

## INVESTIGATION ON WEAR CHARACTERISTICS OF TUNGSTEN CARBIDE AND TiAlN-COATED TUNGSTEN CARBIDE INSERT IN TURNING CARBON STEEL

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*Cutting tool inserts were subjected to turning of carbon steel at cutting speeds of 120 mm/min, depth of cut of 0.5 mm and feed rate of 0.06 mm/rev. Flank wear was measured using stereo microscope and morphology of worn surfaces was observed using field emission scanning electron microscope after 60 minutes turning of carbon steel workpiece. Machining test results show that the TiAlN coating has improved tool life as compared with uncoated cutting insert due to higher hardness and lower friction coefficient. Microstructural changes on the worn surfaces revealed the failure mechanisms in operation during turning were abrasive, adhesive and thermal.*

**Keywords:** TiAlN-coated insert, turning, wear, SEM, CNC

### INTRODUCTION

Cemented tungsten carbide, WC-Co has superior mechanical properties, leading to their massive use for a variety of machining, cutting, drilling and other applications. WC-Co composed of hard-brittle carbide phase for providing the hardness of the alloys and cobalt act as metal binder. Under high temperature condition, decarburization of the alloy can occur due to thermal decomposition or oxidation (1). The decarburization of WC results in a formation of brittle  $W_2C$  phase, hence reduce the mechanical properties of the composite. Thus, to improve the cutting ability under high speed and high temperature various coating films such as TiCN, TiAlN, TiCrN, and TiAlSiN have been applied on the WC-Co cutting insert using physical vapour deposition (PVD) process (2-4).

PVD process involves essentially phase transformation and mass-transport phenomena on the substrate surface. Heat transfer in evaporation provides the production and transfer of vapor atoms or molecules from a source material to the substrate surface. PVD system is used to improve friction, surface hardness, wear corrosion, and surface roughness of tools, moulds, dies and machine components without changing the bulk properties of the substrates.

Earlier researchers reported that the improvement in the cutting performance of TiAlN-coated insert is due to the oxidation resistance of TiAlN properties at higher temperature (5). High wear resistance even at high temperatures is the outstanding property of TiAlN, a characteristic that makes this coating appropriate to cut abrasive work piece material such as cast iron, aluminium silicon alloys and composite materials at high speeds.

During machining process, TiAlN-coated insert is subjected to wear due to friction between the two mating surfaces. mechanism also take place of, Khrais and Lin identified that the micro-wear mechanisms in operation during machining of AISI 4140 steel were edge chipping, microabrasion, micro-fatigue, micro-thermal, and micro-attrition [6]. The main objective of this study is to investigate the wear characteristic of tungsten carbide and TiAlN-coated on tungsten carbide during turning low carbon steel.

### MATERIALS AND METHODS

The wear characteristic of WC and TiAlN-coated WC cutting tool inserts were investigated during turning of carbon steel work piece. Table 1 shows the mechanical properties of cutting tool inserts. Turning tests were carried out on a CNC milling machine model EXCEL SL 360/600I with cutting fluid of metal cut emulsion (SELISO). The tests were conducted on 100 mm in diameter and 140 mm long medium carbon steel rod (1.25 % C, 0.23% Si, 0.12% Mn, 0.24 %, 5.39% Cr, 0.47 % Mo, 0.93 % V, 0.011% W, 0.075% P and balance Fe) with hardness of 38 HRC.

**Table 1. Mechanical properties of inserts**

Insert	WC	TiAlN
Microhardness (HV)	1500	2400
Friction coefficient	0.3	0.25
Roughness RMS (nm)	28.9	73.7

Cutting ability of the inserts was conducted at cutting speed 120 mm/min, depth of cut 0.5 mm and feed rate of 0.06 mm/rev. The tests were carried out for one hour and the flank wear was measured using a microscope at 30 min interval and the inserts were deemed to have failed when the wear lands exceeded 0.3 mm. Figure 1 and 2 shows the microstructure of WC and TiAlN-coated cutting tool insert.

After subjected to turning test, the cutting edges of the inserts were examined using a field emission scanning electron microscope (FESEM) equipped with energy dispersive X-ray (EDX). FESEM operated at 15 kV, using secondary electrons mode. Sample for microstructural investigation were ultrasonically cleaned for 30 minutes.

Figure 2 shows 3D surface modulation of cutting inserts obtained by atomic force microscopy (AFM). It was observed that the TiAlN-coated insert has higher peak height as compared to WC insert. It was also observed that the TiAlN coating on tungsten carbide are not uniformly deposited on the substrate.

