Tool Wear Morphology and Chip Segmentation in End Milling Titanium Alloy Ti–6Al–4V

Turnad L. Ginta, A.K.M. Nurul Amin, A.N.M Karim, Anayet U. Patwari
Department of Manufacturing and Materials Engineering
International Islamic University Malaysia, Kuala Lumpur, Malaysia
Email: turnad70@yahoo.co.id

M.A. Lajis
Faculty of Mechanical and Manufacturing
UTHM, 86400 Batu Pahat
Johor, Malaysia

Abstract— **This paper investigates the tool wear morphology and chip segmentations in end milling of titanium alloy Ti–6Al–4V using uncoated WC-Co inserts under dry conditions. CNC Vertical machining centre was employed during the experimentations. Sandvick end milling of uncoated tungsten carbide inserts were chosen as the cutting tools. The effect of cutting parameter, i.e. cutting speed, feed, and axial depth of cut on tool wear morphology and chip segmentations are comprehensively investigated. Scanning electron microscope is utilized for these purposes. Several type of wear, such as flank wear, crater wear, chipping, etc, is successfully disclosed. Primary and secondary chip serrations also appear on the chip segmentations.**

Keywords-tool wear; chip segmentation;Ti-6Al-4V;end milling

I. INTRODUCTION

Titanium alloys are known as difficult-to-machine materials, especially at higher cutting speeds, due to their several inherent properties. These alloys are widely used in the turbine industry due to their superior mechanical, chemical and high temperature properties. Titanium alloys are generally used for structural applications, such as cases and impellers. For these alloys, machining productivity is limited by intensive tool wear which indirectly represents a significant portion of the machining. However, by properly selecting the tool material and cutting conditions an acceptable rate of tool wear may be achieved and thus lowering the total machining cost [1]. The performance of a cutting tool is normally assessed in terms of its life. Different wear criteria are usually used in assessing tool life. Mostly, flank wear is considered, since it largely affects the stability of the cutting wedge and consequently the dimensional tolerance of the machined work surface [2].

Machining of titanium alloys was the subject of interest for many years. Ginta et al [3] developed the surface roughness models in end milling Ti-6Al-4V using uncoated WC-Co and PCD inserts. They found that feed has the most significant influence on surface roughness, followed by cutting speed and axial depth of cut. Jawaid et al [4] studied the tool wear characteristic in turning titanium alloy Ti-6246. It was found that inserts with fine grain size and a honed edge have a longer tool life. At higher cutting speeds the tool failure was due to maximum flank face wear and excessive chipping on the flank edge.

Chip morphology and segmentation play a predominant role in determining machinability and tool wear during the machining of titanium alloys. At lower cutting speeds the chip is often discontinuous, while the chip becomes serrated as the cutting speeds are increased [5]. Due to its importance, the chip segmentation phenomenon has been extensively investigated and studied worldwide. Attempts to describe the chip morphology in cutting titanium and its alloys date back to the work performed by Cook in 1953 [6]. He investigated the chip morphology of titanium at different cutting speeds and proposed a thermodynamic theory for chip formation. Nakayama et al. [7] and Shaw and Vyas [8] proposed the periodic crack formation theory in machining hard steel. Komanduri et al. [9] studied the chip formation process during the cutting of Ti–6Al–4V and proposed the well-known ‘catastrophic shear chip’ theory. Other early investigations into chip segmentation in the cutting of titanium alloys were performed by Lee [10] and Gente and Hoffmeister [11].

The main objective of this paper is to investigate the tool wear morphology and chip segmentation during end milling Ti-6Al-4V with uncoated WC-Co inserts. Scanning electron microscope was utilized for that purpose.

II. EXPERIMENTAL SET UP AND PROCEDURE

The workpiece material used in all experiments was alpha-beta titanium alloy Ti-6Al4V. The microstructure consists of both coaxial and columnar alpha phase and inter-granular beta phase. Sandvick uncoated WC-Co inserts were used in the experiments.

End milling tests were conducted on a Vertical Machining Centre (VMC ZPS, Model: MLR 542 with full immersion cutting. Machining was performed with a 20 mm diameter end-mill tool holder fitted with one insert. All of the experiments were run under room temperature with full immersion (radial depth of cut of 20 mm). Selected various cutting conditions for the experimentation were determined. Scanning electron microscope (SEM) was utilized to investigate the tool wear morphology and chip segmentations.

