

WEAR MECHANISM OF TiN, TiAlN AND TiCN COATED DRILLS DURING DRILLING OF CARBON STEEL

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Abstract: *This study is to investigate the wear mechanism develops during drilling of High Speed Steel of molybdenum type drill 5 mm in diameter coated TiCN, TiN and TiAlN on the medium carbon alloy steel work piece. The performance tests were conducted on CNC milling machine at spindle rotation of 1,600 rpm and feed rate of 20 mm/min. A carbon steel plate with a thickness of 30 mm was used as a work piece and the depth of drill was set at 25 mm. After drilling, the microstructural changes on each coated drill were observed under the scanning electron microscopy (SEM). In this paper the wear mechanism operated during drilling was discussed. Generally, wear mechanism operated during drilling were found to be a complex combination of abrasive, adhesive and thermal wear.*

Keywords: coated drill, performance test, tool life, wear, SEM, microstructure

1. INTRODUCTION

A compound coating such as TiCN, TiAlN, TiZrN, TiAlN is used to increase the tool life of the cutting tool. It also improves microhardness, wear resistant, corrosion resistant, operating life and productivity, electrical properties and optical properties of engineering components. Previous study by earlier researchers showed that an increase in tool life may be due to the following phenomena: (i) increase in hardness,¹ (ii) greater bonding energy of the coating elements,² and (iii) lower friction coefficient.³ This hard coating can be applied to cutting tool, mould and dies, machine elements, automotive parts, electrical and electric components.

Shizi et al.⁴ reported on average an eight-fold lifetime increase of 2 to 3 μm thick Plasma Assisted Chemical Vapour Deposition (PACVD) coated thin layer twist drill as compared to uncoated drills. On another study, Aboukhashaba⁵ in his tests with 1 to 2 μm TiN-coated and Ti(CN)-coated drills, found that the coated drill required less thrust force, gave lower values of axial and radial vibration, and reduced the chip/tool interface temperature by approximately 450°C during drilling process.⁵ The objective of this study is to study the wear

mechanism develops during drilling of TiCN, TiN and TiAlN coated drills on the medium carbon steel work piece. The failure mechanism of the drill during drilling process was also discussed.

The major wear phenomena observed operated during drilling were abrasion, adhesion and thermal.³ In another study, Chen et al.⁶ observed that the tool wear was due to normal mechanical abrasion and no peeling mechanism occurred on the rake and flute surfaces of the drill. Adhesion is a process of deformation, rupture of interfacial bonding and formation of transfer layer on the wear surfaces whereas abrasion occurs as a result of material removal by a ploughing process. Surface fatigue needs more than one stress cycle for this mechanism to proceed. Surface fatigue results in the generation of striation, microcrack and fatigue formation on the surface, leading to materials removal from the interface.

2. MATERIALS AND METHOD

In this study, High Speed Steel drill of molybdenum type (1.07% C, 0.63% Si, 0.37% Mn, 4.13% Cr, 4.08% Mo, 0.27% Ni, 2.65% V, 0.43% W, 0.43% Co, 0.05% P and balance Fe) TiN, TiAlN, TiCN-coated drill were purchased from the local supplier. The coated drills of 5 mm in diameter were subjected to drilling performance tests using a CNC milling machine. The drilling performance tests were conducted on 30 mm thick medium carbon alloy steel plate (0.72% C, 0.25% Si, 0.19% Mn, 0.25% Cr, 0.51% Mo, 0.82% V, 0.07% W, 0.05% P and balance Fe). The drilling parameters were set as follows: (i) spindle rotation of 1,000 rpm, (ii) feed rate of 20 mm/min, and (iii) the depth of cut of 25 mm. Lubrication was not supplied in this present investigation to expedite the coating failure. The drill life was determined at the point when the drill was unable to penetrate further into the work piece. The number of holes that the drill can produce was counted as the drill life. After the drilling test, each sample was cut for the microstructural examinations on the drill flank using a field emission-scanning electron microscope (FE-SEM) model LEO 1525. Samples were then cleaned with compressed air and then ultrasonically cleaned for 30 min before subjected to the microstructural changes on the drill flank.

