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Friction and Wear characteristics of WC and TiCN-coated Insert in Turning Carbon Steel Workpiece

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Abstract

Titanium Carbo-Nitride (TiCN) coating is widely applied in industry to improve the wear resistance of surfaces, such as for cutting tools, mould and dies, aerospace components and machine elements. It has high hardness with superior chemical and thermal stability. In this work, the turning performance was conducted at cutting speed of 60 mm/min, feed rate of 0.06 mm/rev and 1.0 mm depth of cut, on carbon steel workpiece. The wear behavior of TiCN-coated WC and uncoated WC cutting inserts were investigated using field emission scanning electron microscope equipped with energy-dispersive X-ray analyzer. The tribological characteristic of the sample was evaluated on a pin-on-disc tribometer. TiCN-coated cutting tool inserts were subjected to turning of hardened carbon steel at 50 mm/min, depth of cut at 0.5 mm and feed rate at 0.06 mm/rev under dry turning condition. It was observed that TiCN coating thin film deposited on cutting tools have reduced the friction coefficient, increased microhardness and subsequently improved cutting tool life as compared to uncoated cutting tool inserts.

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Keywords: TiCN coating, friction, wear, cutting insert, SEM .

1. Introduction

Cemented tungsten carbide, WC-Co is the most common cutting tool inserts for machining of castings and alloy steels due high toughness and hardness. 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 WC phase, which reduce the mechanical properties of the composite. Carbide tools are coated with hard materials such as TiCN, TiAlN, TiCrN, and TiAlSiN to improve the cutting ability under high speed and high temperature [2].

TiCN coating is a solid solution of TiN and TiC which having a combine wear-resistant characteristics of both TiN and TiC [3]. The superior tool life of TiCN coated tools over those coated with TiN can be attributed to the inclusion of carbon atom in the TiN lattice which results increase of the film hardness and lowering the friction coefficient [4]. The main objective of this work is to study the cutting ability and wear characteristics of tungsten carbide and TiCN-coated tungsten carbide cutting tool inserts in turning hardened carbon steel.

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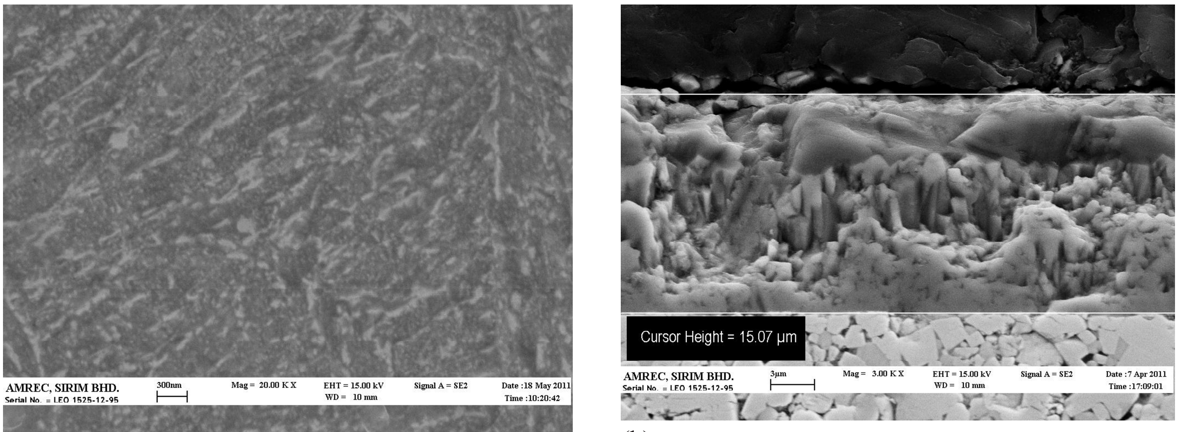
2. Experimental