III. Results and Discussions

A. Tool wear morphology

SEM views of worn tools at various cutting conditions for selected cutting conditions are presented from Fig 1 to Fig. 4. In most cases, abrasion/attrition, plastic deformation and diffusion wear are observed to have occurred. The wear on the major flank is typically in the form of flank wear.

In the case of medium cutting speed, low feed and axial depth of cut, abrasion/attrition wear is evidently occurred close to the rake face as shown in Fig. 1 and Fig. 2. It was due to the fact that attrition, chipping, and plastic deformation are the major causes of wear when machining of aero-engine alloys with carbide tools at lower speed conditions [12]. At low feed, the stresses act very close to the cutting edge and lead to its intensive plastic deformation.

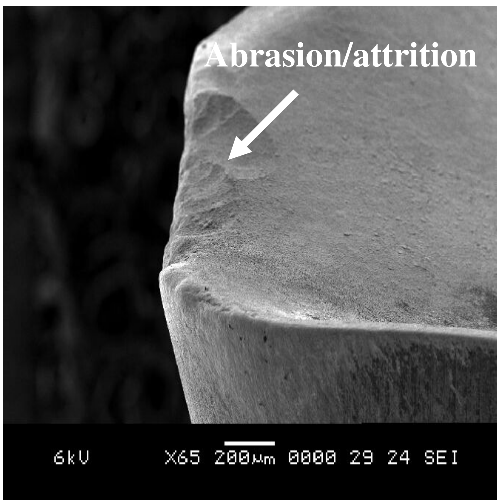

Figure 1. V= 39 m/min, axial DOC = 0.61 mm, feed = 0.06 mm/tooth

As the cutting parameters are increased, non-uniform wear are dominant from nose land to flank land. At high cutting speed and low feed, a combination of diffusion, attrition and plastic deformation was present as shown in Fig. 2, Fig. 3 and Fig. 4. This is related to the effects of high cutting speed in increasing temperature during cutting. In intermittent cutting like end milling, a cyclic thermal stress is principally prominent, which generates fatigue crack and eventually starts the wear.

At higher cutting speed and feed, wear mainly consists of non-uniform wear due to plastic deformation at the nose section as shown in Fig. 4. Combination of high cutting speed and feed substantially increase the stress near the nose and flank zone, generates high temperature and encourages high wear rate. It is related also to the fact that machining at higher speed conditions tend to generate higher temperature close to the nose resulting in excessive stress at the tool nose causing plastic deformation and subsequent tool failure.

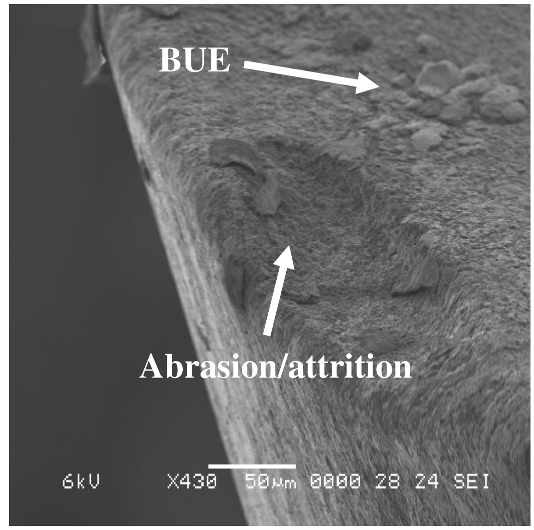

Figure 2. V = 70 m/min, axial DOC =0.61 mm, feed = 0.088 mm/tooth

Furthermore, the rake and flank wear were obviously resulted from dissolution-diffusion and attrition when machining titanium alloys. Dissolution-diffusion wear predominated on the rake face where attrition was the competitive wear mechanism [12]. Due to the very high chemical reactivity of this alloy, it has tendency to weld to the cutting tool during machining which leads to chipping and premature tool failure.

The presence of built-up edge (BUE) is observed during cutting as shown in Fig. 2. It is related to the high temperature generated during cutting which leads to an increase in chemical reactivity between chips or materials and cutting tools, and consequently leads to the formation of BUE.