3. RESULTS AND DISCUSSION

3.1 Performance Test

The drilling performance test showed that the drill coated with TiCN coating outperformed the other coated-drills with the tool life of 33 folds as compared with uncoated drill which capable of drilling up to 24 holes only. This phenomenon was due to its higher hardness and lower friction coefficient characteristics (manufacturer's data) as shown in Table 1 and all coated drills were prepared using Cathodic Arc Physical Vapour Deposition process (CAPVD). Other researchers also found the same phenomena such as Sedlacek.⁷ Based on the above observation, it could be concluded that a compound coating did play an important role in improving the tool life of the drill depending on type of a compound coating employed. Analysis on drilling data also showed that there is no direct correlation between the coating characteristics (microhardness and friction coefficient) with the tool life improvement. For example, microhardness of TiCN coated drill is almost double than the hardness of TiAlN coated drill, but the tool life improvement is not necessary double. Same thing also observed with friction coefficient, where the friction coefficient of TiN coated drill is almost half of the friction coefficient of uncoated drill, but the tool life improvement is about 18 times than uncoated drill.

Table 1: Drilling performance test results

No.	Sample	Microhardness (HV)	Friction coefficient	Number of drilled holes	Tool life improvement
1.	Uncoated	690	0.75	24	-
2.	TiCN	3000	0.25	812	33 times
3.	TiAlN	1600	0.30	668	27 times
4.	TiN	1300	0.40	435	18 times

In the early stage of drilling process, the drill chip (medium carbon alloy steel) was in the shape of long strip. Subsequently, as the number of drill holes increase, the drill chip changes to curly shape as a result of build-up edge on the cutting lip of the drill (Fig. 1). At the end of drill life, the drill chip broke to a smaller size and change to bluish colour due high heat generated during drilling process. Under this condition, the temperature of between 960°C to 1000°C is required to change the chip from original shiny steel to the dark blue coloured chips.⁸ Figure 2 shows the medium carbon alloy steel work piece after 423 drilled holes. EDAX analysis on the drill chip showed that only composed of ferum

element which has a higher melting point whereas other elements in the work piece such as Mn and P which have lower melting point have been disposed during drilling (Fig. 3). Melting point of iron is about 1,538°C, thus we can assume that the flash temperature at the point of contact must be higher than 1,538°C. At this high flash temperature, the other elements in the composition which have low boiling temperatures such as Mn and P might have depleted away and could not be detected by spot EDX analysis. Boiling temperature of Mn and P is about 1246°C and 44.1°C, respectively.

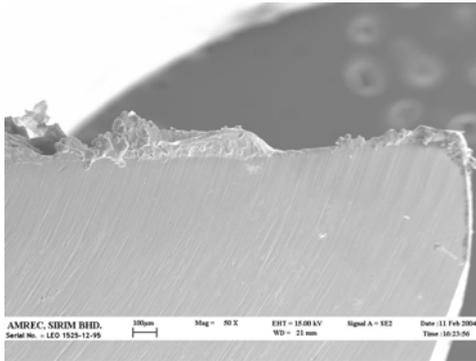


Figure 1: Formation of build-up on the cutting lip



Figure 2: Medium carbon alloy steel work piece after 473 drilled holes

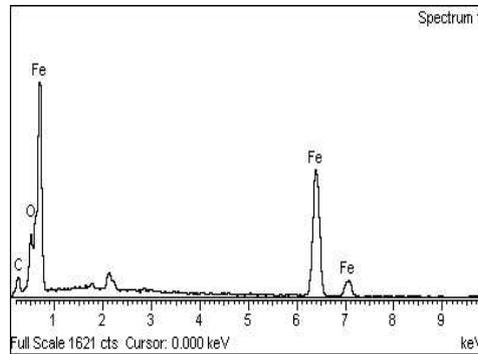
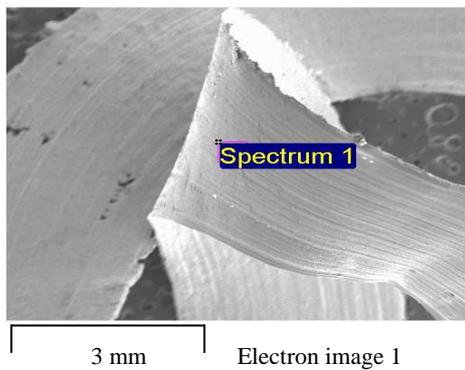


Figure 3: EDAX analysis on medium carbon alloy chip

4. WEAR MECHANISM

Wear does not operate as a single process but a combination of wear mechanism of adhesion, abrasion, fatigue, impact and corrosion. In general, all drill undergo wear mechanism transition from one combination to another and from mild to severe wear as the number of drilling holes or drill speed increases. For uncoated drill, it was observed that a build-up edge was formed on the cutting lip after 12 drilling holes. This phenomenon was due to friction effects between the two mating surfaces. Figure 4 shows the generation of build-up edge and the EDAX analysis reveals that the drill flank composed of element from both the coating (Ti, Al, N) and work piece (Fe) elements. In this observation, the coating still intact, thus the Fe element detected on the drill flank came from the medium carbon alloy steel work piece.

