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STUDIES ON THIN FILM COATINGS DEPOSITION USING CATHODIC ARC PROCESS

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Abstract: *Recent advances in cutting tool materials and Cathodic Arc PVD surface coatings are making high-speed and high feed turning an increasingly viable machining operation in commercial manufacturing sectors. In this investigation, the performance of TiN, TiAlN and TiN+AlCrN coatings were assessed on TNMG160404 Carbide turning inserts used to machine an AISI 304 Steel. As part of the study, the experimental method was used to characterise the performance of turning inserts by measuring the progression of major flank wear. It showed that a single layer TiN coating failed to outperform TiAlN and TiN+AlCrN coated inserts when turning AISI 304 steel under aggressive machining conditions. In the case of TiAlN and TiN+AlCrN coated turning inserts, an improvement in the tribological interaction between the coatings and the AISI 304 steel workpiece and also increased oxidation resistance resulted in a significant reduction in material transfer at the cutting edge. The above results are discussed in terms of the major flank wear.*

Keywords*: PVD; Cathodic arc evaporation; TiAlN; TiN+AlCrN; Turning; Wear*

I. INTRODUCTION

Coated tools constitute the majority of the tools applied in material removal processes. Coated tools have compound material structure, consisting of the substrate covered with a hard, anti-friction, chemically inert and thermally isolating layer, approximately one to few micrometers thick. There are mainly two type coating deposition techniques Chemical Vapour Deposition (CVD) and Physical Vapour Deposition (PVD).

Tool failure is said to occur when the tool no longer performs the desired function where as total failure (ultimate failure) is defined as the complete removal of the cutting edge, a condition obtaining when catastrophic failure occurs [1]. Therefore, in machining operations, tools are considered to be worn out and are changed long before total failures to avoid incurring high costs associated with such catastrophic failures. [2] Some of the tool life rejection criteria presented in ISO 3685 are listed below

1. Average flank wear $\geq$ 0.4 mm
2. Maximum flank wear $\geq$ 0.6 mm
3. Notching $\geq$ 1.0 mm
4. Nose wear $\geq$ 0.5 mm
5. Surface roughness (Ra) $\geq$ 6.0 µm[3]

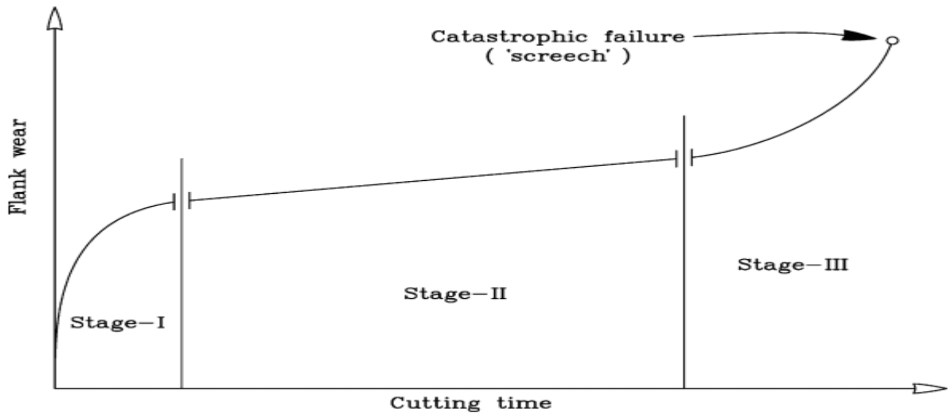


Fig. 1: A schematic diagram of a three-stage wear model [4-6]

II. EXPERIMENTAL PROCEDURE

2.1 Coating Deposition

Coating is carried out using Cathodic Arc Process. Cathodic arc deposition or Arc-PVD is a physical vapour deposition technique in which an electric arc is used to vaporize material from a cathode target. In this process, an arc with a diameter of just a few microns is run over the solid metallic coating material, causing it to evaporate. Because of the high currents and power densities used, the evaporated material is almost totally ionised and forms high-energy plasma. A reactive gas will be supplied through nozzle which will react with the substrate and coating is deposited on the material. The coating is carried out on TNMG160404 carbide inserts using three different types of material by cathodic Arc Process.1) Titanium Nitride (TiN) coating 2) Titanium Aluminium Nitride (TiAlN) coating 3) TiN coating first layer and Aluminium Chromium Nitride (AlCrN) on the outer layer

2.2 *Evaluation of coating characteristics*

The evaluation of coating characteristics is performed through following tests 1)Surface Roughness 2) Microhardness Test 3) Semi Electron Microscope(SEM) and Elemental Dispersive X-ray Spectroscopy (EDS) analysis.