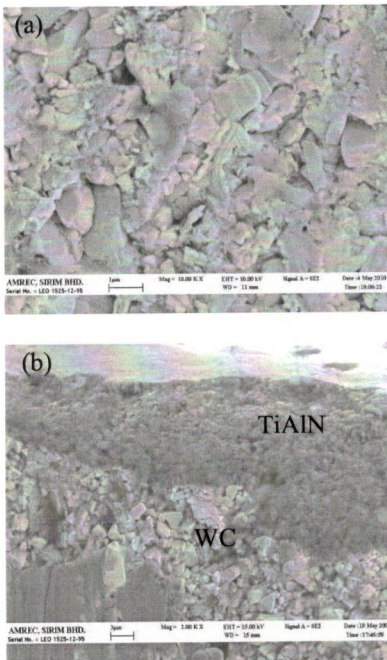


Fig.1. Microstructure of cutting tool insert; (a) tungsten carbide, (b) TiAlN-coated

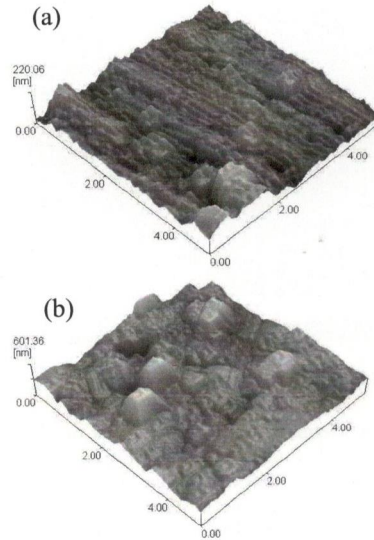


Fig.2. 3D topographic image of AFM, (a) tungsten carbide (b) TiAlN-coated insert

## RESULTS AND DISCUSSION

### Wear characteristics

High temperature is generated on the contact surface during turning process due to friction between the two mating surfaces. It was observed that the cutting chip change to bluish colour. Under this condition, the temperature of between 960 – 1000 °C is required to change the chip from original shiny steel to the dark blue coloured chips [7]. This high temperature causes the metal to flow and begin to adhere on the edge of cutting tool (Figure 3). EDX result revealed that the build-up edge mainly composed of Fe which implies that materials have been transferred from the work piece to the cutting tool (Table 2). This build up edge (BUE) formation could result edge break off as shown in Figure 4 and become embedded in work piece and subsequently produce poor surface finish.

Table 2. EDX results on BUE

Element	Weight%
C K	3.15
O K	7.93
Mg K	2.05
Fe K	86.87
Totals	100.00

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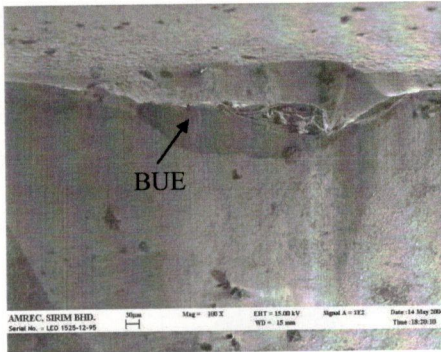


Fig.3. Build edge

The elemental mapping analysis on the worn surface of WC insert is shown in Figure 5. It can be seen from the figure that Fe patches transferred from work piece have covered the tungsten carbide insert (Figure 5b). It was also observed that there are no traces of cobalt which indicated that the cobalt has been removed due high temperature generated during machining.

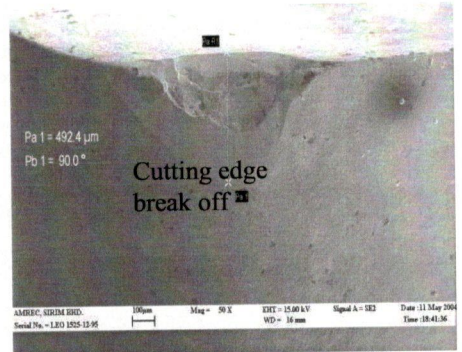


Fig.4. Cutting-edge breaking off on WC insert

High temperature generated during turning also result in melting of lower melting temperature of coating layer and work piece. This can be seen in Figure 6 where the melted material adhered and embedded on the insert. As the turning process progressed, the adhesion of TiAlN coating with the tungsten carbide substrate weakened and finally the coating layer was disposed from the substrate material exposing the substrate material.

