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WEAR MECHANISM OF TICN AND TIALN COATED DRILL IN DRILLING OF CARBON STEEL

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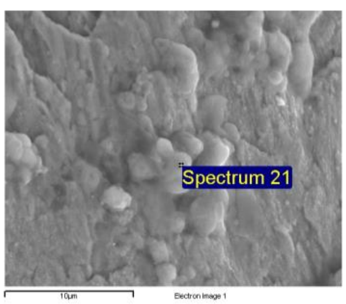
Graphical abstract



Abstract

TiCN and TiAlN coated twist drills were subjected to drilling tests to investigate the failure mechanisms during drilling operation. The drilling tests were performed on a carbon steel plate with a thickness of 25 mm and the depth of drill was set at 20 mm. The drill performance parameters were set at a spindle rotation of 1,600 rpm and feed rate of 20 mm/min. Each sample was then subjected to Scanning Electron Microscopy examination to investigate the wear mechanisms operated during drilling. Microstructural examination showed that the abrasion, adhesion and thermal wear mechanisms are operated during drilling process.

Keywords: Drill, TiCN, TiAlN, SEM, wear, microstructure

1.0 INTRODUCTION

Nitride based hard compound such as TiN, TiAlN, TiCN, TiZrN have excellent wear resistance, high hardness, and lower friction coefficient, are deposited on drill and cutting inserts to improve the tool life [1]. However, the tool life not only depends on the coating materials used but also depends on the type of substrate used, coating process parameters (chamber temperature, pressure, gaseous flowrate, etc), as well as the coating technique employed (chemical vapour deposition process, physical vapour deposition process). The tool life is increased due to increase in microhardness, wear resistant, corrosion resistant, greater bonding energy of the coating elements [2, 3].

The coated drill required less thrust force, gave lower values of axial and radial vibration during drilling process which will also influence the tool life [4]. TiAlN coated cutting tool has improved the dry machining performance be due to the fact that this coating is able to maintain high hardness and resistance to oxidation at high operating temperatures [5]. The objective of this study is to investigate the wear mechanism operated on TiCN and TiAlN coated drill during drilling of carbon steel.

2.0 MATERIALS AND METHOD

A commercial High Speed steel, TiCN and TiAlN coated drills were subjected to drilling performance tests using a CNC milling machine. The drilling performance test was conducted on 25 mm thick medium carbon steel plate (1.39 % C, 0.25% Si, 0.19% Mn, 0.25 %, 5.39% Cr, 0.51 % Mo, 0.82 % V, 0.07% W, 0.05% P and balance Fe). The drilling parameters were set at a spindle rotation of 1,600 rpm, feed rate of 20 mm/min, and the depth of cut was set at a distance of 20 mm. Pecked-drilling by lifting the drill once every 5 mm depth of drilling is practiced in this performance test so that that the chip can be removed smoothly during drilling performance tests, thus reducing the heat. In this present work, lubrication was not in use during this drilling experiment test to expedite the coating failure. The microstructural changes on the worn surfaces were observed using Field Emission Scanning Electron Microscopy (FE-SEM) Model LEO 1525. The samples were cleaned with compressed air and then ultrasonically cleaned for 30 minutes. On the other hand, the sample for thickness measurement was cut, cold-mounted, polished to a surface finish of 1 μm and then ultrasonically cleaned for 30 minutes.

3.0 RESULTS AND DISCUSSION

3.1 Chip Morphology

It was observed that at the end of tool life, the drill start to produce noise and vibrate as well. This phenomenon was due to the exposure of substrate material as the coating film has been disposed during drilling process. The exposure of the substrate materials results in higher surface temperature due to higher COF between the substrate material and workpiece. Subsequently, the chips were cut into smaller size and having a bluish colour. It was reported that the drill temperature could be as high as 1060°C [6]. Figure 1 shows the microstructures of the chip produced during drilling process. Lamella structures were observed on the back of the chip produced by all the coated drills. It was reported that the most observed structure in chip of the metallic materials are lamella structures [7]. The abrasive wear mechanism is observed to be operated on the free side of the chip. Whereas a segmented chip with a typical saw-tooth shape was observed on the top side of the chip and term as continuous fragmentary chip which is very common when machining ductile materials [8].