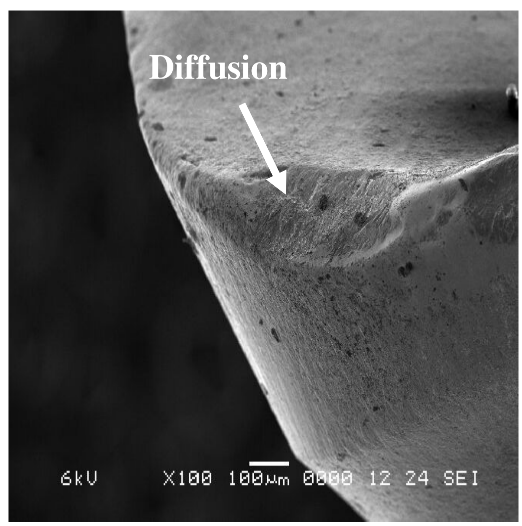

Figure 3. V = 127 m/min, axial DOC = 1 mm, feed = 0.088 mm/tooth

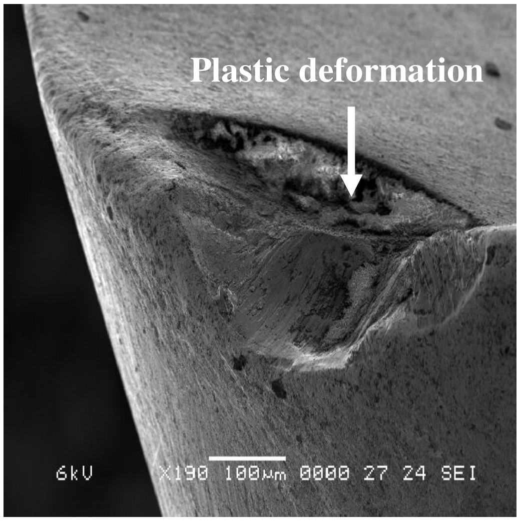

Figure 4. V= 160 m/min, axial DOC = 1 mm, feed = 0.15 mm/tooth

B. *Chip morphology*

Figure 5 presents the SEM views of the chip morphology which is formed in end milling of titanium alloy Ti-6Al-4V. It can be observed from the SEM view of chip that there are chip serrations running across the whole width of the chips. These teeth are termed as 'primary serrated teeth'. There are also marks of grouping of several serrated elements at the upper – free edge and in some cases at the lower – tool nose-side edge of the chip. These larger coagulated elements are termed as 'secondary serrated teeth'. Fig. 6 presents the cross section of chip morphology. The figure introduces a term 'peak to valley (PV) ratio, which depicts the stability of the chip. The lower the PV ratio, the more stable the chips produced.

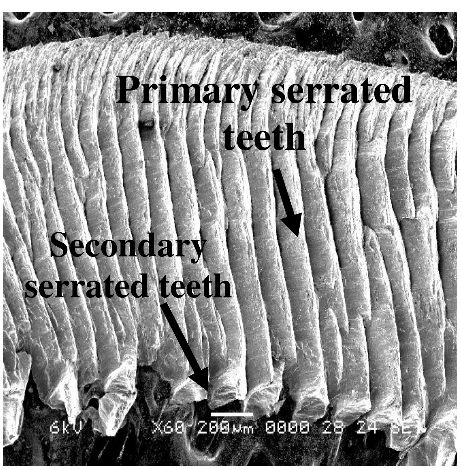

Figure 5. Chip morphology after end milling titanium alloy (V = 70 m/min, axial DOC = 1 mm, feed = 0.088 mm/tooth)

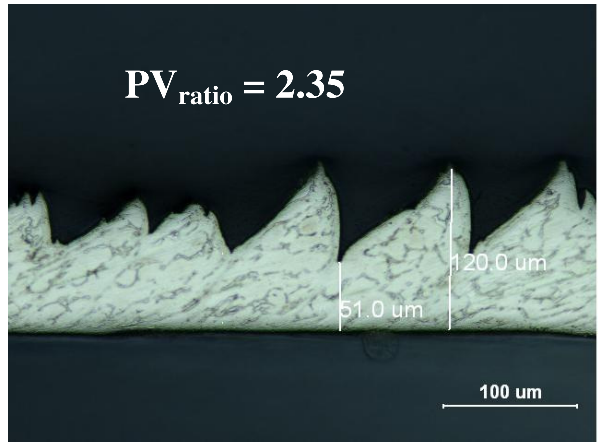

Figure 6. Peak to valley ratio of chip segmentation (V = 70 m/min, axial DOC = 1 mm, feed = 0.088 mm/tooth)