Surface Roughness: Arithmetic average roughness, Ra test was used to determine the roughness of each coatings. Ra is calculated as the integral of the absolute value of roughness profile height over the evaluation length, or the area between the roughness profile and its mean line. The Ra value for TiN is 0.5206 micro meter for TiAlN 0.2702 micro meter and for TiN+AlCrN is 0.5618 micro meter.

Micro Hardness Test: Micro hardness test was conducted to determine the hardness of each coating at HV0.05 scale. The hardness value for TiN is 2400, for TiAlN is 3200 and for TiN+AlCrN coating is 3300

SEM and EDS Analysis: EDS analysis was carried out to determine the elemental composition of coating and SEM analysis was carried out to study the surface morphology of the coating.

Major element	TiN	TiAlN	TiN+AlCrN
Ti	27.12	29.30	0.47
Al	-------	9.08	27.83
Cr	-------	--------	26.43
N	55.12	48.20	45.26

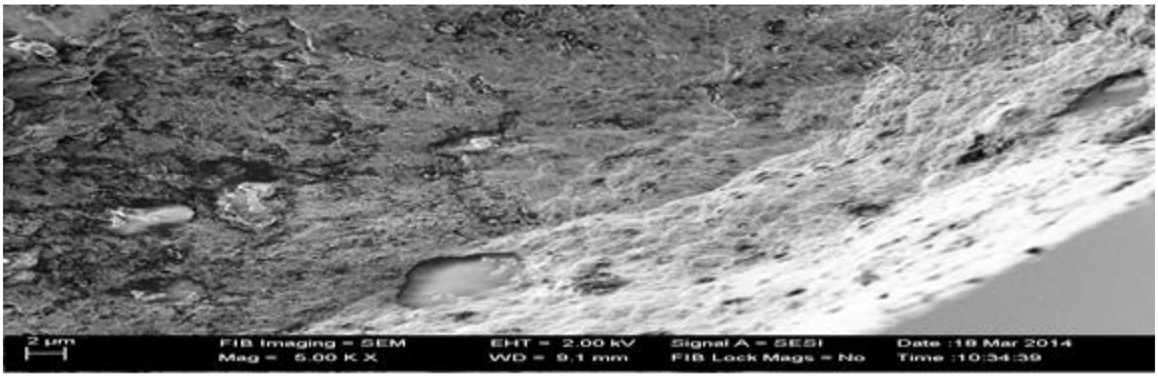


Fig. 2: SEM image of TiN+AlCrN

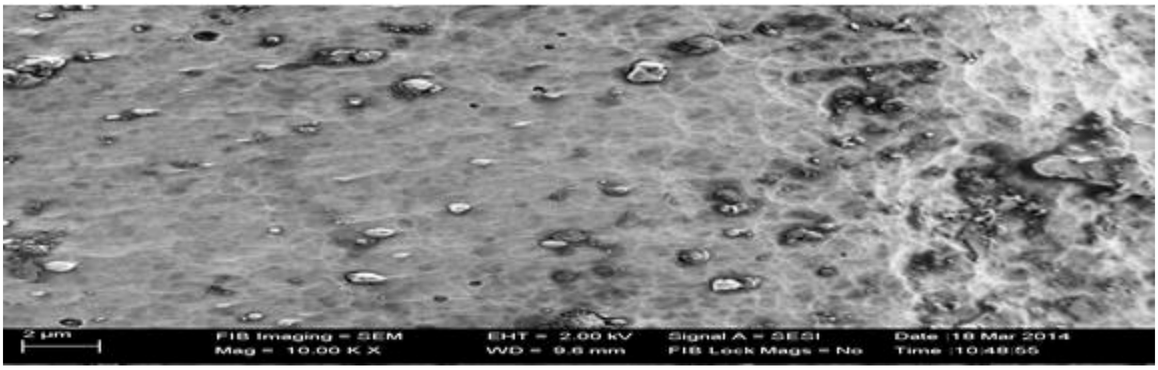


Fig.3: SEM image of TiAlN

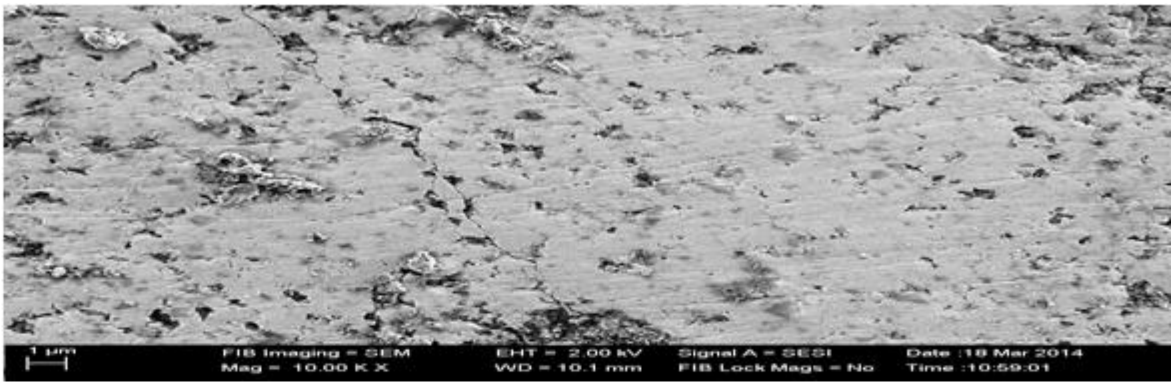
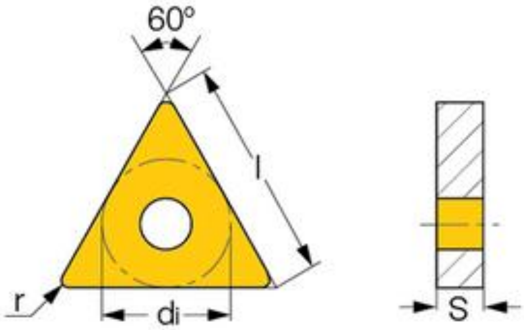


Fig.4: SEM image of TiN

2.3. Cutting tool testing

Machining is performed using CNC lathe. In this study standard carbide inserts of TNMG160404 are taken. The TNMG 160404 is a double sided 60° Triangular insert, with a 16mm cutting edge length and is approximately 4mm in thickness. The corner radius (04) is the most commonly used due to its versatility to provide a balance of both strength and excellent finish