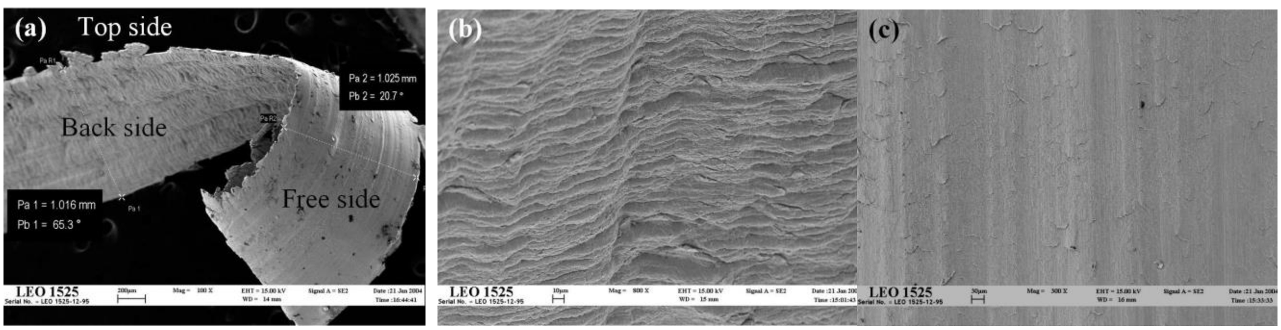


Figure 1 Microstructure of drilling chip; (a) drilling chip, (b) lamella structure on the back of the chip, (c) abrasion on free side of the chip, and (d) continuous fragmentary chip

3.2 Wear Mechanism

It was observed that the cutting lip of TiAlN-coated drill was only abraded-off after drilling of 728 holes and still capable to drill until up to 835 holes before catastrophic failure occurred. EDAX analysis on the worn area confirmed that the abraded-off area has exposed the substrate material. EDAX analysis on the flank of the coated drill showed this area was still covered with TiCN coating films (Figure 2). For TiCN-coated drill, it was observed that the cutting lip was only abraded-off after drilling of 913 holes (Figure 3) and still capable to drill until up to 1014 holes before catastrophic failure. EDAX analysis on the worn area confirmed that the abraded-off area has exposed the substrate material. This worn area composed of material from a work piece (Fe and Cr, V) coating elements (Ti, C and Nitrogen) and substrate elements (W and C). This shows that there is a process of two-way transfer of material from the work piece and the drill which subsequently generate the mechanical alloying transfer layer on both the mating surfaces [9].

3.3 Abrasion Mechanism

Microscopic scale of engineering surface is rough and has peak and valley. Abrasive wear occurs as result of ploughing and scratch of hard asperities or particles on the softer surface as shown in Figure 5. Normally, abrasion wear can be notice by the appearance of wear surface in the form of scores, grooves, stations and scratches. In the early process of drilling, the peak asperities ploughed into the mating surface as shown in Figure 4b. With subsequent drilling, the peak asperities were sheared and became blunt (Figure 4c). The abrasion mechanism was observed throughout the drilling performance test.