A commercial available tungsten carbide (WC) and TiCN-coated on the tungsten carbide cutting tool inserts were used in this wear characteristics investigation (Table 1). The turning performance of the cutting tool inserts in dry machining was conducted at cutting speed of 60 mm/min, feed rate of 0.06 mm/rev and depth of cut at 1.0 mm. The tests were conducted on 100 mm diameter and 140 mm long carbon steel rod (0.40 % C, 0.25% Si, 0.77 % Mn, 0.011% P, 0.24 % S and balance Fe) with hardness of 404 HV. The performance tests were carried out until the cutting tool inserts were unable to cut the work piece and the inserts were deemed not complying with international standard organization ISO 3685 [5] requirement if the tool life is less than 5 minutes. Fig. 1 shows the microstructure of the work piece and TiCN-coating film thickness deposited on WC substrate.

The information on the tribological properties were gathered from the experiment conducted on a pin-on-disc CSEM tribometer (CSEM, Switzerland) using a 6 mm diameter alumina ball at sliding speed of 5.0 cm/s and radius of 6 mm for a distance of 1000 m under a load of 5N. The wear characteristics of the inserts were examined using a field emission scanning electron microscope (FESEM) model LEO 1525 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 prior to that SEM examination. Samples for subsurface examination were cut perpendicular to the coated surface using a diamond cutter. The sample was mounted and polished to a surface finish of 1 μm using emery cloth and diamond suspension.

Table 1. Mechanical properties of inserts

Insert	WC	TiCN
Microhardness (HV)	1500	2700
Thermal conductivity (kW/mK)	80.2	0.10
Roughness RMS (nm)	27.01	116.3



(a) (b)

Fig. 1. SEM microstructure of (a) work piece and (b) Cross-section of TiCN-coated insert.

3. Results and Discussion

3.1. Friction Coefficient

Fig. 2 shows the friction coefficient test results of TiCN coated and uncoated cutting tool inserts. It was observed that the TiCN coating has lowered the coefficient of friction as compared with uncoated sample. This can be due to the diffusion of graphite into the substrate which eventually reduced the friction coefficient as the result of solid lubrication (graphite) formation on the surface. It can also be seen from Fig. 3b that the TiCN coating layer still not damage even after 1,000 meters of alumina ball sliding on TiCN coating layer. If the coating layer has been damage, the uncoated surface will be exposed; the friction coefficient reading will show a reading of about 0.45, which is the reading of coefficient of friction of uncoated sample. This indicates that the TiCN coating had a good adhesion between the coating/substrate interface and at the same time reduces the friction coefficient. The coefficient of friction on TiCN-coated sample demonstrates to increase gradually after 800 m of sliding distance