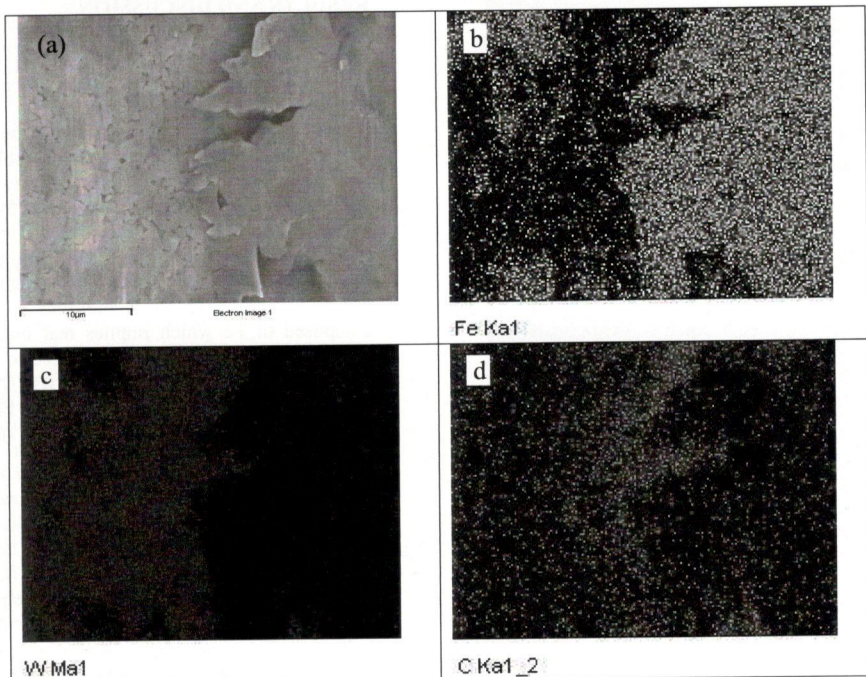


Fig. 5. SEM image of worn surface of (a) TiAlN-coated insert, (b) mapping of W, (c) mapping of Fe and (d) mapping of C

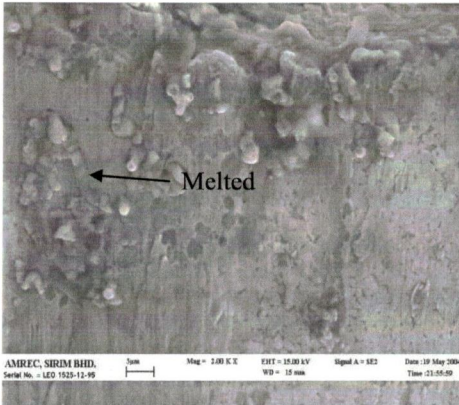


Fig.6. SEM image showing generation of thermal droplet and layer

Figure 7 shows the worn surface of insert flank. On the right side of the flank it be seen that coating layer still intact even though it has been slightly abraded during turning. EDX spectrum in Figure 7b exhibited that Ti, Al, and V were detected on this area. Ti and Al came from the coating layer while V came from work piece. This indicated that V has been transferred from the work piece to the insert flank.

On the other end, worn surface has been covered with materials transferred from carbon steel work piece (Figure 8). EDX spectrum shows that area has been covered with mechanically alloyed material composed of Fe, Mn and carbon. This mechanical alloying is a process of two-way transfer of material from the two mating surfaces. This is a symptom of adhesion wear mechanism.

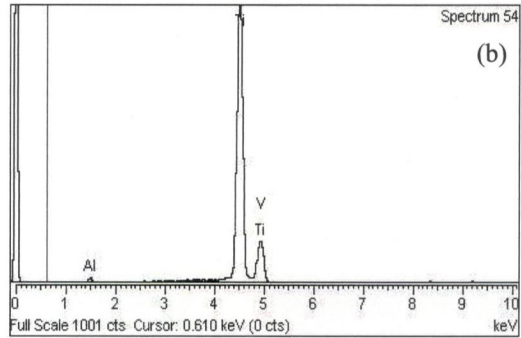
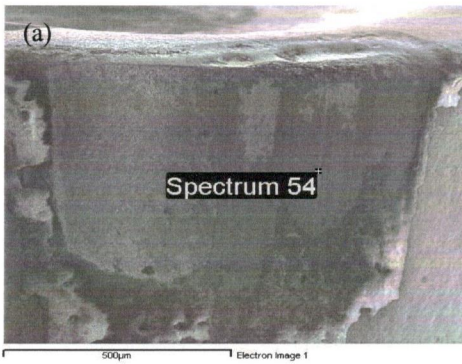


Fig.7. SEM image on insert flank; (a) worn surface on TiAlN-coated area, (b) EDX spectrum with composed of coating material and transferred material from workpiece.