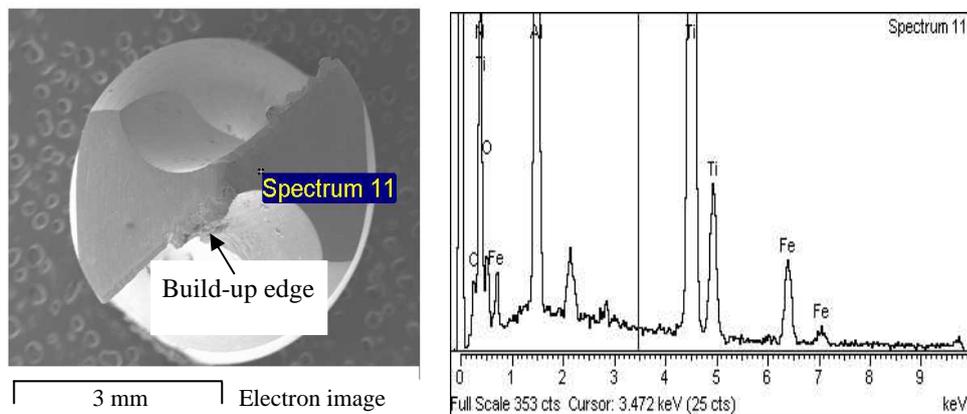


Figure 4: EDAX analysis on drill flank of TiAlN coated drill

With subsequent drilling, the flaking of materials occurred on the worn surface of the drill tip (Fig. 5). EDAX analysis shows that the coating adhesion film failure has occurred, exposing the drill substrate material which only composed higher melting elements (Fe, W, V, Mo, Cr). At the end of drill life, it was observed that the cutting edge became blunt and some materials have been chip-off from the drill edge (Fig. 6). Abrasion mechanism was found to operate during this period. Finally, the drill was unable to penetrate further into the work piece as a result of severe adhesive mechanism on the drill flank as shown in Figure 7.

