

TURNING PERFORMANCE OF DIAMOND-COATED INSERT

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ABSTRACT

Diamond-coated tungsten carbide (WC) insert is used for machining of non-ferrous material such as brass, bronze, aluminium alloy, and metal matrix composite. However in this study, diamond-coated insert was subjected to machine medium carbon steel at cutting speed of 60 mm/min, feed rate of 0.254 mm/rev, and depth of cut 2 mm. The machining test was performed on CNC turning machine. The purpose is to investigate the microstructural changes on the flank and crater of the insert and then postulate the failure mechanism of the insert. From the SEM examinations and EDAX analysis, the two-way transfer materials were observed to occur on the worn surfaces of the insert and workpiece. It was postulated that the carbon contents from the diamond diffused interstitially into the work piece materials and formed metal carbides (MC) on the work piece, thus resulting in the blunting of the diamond-coated insert. This failure mechanism prevents the usage of the diamond-coated insert on machining of the ferrous materials even though it is the hardest material on the earth.

INTRODUCTION

Coated cutting tool such as TiN, TiAlN, TiCN, and CBN is used to improve the hardness, wear resistance, and tool life of the insert. The cutting force and surface roughness of the machined surface is reduced when the cutting insert was coated with diamond coating [1]. The lifetimes of tools can be increased from 8 for twist drills to about 40 for ejector dies [2]. During machining, the temperature of between 960 – 1000°C is required in order to change the chip from original shiny steel to dark blue chips [3]. At this temperature, diffusion and oxidation process may occur at the worn area of the cutting tool. The generation of thermal fatigue crack on the substrate are due to the phenomena of thermal cycling coupled with thermal shock during machining [4]. During machining process, wear mechanism also takes place, depending on the coating materials employed and work piece used. In their study on failure mechanisms of TiCN-coated drill, Talib et al. postulated that the failure mechanism in operation during drilling were abrasive and adhesive wear mechanism [5]. The above phenomena may cause the cutting tool failure.

Diamond is the hardest known material, has the lowest coefficient of thermal expansion, is chemically inert, wear resistant, offers low friction, lowest compressibility, Good electrical insulator and has high thermal conductivity [6]. It can also be used as inserts and/or wear-resistant coatings for cutting tools. Diamond-coated cutting performance for non-ferrous materials outclasses the other coated materials. But for cutting the

ferrous material, diamond-coated insert will heat up during machining and, in the case of ferrous materials the diamond coating will ultimately react with the iron and dissolve into the workpiece or tool substrate. This will hinder the usage of diamond-coated insert for machining the ferrous materials. In this research work, investigation will be made on the microstructural changes on the diamond-coated insert and work piece and then postulate the failure mechanism involve during machining.

EXPERIMENTAL

A commercial diamond-coated insert was used in this study. Each sample was subjected to machining tests using a CNC milling machine model EXCEL SL 360/600I. The machining test was conducted on 100 mm diameter x 140 mm length 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 35 HRC. Figure1 shows the microstructure of the work piece. The machining test was conducted at cutting speed of 60 mm/min, feed rate of 0.254 mm/rev, and depth of cut 2 mm. The tool life was determined at the point when the insert was unable to cut the workpiece. The machining test was stopped the cutting chip produced was broken into small pieces instead of in the continuous form.

After subjected to turning test, the diamond-coated inserts were then subjected to microstructural examination using field emission scanning electron microscopy model (FE-SEM) model LEO 1525. Sample for microstructural changes investigation were ultrasonically cleaned for 30 minutes. Whereas, the sample for thickness measurement was cut, cold-mounted, polished to a surface finish of 1 μm and then ultrasonically cleaned for 30 minutes.

RESULTS AND DISCUSSION

Machining tests

Failure test results showed that the diamond-coated insert could last eight times longer than the high speed steel insert. High speed steel insert fail to machine the workpice at 45 minutes compared to diamond-coated which can go up to 6 hours. In term of insert cost, this improvement is not so significant. That why, coated insert is not suitable to be used for machining ferrous material due to carbon diffusion into the work piece which form metal carbide on the workpice. It was observed that the chip change to dark blue colour after four hours of machining (Figure 2), which indicates that the temperature during machining is between 960 – 1000 $^{\circ}\text{C}$ as reported by Ning et al [2].

Wear mechanism

Heat is generated during turning process due the friction between the insert and the work piece. This phenomenon resulted in diffusion of carbon contents from the diamond coating into the work piece materials and formed metal carbides (MC) on the work piece. The formation of metal carbide on the work piece which is quite hard depending on the metal element may damage the diamond coating as shown in Figure 3.