The specifications of workpiece are according to ISO3685 standards.The feed, speed and depth of cut was kept constant for all the three inserts. The performance of turning inserts was characterised by measuring the progression of flank wear lands using Vision Measuring Machine(VMM) and optical microscope.

III. RESULTS AND DISCUSSION

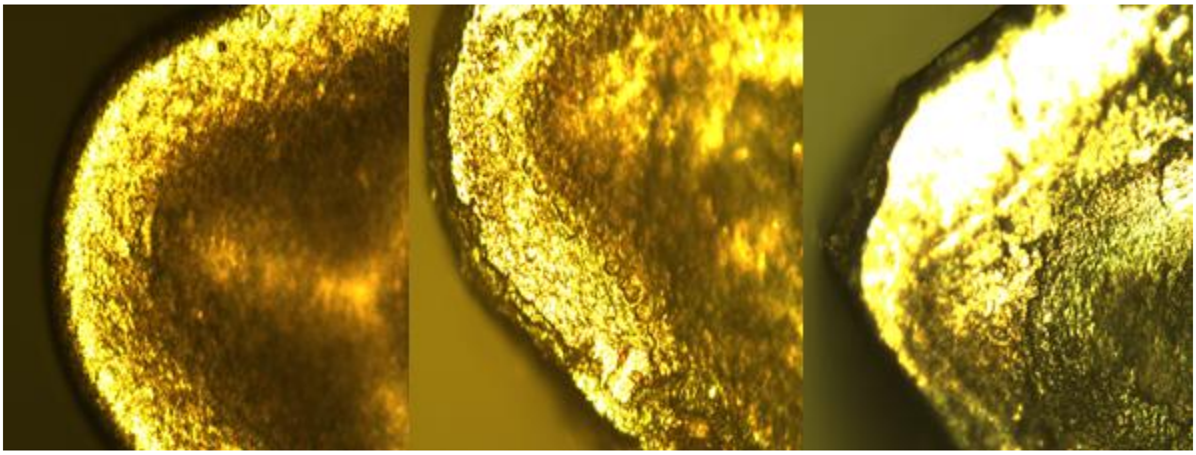
3.1. Coating characterisation

From SEM images of TiN it is observed that there are hair line cracks present on the surface and other area appears to be smooth. The coating does not propagate these cracks during the machining operations this effect is known as gargling effect [5]. From the SEM images of TiAlN it has been observed that there are some amount of particles like structure present on the surface. It is because of presence of aluminium with titanium which forms the uneven surface and this increases the hardness of coating and the oxidation resistance of the coating will also be increased. SEM images of TiN+AlCrN show that the coating is lesser even/smooth surface compared to TiN and TiAlN. It is because of presence of AlCrN as the outer layer of the coating. The chromium is one of the hard material which reacts with aluminium in the presence of nitrogen atmosphere which results in uneven surface and the presence on TiN also adds to it.