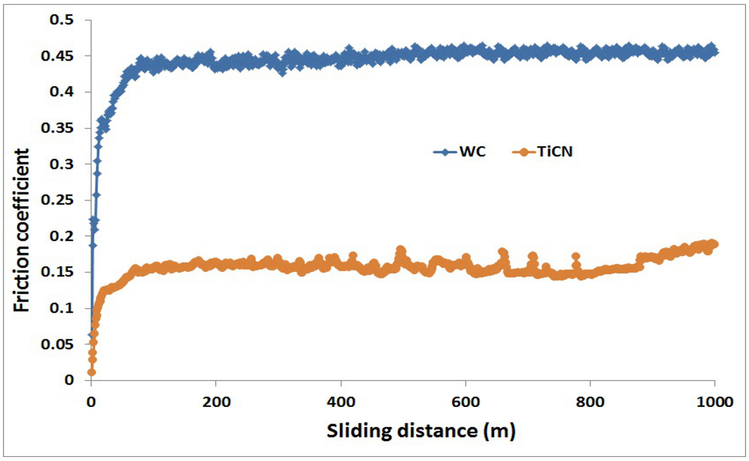
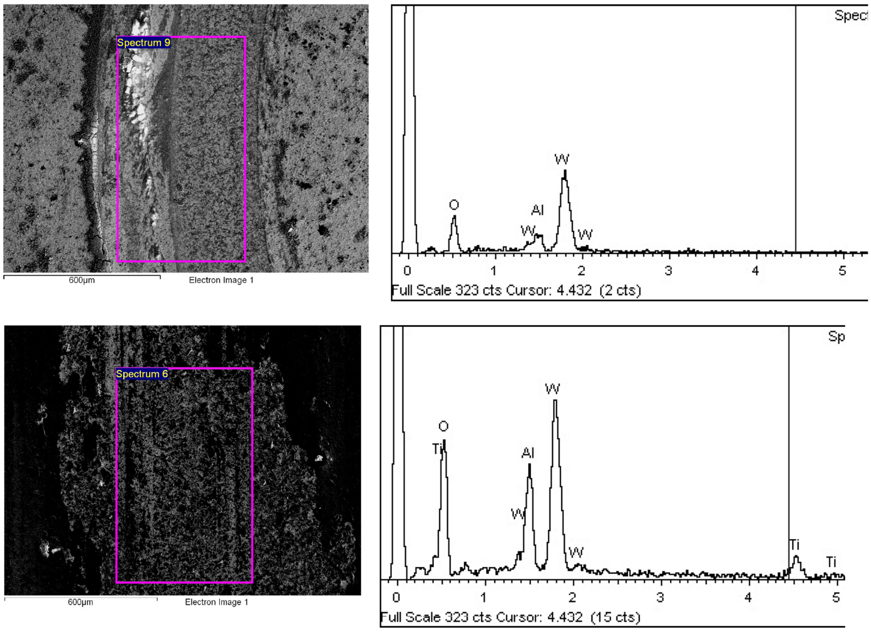


Fig. 2. Coefficient of friction against sliding distance.

EDX spectrum on wear track of uncoated and coated samples prove that there is a process of the transfer of material (Al) from the alumina ball as shown in Fig. 3. It was observed that the alumina ball has penetrated into the surface of uncoated samples (Fig. 3a). Fig. 3b shows that the TiCN coating layer has been deteriorated; exposing the substrate surface which composed of tungsten. The existence of Ti on the worn area of coated insert indicates the coating layer was not fully disposed from the surface even after 1,000m of sliding distance.



(a)

(b)

Fig. 3. Microstructure of wear track and EDAX spectrum of (a) uncoated inserts and (b) TiCN-coated insert.

3.2. Turning Results

Test results shows that the TiCN-coated insert can last up to 42 minutes as compared to tungsten carbide insert where it can only last up to 4.5 minutes (Table 2). By depositing TiCN-coating with a thickness of 15.1 µm (Fig. 1a), the tool life has been increased more than 9 times. This phenomenon could be due to higher hardness and lower friction coefficient TiCN-coated insert as shown in Table 1. The carbon atom diffused into the tungsten carbide substrate during the deposition of carbon nitride may also increase the insert life [4]. The temperature at the cutting edge can reach up to 1000 ºC which may result in the formation of solid lubrication of graphite, thus reducing the wear resistance of the insert during turning of hardened steel work piece. Fig 4 shows the chip change colour from brown to dark blue colour after 32 minutes of machining, which indicates that the temperature during machining is high between 960 to 1000 ^{O}C as reported by Ning *et al* [6]. The asperity contact between the work piece and insert results a high flash temperature. As the machining process progress, the contact area grows and finally hot patches are generated as shown in Fig. 5. The temperature of hot patches can reach the melting points of the materials as postulated by Kennedy [7].

Table 2. Turning test results

Insert	Flank Wear, VB (mm)	Tool life (minutes)
WC	1.43	4.5
TiCN	1.31	42

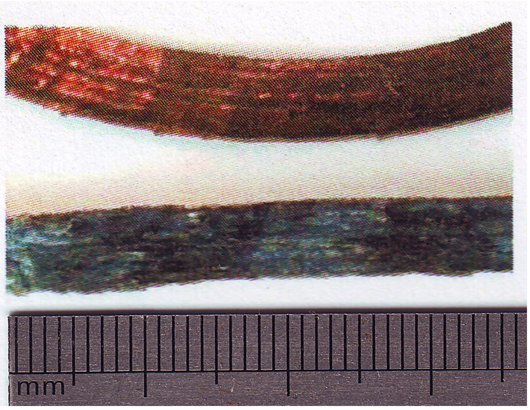


Fig. 4. Chip colour changes from brown to dark blue as the temperature increases during machining process.