As the turning process progressed, the adhesion of diamond coating with the substrate will be weakened and finally diamond coating was disposed from the substrate material. Subsequently exposing the substrate material and forming build-up edge (Figure 4a and Figure 4b).

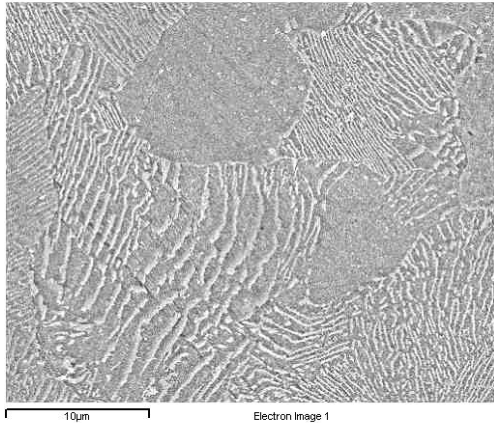


Figure 1: Pearlitic structure of work piece

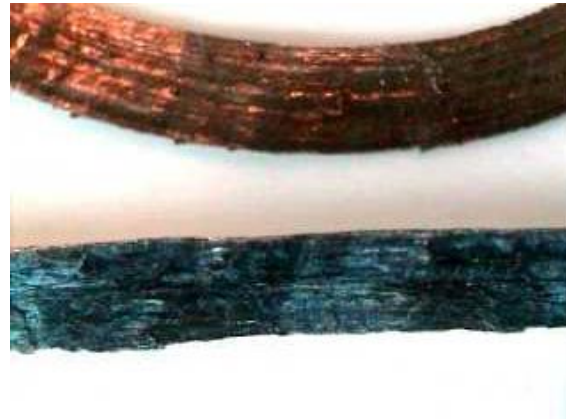


Figure 2: Change of chip colour from brown to dark blue

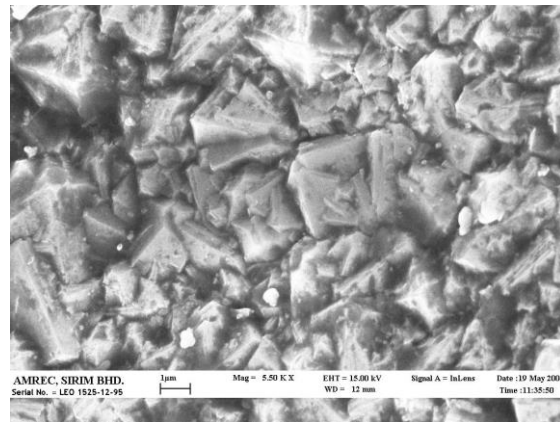
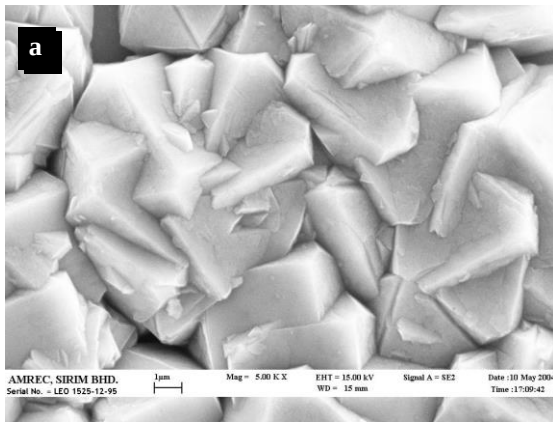


Figure 3: SEM image of diamond coating; (a) before turning test, (b) after turning test