3.2 Turning inserts performance and wear

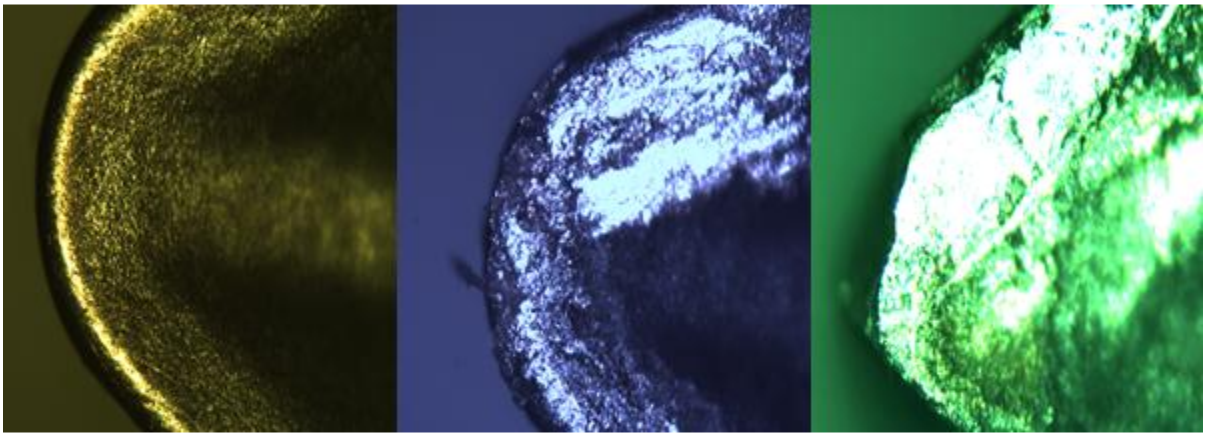
The performance of PVD coated turning inserts and the pattern of major flank wear was examined using optical microscope and tool pre-setting machine. The wear patterns observed are shown in Figs5-7. After every four cuts the performance of the turning inserts and the wear pattern were evaluated. All PVD coated turning inserts showed negligible material transfer after the first four cuts. In the case of the TiN coated turning inserts, the resistance to transfer of workpiece material after the first twelve cuts very quickly diminished such that after twenty cuts there was significant material transfer on the major flank. This rapid onset of material transfer led to complete cutting edge wear which in turn resulted in catastrophic failure. In contrast, the TiAlN and TiN+ AlCrN coated turning inserts after 20 cuts showed only a slight increase in the size of the major wear lands and negligible material transfer of workpiece.

A more accurate representation of the wear of these coated turning inserts in the intermediate Stage II wear region is established after a tool life of 40 cuts as shown in Figs7-8. The size of the outer corner wear land has increased in addition to an increase in the extent of workpiece material transfer on the cutting edge. The wear land and material transfer continued to increase at a constant rate throughout Stage II until the entire cutting edge was covered in material transfer. At this point, the rate of wear increased rapidly as the wear mode switched to Stage III prior to catastrophic failure. The onset of Stage III wear at the outer corner corresponded to the loss of a cutting edge in all cases.



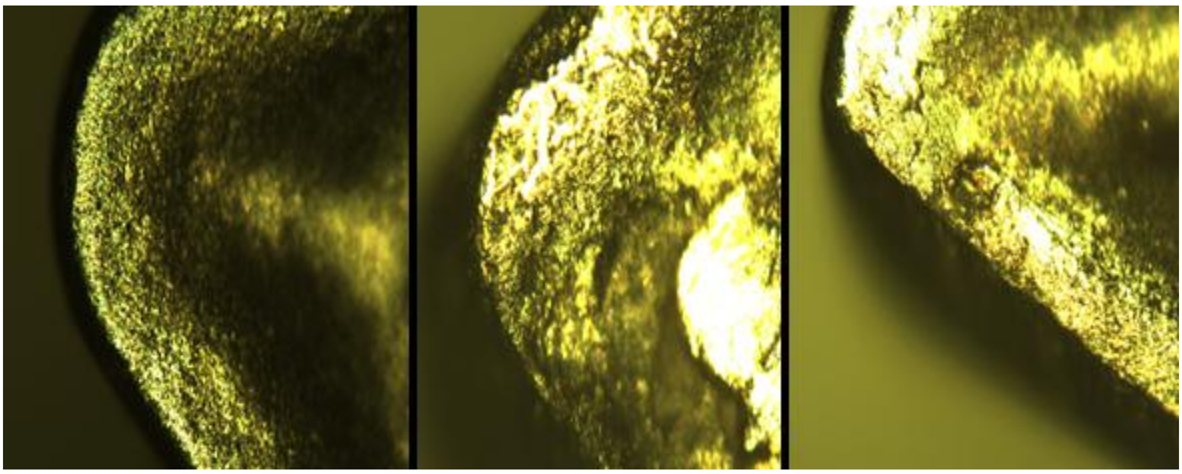
(a) (b) (c)