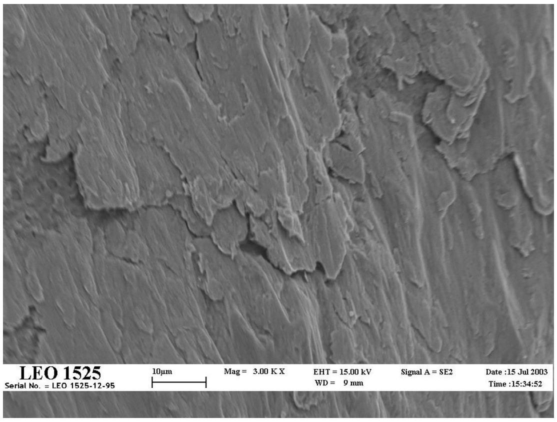
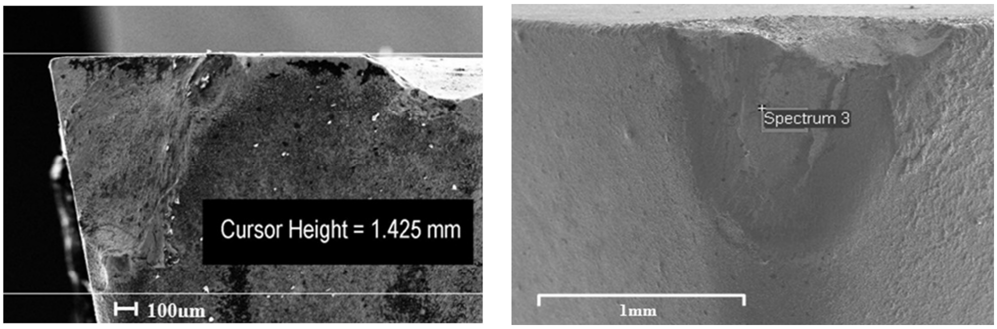


Fig. 5. Formation of hot patches.

3.3. Wear characteristics

Fig. 6 shows typical tool wears on the cutting tool insert during turning process. It can be seen that the WC insert experienced catastrophic failure during the turning machining process (Fig. 6a). In case of TiCN-coated insert, it was observed that coating film was disposed gradually until the exposure of tungsten carbide substrate as shown in Fig. 6b. It was noticed that the width of the flank wear land of coated is slightly smaller than uncoated insert but still having tool life nine times longer than uncoated. This demonstrates that the TiCN coating improved the tool life of the insert significantly even with a coating thickness of 15.1 μm.



(a) (b)

Fig. 6 Tool wear patterns on; (a) catastrophic failure of WC insert, (b) TiCN-coated.

The heat generated during dry turning results in reducing the adhesion of TiCN coating film with the WC substrate and finally exposing the substrate material as the turning process progressed. Fig. 6b and Fig. 7 show the elemental analysis spot and EDX spectrum respectively. EDX spectrum shows that the substrate material (WC) has been exposed even though there are still traces of titanium. EDX analysis also shows that there are no traces of cobalt on the surface layer, which demonstrating that the cobalt has been removed during the turning process due to high temperature generated during turning process. It was observed several materials from work piece (Fe, Mn, Cr) was transferred onto the worn surface of the cutting insert. The EDX analysis shows that this spot composed of materials from work piece (Fe, Cr, Mn), coating material (Ti) and substrate material (W, C). This phenomenon is due the process of mechanical alloying where a process of two-way transfer of material from the two mating surfaces (insert and work piece) during the turning process.