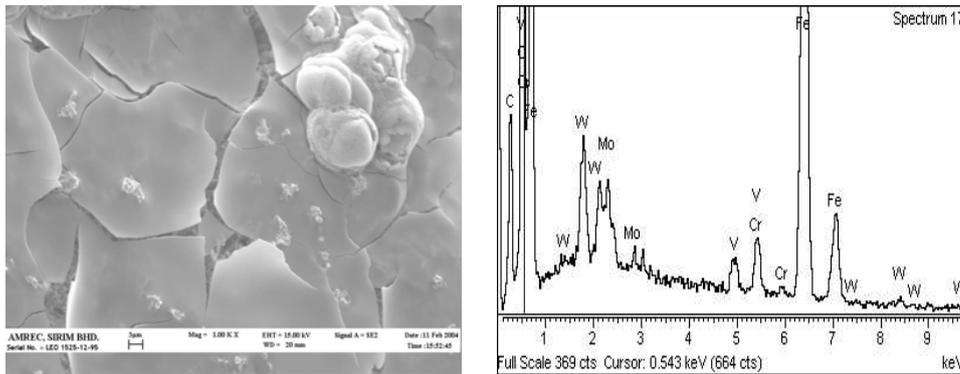


Figure 5: Flaking mechanism: (a) SEM morphology and (b) EDAX spectrum

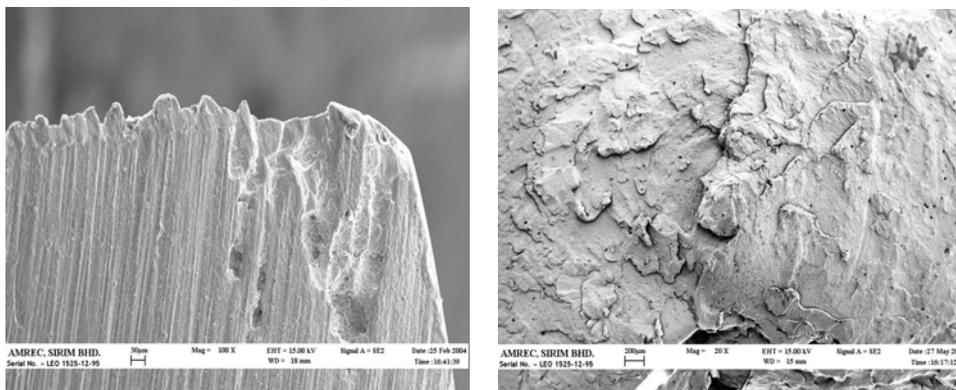


Figure 6: Chipping-off phenomena and abrasion wear mechanism

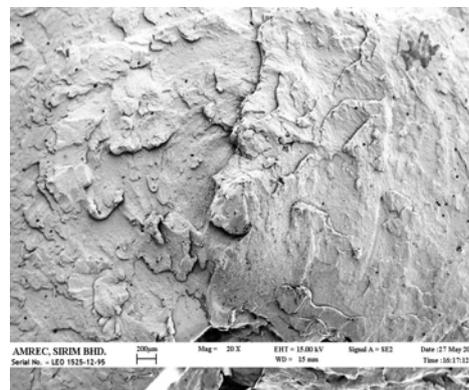


Figure 7: Severe adhesive wear mechanism on the flank

4.1 Abrasion Mechanism

Generally, engineering surface is rough on microscopic scale and has peaks and valleys. In the early process of drilling, the harder peak asperities ploughed onto the cutting lip as well as on the flank surfaces as shown in Figure 8. This is a manifestation of wear abrasion mechanism. As the drilling process progresses, the peak asperities were sheared and became blunt (Fig. 9). The abrasion mechanism was observed on the drill flank throughout the drilling performance test.

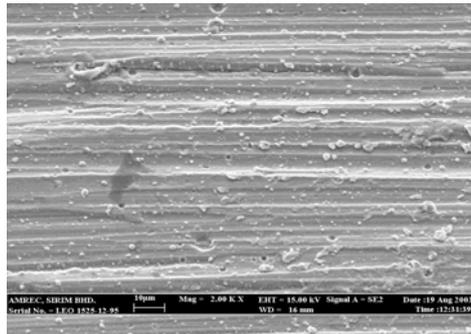


Figure 8: SEM image on abrasion mechanism on drill flank of TiN-coated drill

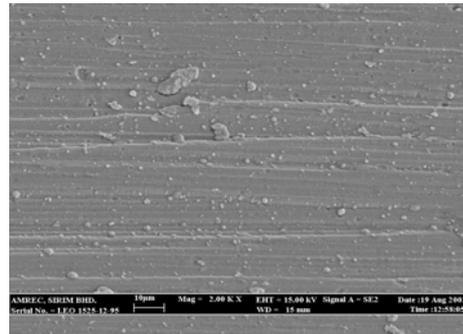


Figure 9: Peak asperities were heard and compacted on the worn surface on drill flank of TiN-coated drill

4.2 Adhesion Mechanism

During drilling process, the peak asperities are subjected to repeated contact resulting in plastic deformation. Subsequently, the material at the peak asperities becomes unstable to the local shear, detaches, forming junctions as well as starts growing as shown in Figure 10. Subsequently, it forms a transfer patches. As the drilling process progresses, the two-way transfer during sliding caused the formation of transfer layers on both sides of the sliding surfaces. Figure 11 shows EDAX analysis on the drill flank. It was observed that the transferred layers composed of element from both the coating elements (Ti, Al, C, N, Cr) and work piece materials (Fe, Mn, Cr) as shown in Table 2. This process is known as mechanical alloying of transfer layer as observed by other researchers such as Chen and Rigney.⁹

The generation of the transfer layers was due to the compaction, smearing and shearing of wears debris and a newly transferred fragment during drilling process. When the shearing action overcomes the cohesive bond strength of the film, the film splits and adheres to both sliding surfaces. After some sliding, some of the mixed transfer layers fall out as wear debris, but most of which remains as a transfer film. The transfer films are continuously smeared and sheared on the sliding surfaces, covering the worn surfaces and finally generating multilayers on the worn surface as shown in Figure 10(c).