IV. CONCLUSIONS

The following specific conclusions have been drawn on the work:

1. Tool wear morphology and chip segmentation have been succesfully investigated after end milling of titanium alloy Ti-6Al-4V using uncoated WC-Co inserts.
2. Abrasion/attrition, plastic deformation and diffusion wear are the most cases which are observed. Furthermore, in the case of medium cutting speed, low feed and axial depth of cut, abrasion/attrition wear is occurred close to the rake face.
3. At higher cutting speed and feed, wear mainly consists of non-uniform wear due to plastic deformation at the nose section. Combination of high cutting speed and feed substantially increase the stress near the nose and flank zone, generates high temperature and encourages high wear rate.
4. Both primary and secondary serrated teeth are formed in end milling of titanium alloy Ti-6Al-4V using uncoated WC-Co inserts. The peak to valley ratio of chip segmentation can be introduced to investigate the stability of a chip.

ACKNOWLEDGMENT

The authors wish to thank Ministry of Science, Technology and Innovation (MOSTI) Malaysia for their financial support to the above project through the e-Science Fund Project (Project No.03-01-08-SF0001), and the Research Management Centre IIUM for overall management of the project.

REFERENCES

[1] H.A. Kishawya, C.E. Becze, D.G. McIntosh., "Tool performance and attainable surface quality during the machining of aerospace alloys using self-propelled rotary tools", Journal of Materials Processing Technology, 152, 2004, pp. 266–271.

[2] Turnad L. Ginta, A.K.M. Nurul Amin, A.N.M. Karim, Agus G. Sutjipto.,"Tool life prediction by response surface methodology for end milling titanium alloy Ti–6Al–4V using uncoated carbide inserts", Proc. of ICME 2007, Dhaka.

[3] Turnad L. Ginta, A.K.M. Nurul Amin, A.N. M Karim, M. H. Ishtiyaq., "Modeling for Surface Roughness in End-Milling of Titanium Alloy Ti-6Al-4V Using Uncoated WC-Co and PCD Inserts", Proc. of The 4th International Conference on Leading edge Manufacturing in the 21st Century, Fukuoka, 2007, pp. 23 – 28.

[4] Jawaid, C.H. Che-Haron, A. Abdullah., "Tool wear characteristics in turning of titanium alloy Ti-6246", Journal of Materials Processing Technology, 1999, 92-93 pp. 329-334.

[5] Jiang Hua and Rajiv Shivpuri, "Prediction of chip morphology and segmentation during the machining of titanium alloys", Journal of Materials Processing Technology 150, 2004, pp. 124–133.

[6] N.H. Cook,"Chip formation in machining titanium", in: Proceedings of the Symposium on Machine Grind. Titanium, Watertown Arsenal, MA, 1953, pp. 1–7.

[7] K. Nakayama, M. Arai, T. Kanda, "Machining characteristics of hard materials", CIRP 37 (1), 1988, pp. 89–92.

[8] M.C. Shaw, A. Vyas, "Chip formation in the machining of hardened steel", CIRP 42 (1), 1993, pp. 29–33.

[9] R. Konmanduri, T.A. Schroeder, D.K. Bandhopadhyay, J. Hazra, "Titanium: a model material for analysis of the high-speed machining process, advanced processing methods for titanium", in: D.F. Hasson, C.H. Hamilton (Eds.), The Metallurgical Society of ASME, 1982, pp. 241–256.

[10] Lee, "The effect of cutting sped on chip formation under orthogonal machining, J. Eng. Ind., Trans. ASME 107 (1), 1985, pp. 55–63.

[11] Gente, H.W. Hoffmeister, "Chip formation in machining Ti–6Al–4V at extremely high cutting speeds", CIRP 50 (1), 2001, pp. 49–52.

[12] P.A. Dearnly, A.N. Grearson. "Evaluation of principal wear mechanisms of cemented carbides and ceramics used for machining titanium alloy IMI 318", Mater. Sci. Technol. 2, 1986, pp. 47 – 58.