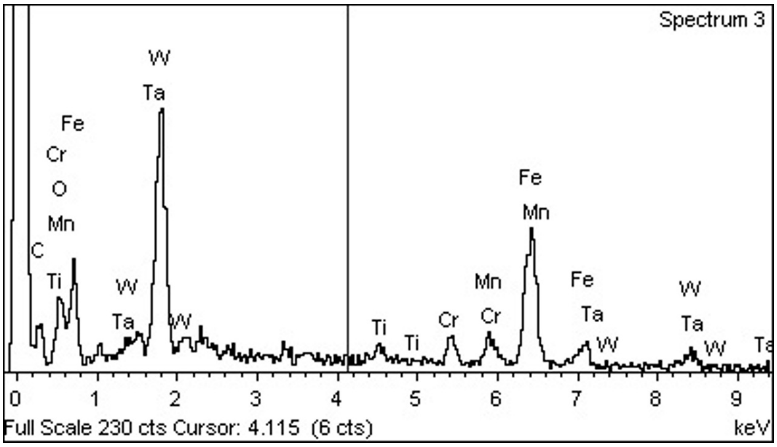
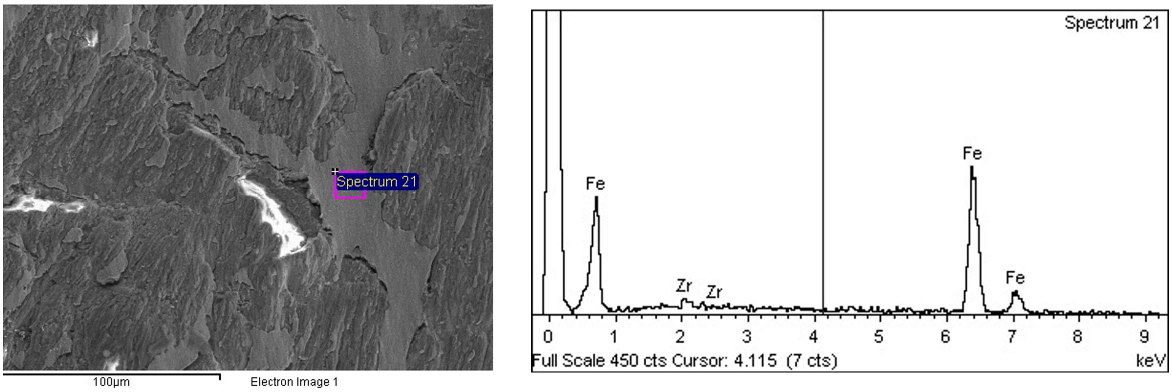


Fig. 7. EDX spectrum on worn surface of coated insert.

The temperature during turning can reach up to 1000 ºC [6]. As a result of high temperatures, the material transfer from workpiece were melted and plastic flow occurred as turning process progressed (Fig 8). EDAX analysis on the plastic flow shows that only element of ferum left which have melting point of 1538 ^{O}C, whereas other elements which have low melting points in workpiece such as Mn (1246^{O}C), P (44.1 ^{O}C), Ni (1453 ^{O}C) may have depleted away and cannot de be detected by spot EDAX as shown in Fig. 8b.



(a) (b)

Fig. 8. Worm surface insert (a) microstructure and (b) EDX spectrum.

4. Conclusions

Results of turning tests and microstructural examinations in the present investigation revealed the following phenomena; (a) TiCN-coated insert perform 9 times longer than uncoated insert due to lower friction coefficient and higher hardness, (b) The uncoated insert failed catastrophically whereas the TiCN coating was disposed gradually until exposure of substrate materials and (c) the mechanical alloying of both materials from the mating surfaces was observed on the worn surface of insert. It was also observed that the TiCN coating has reduced the friction coefficient from 0.45 to 0.17. The reduction in friction of coefficient reduced the wear resistance and, subsequently improved the tool life. Tribological test results also show that the coating layer was not fully disposed from the substrate surface even after a sliding distance of 1,000 meters.

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