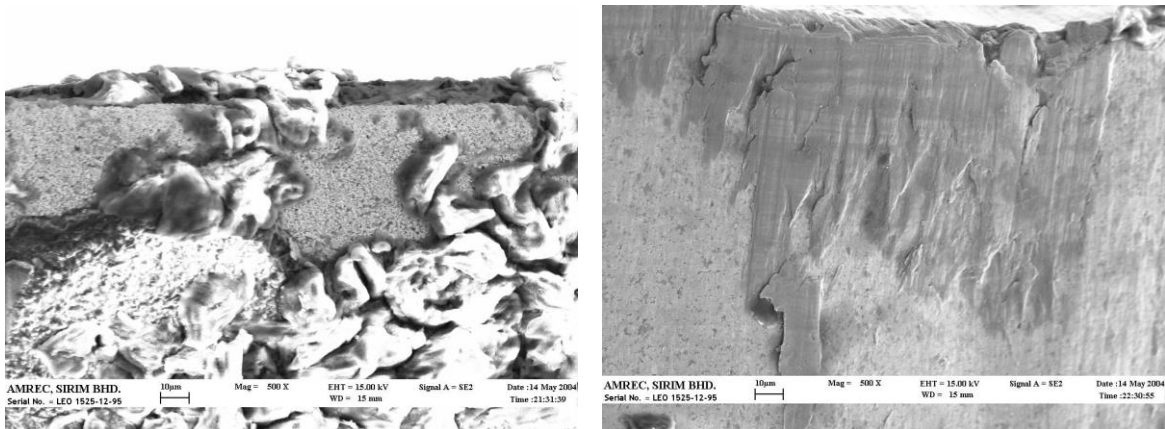


Figure 4: SEM images of diamond-coated surface, (a) damaged surface, (b) BUE

In the early stage of machining, the transfer of material from the work piece to the diamond-coated insert was observed as shown in EDAX analysis. Table 1 and Figure 5 show the elements composed in the work piece material such as magnesium, aluminium, silica, and iron have been transferred on to the flank edge of the diamond-coated insert. Figure 6 shows the EDAX analysis location on the flank and it was found that the element of iron has penetrated into the flank. As the machining progressed, it was observed that only element of high melting point such iron, silica, and cobalt left on the flank. Whereas, the other elements in the composition, which have lower melting temperature such as magnesium and aluminium have evaporated to the atmosphere.

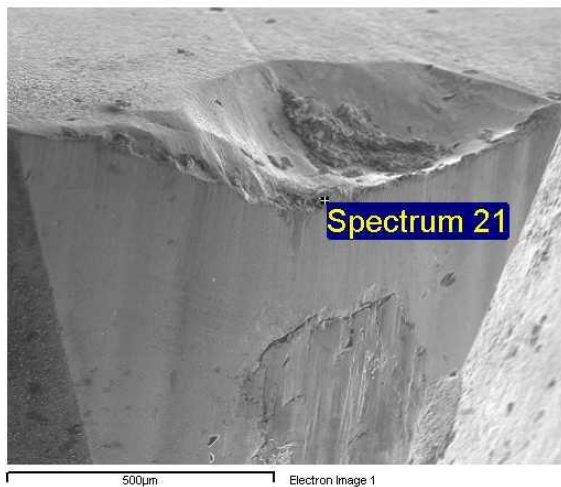


Figure 5: EDAX analysis on the flank edge

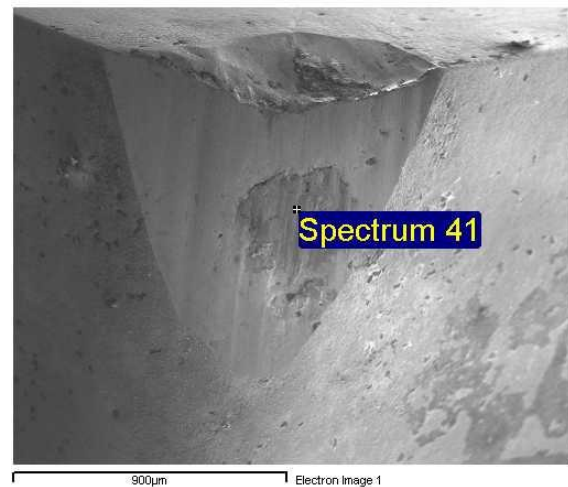


Figure 6 EDAX analysis on the flank edge

Table 1. Element composition on the flank edge

Element	Weight%
C K	54.85
O K	30.21
Mg K	0.37
Al K	0.44
Si K	4.17
Fe K	6.45
Co K	1.74
W M	1.78

Table 2: Element composition on the flank

Element	Weight%
C K	7.12
O K	2.09
Fe K	0..9
Si K	2.10
Co K	5.29
W M	82.5

Figure 7a shows worn surface of the insert where the left side was the substrate surface after diamond coating has been disposed from and the right side was a diamond coating. When the substrate materials have been exposed, the harder peak asperities were ploughed into the wear surface (Figure 7b). This process is a manifestation of abrasion wear mechanisms. The abrasion mechanism was not observed on the subsequent turning and this phenomenon was taught to be due to blunting of the peak asperities during the turning processes. At the same, it was also observed that the material fragment from the work piece was transferred onto the insert surface and has started to form metallic junctions as well as to start growing. As turning process progressed, the transfer materials will be smeared and sheared on the worn surface of the insert (Figure 7c). The transferred films were continuously compacted, smeared and sheared on the sliding surfaces as the drilling progressed and finally formed a compound layer composed of tungsten carbide substrate material and element from work piece (Figure 7d). Energy Dispersive Analysis of X-Ray (EDAX) revealed that the transfer layers generated on the worn surface contain both materials from tungsten carbide substrate material and work piece. This process was due to process of mechanical alloying on transfer layers, a phenomenon observed by other researchers such as Chen & Rigney [7].