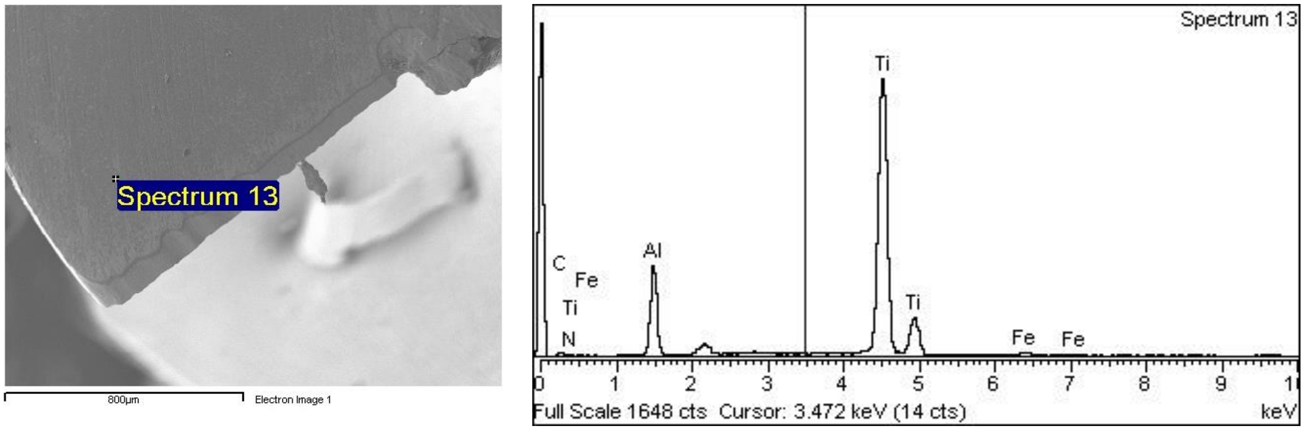


Figure 2 SEM image and EDX spectrum on drill flank of TiAlN-coated drill

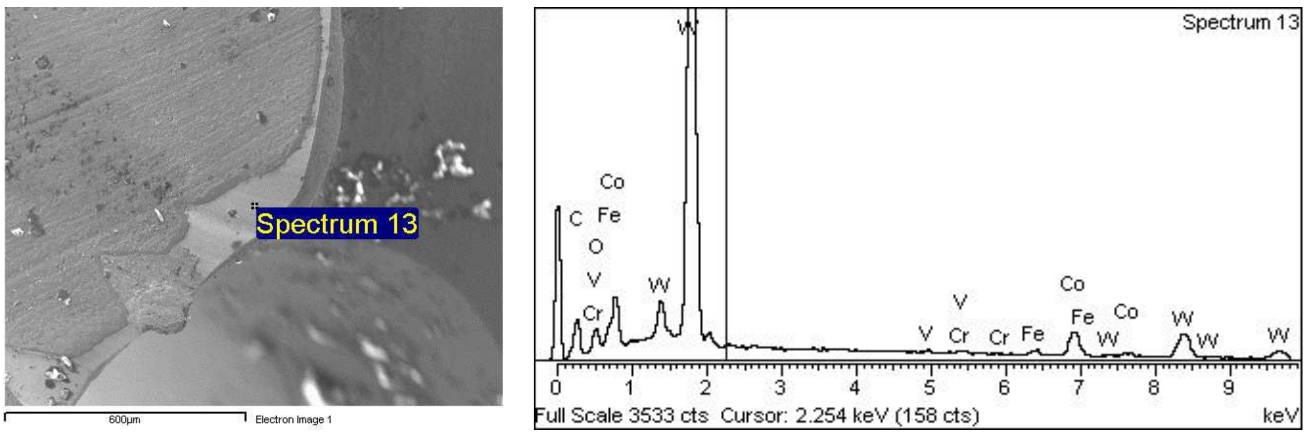


Figure 3 SEM image and EDX spectrum on cutting edge of TiCN-coated drill

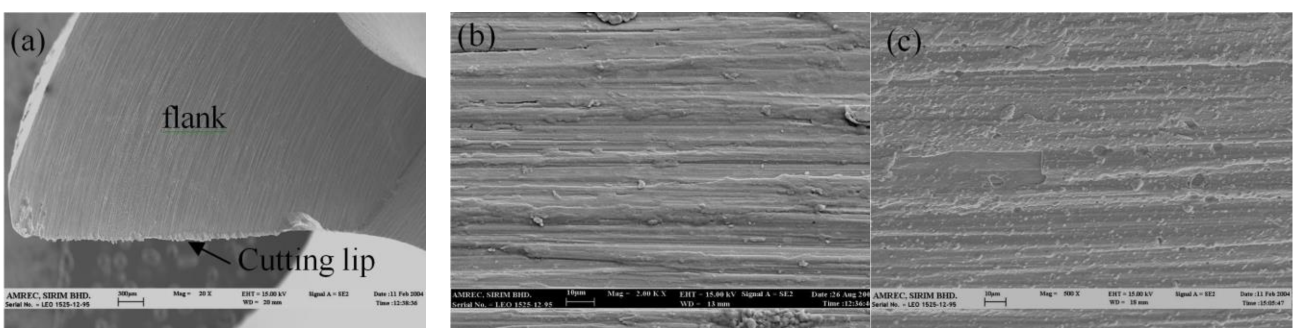


Figure 4 SEM image on abrasion mechanism; (a) cutting lip, (b) Early stage of abrasion mechanism, (c) Peak asperities were sheared and compacted on the worn surface

3.4 Adhesion Mechanism

In the process of drilling, the peak asperities are subjected to repeated contact, resulting the generation of plastic deformation on the peak asperities. The material at the peak asperities become unstable to the local shear, detaches, and transfers to the opposite mating surface forming a transfer patches as the drilling process progressd (Figure 5a). With subsequent drilling, the transfer patches were observed to form on the drill surface due to the compaction of transfer patches and a newly transferred fragment (Figure 5b). The transfer films were continuously smeared and sheared on the sliding surfaces and finally formed multi-layers on the worn surface (Figure 5c). EDAX analysis on the transfer layer