Fig. 5 Optical microscope images of flank wear lands of TiN coated carbide turning inserts (a) Stage I wear mode (after 4 cuts), (b) Stage II wear mode (after 12 cuts) and (c) Stage III wear mode(after 26cuts)



(a) (b) (c)

Fig. 6 Optical microscope images of flank wear lands of TiN coated carbide turning inserts (a) Stage I wear mode (after 4 cuts), (b) Stage II wear mode (after 25 cuts) and (c) Stage III wear mode(after36 cuts)



(a) (b) (c)

Fig. 7 Optical microscope images of flank wear lands of TiN coated carbide turning inserts (a) Stage I wear mode (after 4 cuts), (b) Stage II wear mode (after 25cuts) and (c) Stage III wear mode(after 40 cuts).

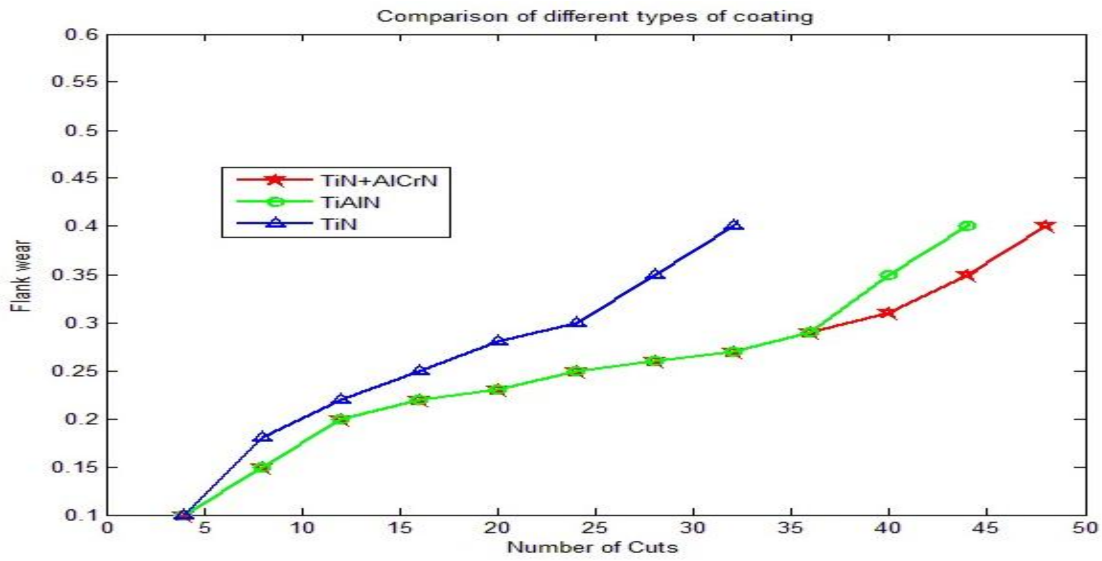


Fig.8: Flank Wear Comparison of all the three coatings

IV. CONCLUSIONS

In the present investigation, the machining performance of different PVD coated turning inserts were compared when turning an AISI 304 steel. The coatings were deposited using a multi-source cathodic arc system and included TiN, TiAlN and AlCrN coatings. As part of the study, measurement of the major flank wear was carried out. The study showed that the TiAlN and AlCrN coated inserts outperformed the TiN coated turning inserts

Notwithstanding the initial resistance to material transfer by TiN coated turning inserts, after a tool life of 20 cuts inserts showed a rapid onset of material transfer over the entire cutting edge. The rapid change in the tribological interaction between the turning inserts and the workpiece is thought to be a result of coating oxidation which resulted from the high temperatures and friction generated at the cutting edge. It is evident from the present results that the material transfer via adhesive wear is the key mechanism which dominated the tool failure.

The high oxidation resistance and improved tribological interaction of the TiAlN and TiN+AlcrN based coatings made these coatings effective at resisting material transfer and improving cutting tool performance under the aggressive machining conditions. The fact that the TiN+AlCrN and TiAlN coated turning inserts outperformed the TiN coated turning inserts was likely due to the improved oxidation resistance of the coating and to the multilayered structure of the TiN+AlCrN coatings.

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