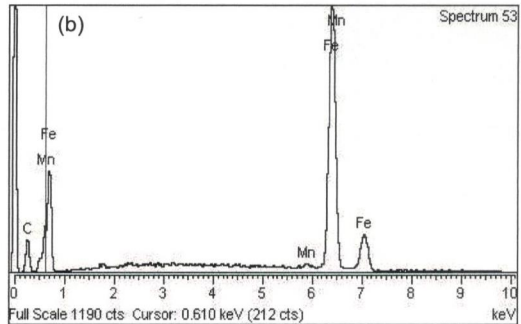
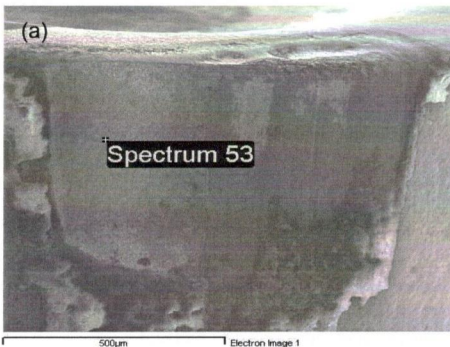


Fig.8. SEM image of insert flank; (a) worn surface on transferred layer, (b) EDX spectrum with composed transferred materials from work piece

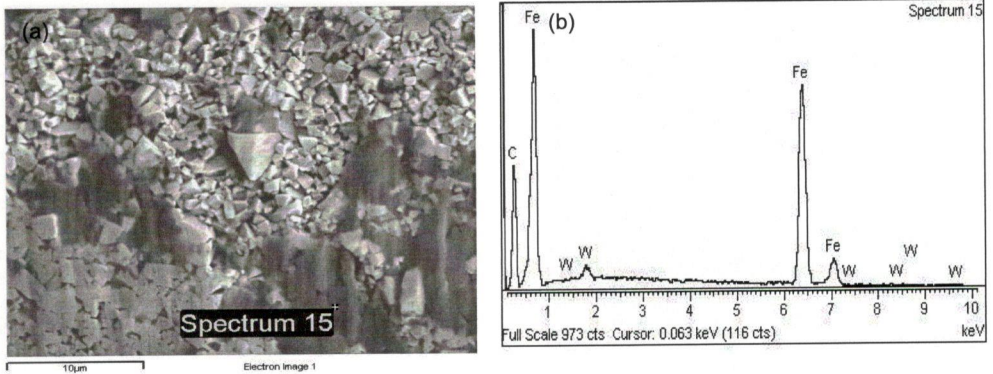


Fig. 9. SEM images; (a) worn surface, (b) EDX spectrum

Fig.9 shows that under high temperature, cobalt as a binder has been removed from the surface layer. Thus, WC became loose in the matrix and easily embedded of WC fragments to form a surface layer. EDX analysis on the surface layer composed of tungsten carbide and iron.

As the turning process progressed, the transferred layer on the flank (left side) was abraded by the third hard particles (loose WC) on the worn surface or hard particle (FeC, VC) on the work piece (Figure 11). This is a manifestation of abrasion mechanism. On the right side is the TiAlN coating layer, whereas in the middle is the transition side.

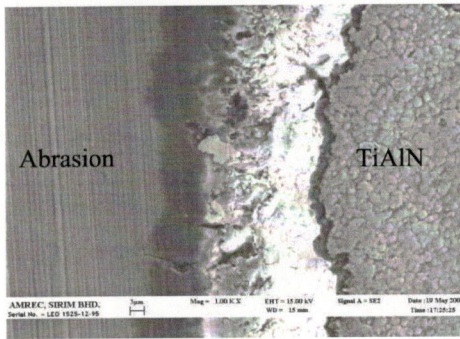


Fig.10. Abrasion wear mechanism

**Turning results**

Test results showed that the flank wear of tungsten carbide is four times longer than TiAlN-coated insert (Table 3). It was also noticed that the cutting chip of tungsten carbide insert starts to break faster (15 minutes) whereas for TiAlN-coated insert only starts to break after 55 minutes of turning. As cutting tool insert wear-off, some compression take

place at the tool contacts work resulting in discontinuous chip removal. Longer tool life of TiAlN-coated as compared with tungsten carbide was taught due to its higher hardness and lower friction coefficient. In this study, it was observed that the hardness of TiAlN-coated insert is only 1.5 higher than tungsten carbide insert, but its tool life is 4 times longer. Thus, it could be postulated that the tool life is not linearly correlated with increase in hardness.

Table 3: Machining test results

Insert	Flank Wear, VB (mm)
WC	1.12
TiAlN-coated WC	0.28

**CONCLUSIONS**

Turning of tungsten carbide and TiAlN-coated cutting tool inserts on carbon steel have been performed in this investigation. Based on test results, it was found that the TiAlN coating has improved tool life as compared with uncoated cutting insert due to higher hardness and lower friction coefficient. It was also observed that the tool life is linearly correlated with increase in hardness.

Wear mechanism during turning include removal of binder phase from the surface layers, fracture and fragmentation of the grains and formation of transfer layer. The predominant wear mechanisms in operation during turning were found to be abrasive, adhesive and thermal.

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