revealed that the layers generated on the worn surface contain both materials from coated drill (Ti, Al, N) and work piece (Fe, Cr, Si, Mn, C) known as mechanical alloying of transfer layers [9].

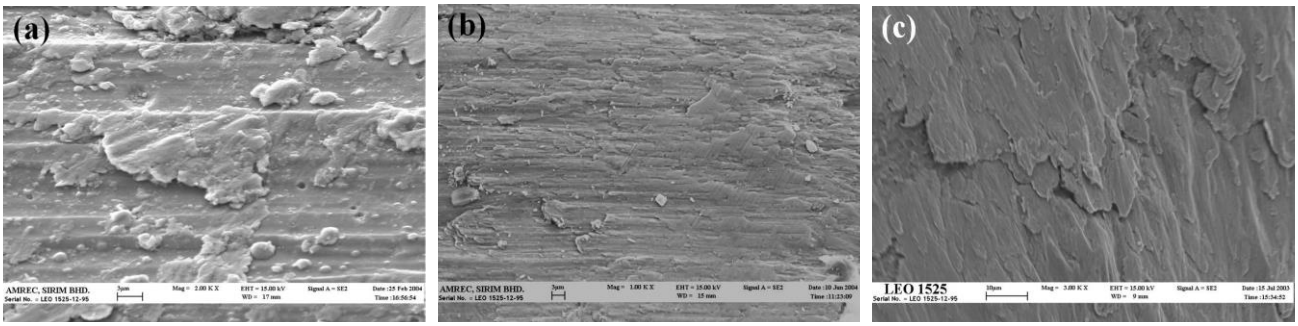


Figure 5 Adhesion wears mechanism: (a) Early stage of drilling process, wear particles and scratch markings were observed on the worn surface, (b) transfer patches, (c) formation of multilayers

3.5 Thermal Mechanism

Heat is generated during drilling process causes the temperature rise on the worn surface and subsequently melts the metal composition in the drill and forms metal droplets on the contact areas as shown in Figure 6. EDAX analysis shows that only element of ferum and carbon left in the metal droplet which have melting point of 1538 OC and 5000 OC respectively, where other elements which have low boiling point such as Mg (650OC), Ca (842 OC) have evaporated to the atmosphere. As the drilling process continued, the temperature rise at the contact areas introduced thermal stresses on contact areas, and subsequently could superimposed onto the mechanical stresses resulting in generation of multiple themomicrocrack (Figure 7).