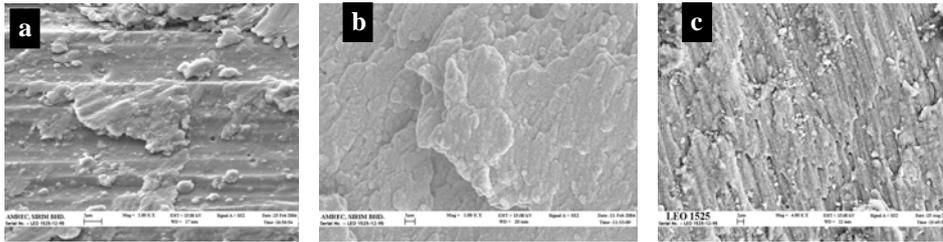


Figure 10: SEM image of adhesion wears mechanism on the TiN-coated drill: (a) early stage of drilling process, wear particles and scratch markings were observed on the worn surface, (b) formation of transfer layer, and (c) formation of multilayers

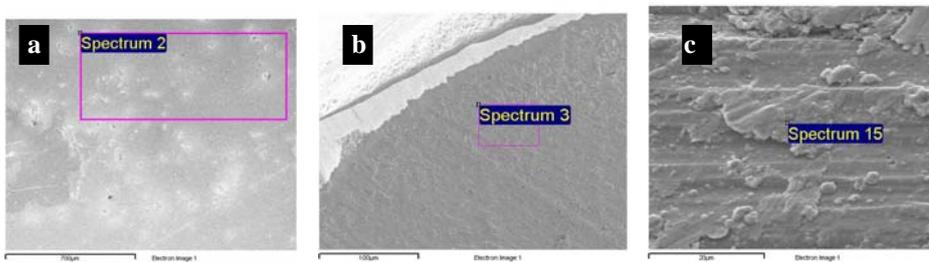


Figure 11: SEM images on the worn area: (a) TiAlN-coated drill, (b) TiCN-coated drill, and (c) TiN-coated drill

Table 2: Element composition on the worn surfaces

Element	Weight (%)		
	TiAlN	TiCN	TiN
C K	4.76	10.43	4.3
N K	13.4	8.39	15.6
O K	4.25	21.40	3.44
Al K	13.10	-	-
Ti K	35.59	27.9	1.54
Cr K	-	0.47	1.57
Mn K	1.1	0.49	1.85
Fe K	27.8	30.92	71.7
Total	100.00	100.00	100.00

4.2 Thermal Mechanism

During drilling process heat is generated as a result of sliding friction between the drill and the work piece especially when the coating film has been removed from the drill surface. This accumulation of heat causes the temperature rise at the contact area and produces higher pressure and temperature in that region. This phenomenon result in more localized thermal expansion. EDAX analysis shows that only element of ferum and carbon left in the metal droplet which have melting points of 1538°C and 5000°C, respectively, whereas other elements which have low melting point such as Mn (1246°C), P (44.1°C), Ni (1453°C) might have depleted away and could not be detected by spot EDAX as shown in Figure 12.

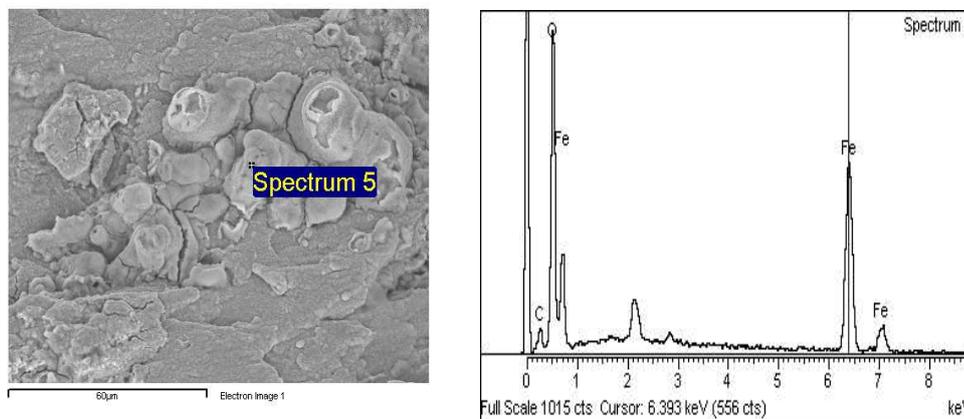


Figure 12: EDAX analysis on contact area: (a) SEM image of contact area and (b) EDAX spectrum

