature oxidation resistance, and the oxidation rate of Ti–Al–N coatings decrease with increasing

As per the literature, the following results are obtained by performing experiment, by using different types of coating materials.

Copper content, thickness, hardness and surface roughness of the coatings[3]

Coating	Cu (at%)	Cu (wt%)	Thickness (μm)	Hardness (Gpa)	Surface roughness R_a (μm)
MoN	—	—	2.5	37±0.6	0.19±0.05
MoN–Cu	5.5	3.7	2.4	42±0.7	0.18±0.09
TiN	—	—	2.5	32±0.6	0.23±0.02
TiN–Cu	12.8	16.3	1.8	30±0.6	0.18±0.09
CrN	—	—	3	28±0.5	0.14±0.08
CrN–Cu	11.2	13.3	3.8	27±0.5	0.16±0.09

As per the literature, The mechanical characterization results for the AlCrN and TiAlN coatings[2]

Coating	Surface roughness (R_a) (μm)	Microhardness (HV_{50g})	Nanohardness (GPa)	Elastic modulus (E) (GPa)	Critical load (L_c) (N)
AlCrN	0.12 ± 0.01	3106 ± 48	32.48 ± 6.51	568.42 ± 68.12	1.208 ± 0.103
TiAlN	0.14 ± 0.02	3331 ± 70	35.72 ± 9.84	460.35 ± 80.33	1.847 ± 0.026

These above result found by performing experiment with different coating methods from the previous research and literature aluminum content. As the addition of aluminum improves the oxidation and wear resistance of TiN coatings, the replace- ment of chromium atoms by aluminum atoms significantly increases the oxidation and wear resistance of the coatings. It is documented that oxidation resistance of CrN coatings is superior to that of TiN coatings.[4] Hard coatings are thin films which are deposited on too substrates in order to improve their desired properties such as hardness, friction, wear resistance, and corrosion resistance, while not changing properties of the bulk material.14 From a functional point of view the most important coating properties are hot hardness, good adhesion to the substrate, and chemical stability. The coating performance can be further improved by optimum coating thickness, fine microstructure, and compressive residual stresses. These properties can essentially be fulfilled only by ceramic materials. In practice, the choice is limited to transition metal nitrides and partly carbides and oxides. Such materials can be reliably deposited in a thin film form by CVD or PVD techniques. In contrast to the CVD methods, the starting material for PVD process is a solid (e.g., titanium), while the volatile elements are usually added as a gas (e.g., nitrogen). The PVD hard coatings have a certain advantages: low deposition temperature preserves cemented carbide toughness, they can be applied to sharp cutting edges, compressive residual stress inhibits microcracks, they have finer grains (smoother surface), higher microhardness, nonequilibrium compositions which are not possible with CVD, their deposition is environmentally clean process.[1,7]

A. *Deposition of Hard Coatings*

Coatings are deposited by three types of processes which compose of gaseous state, solution state, molten, or semimolten state processes. Two important characteristic parameters for the coating processes are the thickness of the coatings that can be achieved (from 0.1 mm to 10 mm) and the deposition temperature (from room temperature up to 1000 1C). Two basic deposition processes used in application of hard coatings on cutting tools are CVD and PVD. CVD process is a chemical process which is based on introduction of the material to be deposited in gaseous state into a reaction chamber and then condensation of these gases on to the substrate to form a coating at deposition temperatures in the range of 800–1200 1C. Identification of the wear patterns can be very useful in understanding the wear process. This increases the probability of finding efficient technological solutions. Fig. 1 presents typical wear patterns of the coated cutting tools during machining of Ni-based superalloys (wear patterns during machining of Ti-based alloys are similar [7]). Fig. 1a shows wear patterns under turning conditions and Fig. 1b presents wear patterns under end milling conditions.[1,6]

VI. CONCLUSION

As per the literature survey of performance various experiments here we conclude that, The CrN, AlCrN and AlTiN coatings were deposited by the multi-arc ion plating technique and mechanical properties were studied. Both the CrN and AlCrN coatings experienced appreciable tribological oxidation during the wear tests. The AlCrN coating formed by CrN alloying with aluminum would show significantly improve- ment in high temperature oxidation resistance but not necessarily in wear resistance under the condition of ambient temperature.[7] Compared to the TiAlN coating, the AlCrN coating presented better characteristics of anti-oxidation, anti-spalling and removing debris from the contact interface.[2] Doping TiN, CrN, and MoN with Cu significantly altered the structural morphology of these films. Mechanically, the microhardness values of the coatings other than MoN were slightly reduced by Cu doping. Friction and wear of base TiN, CrN, and MoN were affected significantly by the presence of Cu in the microstructure.[3] The study of the relationship between the tool life of a coated tool and the cutting speed showed that a tool with a thicker coating (13.0 µm) tends to drastically reduce its tool life with an increase in cutting speed. Meanwhile, a tool with a smaller thickness of wear-resistant layer (2.0–6.0 µm) showed a significantly smaller decrease in wear resistance with an increase in cutting speed.[5]

REFERENCES

[1] H Caliskan, Bartin University, Bartin, Turkey , P Panjan, Jožef Stefan Institute, Ljubljana, Slovenia, C Kurbanoglu, Istanbul Medeniyet University, Istanbul, Turkey "Hard Coatings on Cutting Tools and Surface Finish"

[2] J.L. Moa, M.H. Zhua,∗, B. Leia,b, Y.X. Lenga, N. Huanga , "Comparison of tribological behaviours of AlCrN and TiAlN coatings—Deposited by physical vapor deposition" A Key Laboratory of Advanced Technologies of Materials, Ministry of Education, Tribology Research Institute, Southwest Jiaotong University, Chengdu 610031, China

[3] O¨ ztu¨ rka, K.V. Ezirmika, K. Kazmanlıa, M. U¨ rgena,_, O.L. Eryılmazb, A. Erdemirb "Comparative tribological behaviors of TiN–, CrN– and MoN–Cu nanocomposite coatings"

[4] J.L. Mo,M.H.Zhu _ Tribology Research Institute, Traction Power State Key Laboratory, Southwest Jiaotong University, Chengdu 610031,China. "Tribological oxidation behavior of PVD hard coatings."

[5] Alexey Vereschakaa*, Sergey Grigorieva, Nikolay Sitnikovb, Gaik Oganyana and Catherine Sotova. "Influence of thickness of multilayer composite nano-structured coating Ti-TiN-(Ti,Al,Cr)N on tool life of metal-cutting tool".

[6] Biksa a, K.Yamamoto b, G.Dosbaeva a, S.C.Veldhuis a, G.S.Fox-Rabinovich a, A.Elfizy c, T.Wagga, L.S. Shuster d "Wear behavior of adaptive nano-multilayered AlTiN/MexN PVD coatings during machining of aerospace alloys."

[7] M.Y.P. Costa n, M.O.H.Cioffi, H.J.C.Voorwald, V.A.Guimaraes "An investigation on sliding wear behavior of PVD coatings."