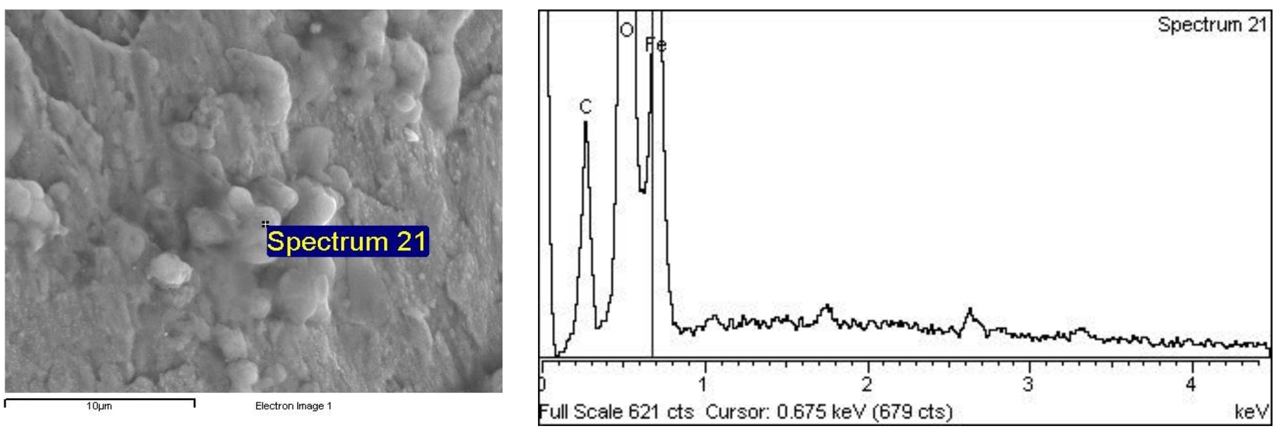


Figure 6 SEM image and EDAX spectrum of contact area

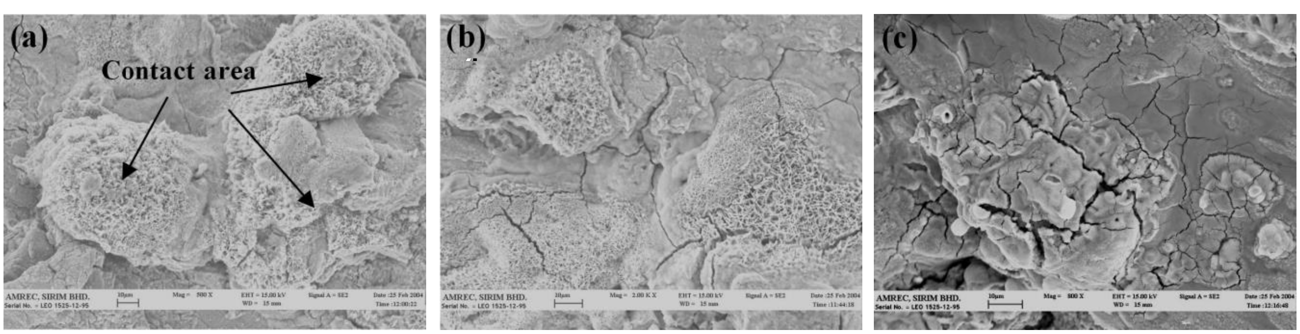


Figure 7 Formation of thermomicrocraks; (a) contact area, (b) early stage of thermomicrocraks generation, (c) multiple thermomicrocraks

4.0 CONCLUSION

The microstructural investigation revealed that the wear mechanisms operated during drilling were abrasion, adhesion and thermal. In early stage of drilling, the wear mechanism operated during drilling process were a combination of abrasion and adhesion wear. Subsequently, the wear mechanism changed to a combination of severe adhesion and thermal wear. The drill was unable to further penetrate into the work piece as a result of broken cutting lip and land, and blunting-off chisel wedge.

Acknowledgement

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