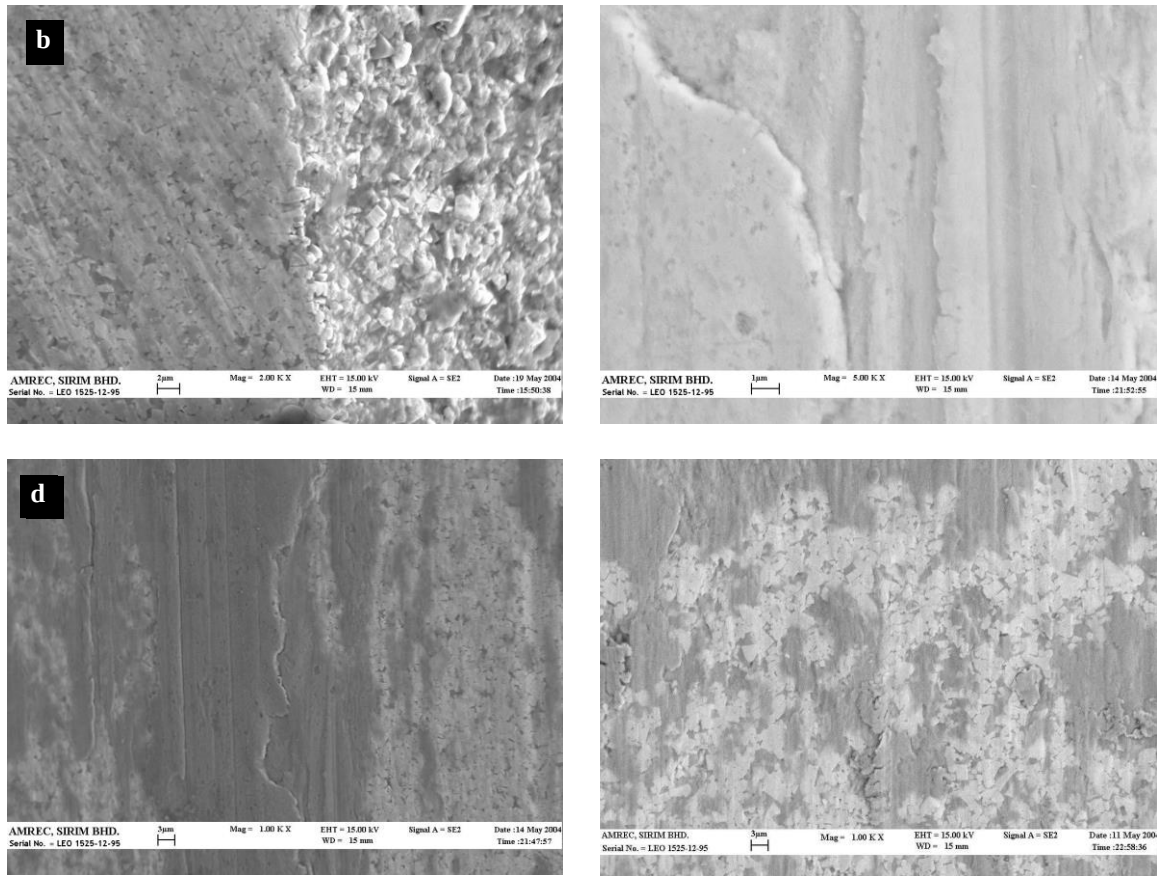


Figure 7: Surface morphology of substrate material. (a) wear surface (b) formation fragment material and abrasion mechanism, (c) transfer layer, (d) compound layer

CONCLUSIONS

In this study, it was observed that the wear mechanism operated during turning was a complex mixture of abrasion and adhesive wears. Abrasion wear only occur at the early stage of turning process. Whereas the adhesion wear is a continuous process, started with the formation metallic junction and finally formed a compound transfer layer. It was also revealed that the two-way transfer of materials did occur during turning process. Heat generated during turning process resulted in the formation of metal carbide which may cause to the damage of diamond coating. This phenomenon causes the diamond coating disposed from the substrate surface.

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