Figure 13(a) shows that the localized thermal expansion areas were located at a higher position on the wear surfaces and thus became the contact area as the drilling progressed. These small contact areas were subjected to high pressures as they have to carry high loads. The temperature keeps increasing during drilling at the contact area until at one stage some of the elements in the composition start to evaporate [Fig. 13(b)]. The temperature rise at the contact area introduced thermal stresses, which could superimpose onto the mechanical stresses and causes increased total contact stresses, resulting in the generation of thermomicrocracks on the contact area. As drilling progresses, thermomicrocracks grew, propagated and finally joined together forming multiple thermomicrocracks as shown in Figure 13(c).

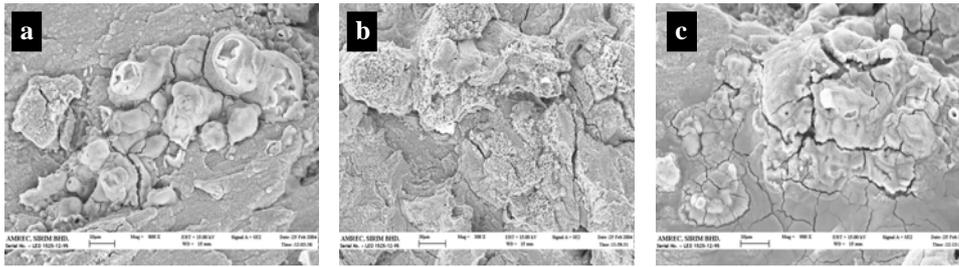


Figure 13: SEM images of thermomicrocrack generation on TiAlN coated drill: (a) contact area due to localized thermal expansion, (b) early stage of microcrack generation, and (c) generation of multiple thermomicrocrack

5. CONCLUSIONS

The wear mechanism operated on the drill flank and cutting lip of the TiN, TiCN and TiAlN coated drill during drilling process was found to be a complex mixture of abrasion, adhesion and thermal wear. Wear mechanism interacted with one another, but only one mechanism will dominate. In the early stage of drilling, it was observed that a complex mixture of wear mechanism of abrasion and adhesion were taken during drilling process. Then, the wear mechanism changed to a complex mechanism which involved a mixture of abrasion, severe adhesion and thermal wear mechanism at the end of drill life. It was also observed that the severity of wear mechanism increases with increasing number of drilling holes. Finally, 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.

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7. REFERENCES

1. Zeng, X., Zhang, S. & Hsieh, J. (1998). Development of graded Cr-Ti-N coatings. *Surface and Coating Technology*, 102, 108–112.
2. Lin, K.L., Chao, W.H. & Wu, C.D. (1997). The performance and degradation behaviours of the TiAlN/interlayer coatings on drills. *Surface and Coating Technology*, 89, 279–284.
3. Talib, R.J., Saad, S., Toff, M.R.M., Hashim, A.H., Abdullah, M.Z., Afandi, S. & Rahman, M.A. (2003). Drilling performance of TiN-coated drill bits: A preliminary result. *Journal of the Institute of Materials Malaysia*, 4(1), 61–72.
4. Shizhi, L., Cheng, Z., Xiang, S., Hongshun, X, Yan & Wu, H. (1990). The application of hard coatings produced by plasma assisted chemical vapour deposition. *Surface and Coating Technology*, 43/44, 1007–1014.
5. Aboukhashaba, A.A. (1988). Life of TiN and Ti(C,N) coated and uncoated HSS drills. *Surf. Eng.*, 4(4), 316–321.
6. Chen, M., Jian, X.G., Sun, F.H., Hu, B. & Liu, X.S. (2002). Development of diamond-coated drills and their cutting performance. *Journal of Materials Processing Technology*, 129, 81–85.
7. Sedlacek, V. (1982). *Metallic surfaces, films and coatings*. Czechoslovakia: Elsevier.
8. Ning, Y., Rahman, M. & Wong, Y.S. (2001). Investigation of chip formation in high speed end milling. *Journal of Materials Processing Technology*, 113(2001), 360–367.
9. Chen, L.H. & Rigney, D.A. (1985). Transfer during unlubricated sliding of selected metal systems. *Wear*, 59, 213–221.