euspen's 15th International Conference & Exhibition, Leuven, Belgium, June 2015
www.euspen.eu

Study on shape similarity of single crystal diamond tool wear land with large nose radius in ultra-precision cutting of aluminum alloy

Eiji KONDO[1], Ryuichi IWAMOTO[2] and Yuya KOBARU[3]

[1]*Kagoshima University*
[2]*Kagoshima Prefectural Institute of Industrial Technology*
[3]*Kagoshima National College of Technology*

kondo@mech.kagoshima-u.ac.jp

Abstract
Purpose of this study is to relate area of tool wear land of cutting edge with local width of wear which generates finished surface in ultra-precision cutting of aluminium alloy. To achieve this purpose, the relationship between the area of wear land and the local width of wear was experimentally investigated in ultra-precision face turning of aluminium alloy with a single crystal diamond tool having large nose radius. As a result of the cutting tests and measurements, it was found that local widths of wear land obtained under different cutting conditions were formulated by a function if local width of wear land was normalized by local uncut chip thickness, distance from top end of wear land was normalized by width of cutting cross section, and area of wear land was normalized by area of cutting cross section.

Keywords: Ultra-precision Cutting, Tool Wear, Single Crystal Diamond Tools, Aluminium Alloy

1. Introduction

Many approaches of condition monitoring in machining have been proposed to accomplish practical application of fully automated machine tools [1]. While large wear of single crystal diamond tool deteriorates finished surface in ultra-precision cutting, the local wear land width of cutting edge generating finished surface of workpiece fairly affects the surface integrity. Consequently, monitoring of local wear of cutting edge is important for machining high quality parts. However, it is difficult to monitor local wear of cutting edge generating finished surface since the local wear generating finished surface is very small. On the other hand, area of tool wear land could be monitored by static cutting forces, dynamic cutting force components, and AE signals in previous studies [2-4]. Consequently, Purpose of this study is to relate area of wear land of cutting edge with the local wear land width of cutting edge generating finished surface in ultra-precision cutting of aluminum alloy. To achieve this purpose, the relationship between the area of tool wear land and the local width of wear land of cutting edge was experimentally investigated in ultra-precision face turning of aluminum alloy with a single crystal diamond tool having large nose radius.

2. Experimental method

Table 1 shows experimental conditions. Large and small cylindrical workpieces were used in cutting tests. End face of a cylindrical workpiece was machined in face turning with a single crystal diamond tool having large radius nose on the ultra-precision lathe, using kerosene as cutting fluid. Large cylindrical workpieces of 197 mm in diameter were just used for extending cutting length. Small cylindrical workpieces of 30 mm in diameter were used in the cutting tests. Furthermore, annealed workpieces were machined with the diamond tool of 2 mm in nose radius, and workpieces as rolled were machined with diamond tools of 0.8 and 5 mm because of consideration of effect of workpiece hardness on features of tool wear. Single crystal diamond cutting tools used in this study are widely available in Japan. Features of tool wear were observed by SEM. Experimental data obtained by using cutting tool of 0.8, 2, and 5 mm in nose radius under experimental condition in Table 1 will be symbolized by R0.8, R2, and R5 in this paper after this.

Table 1 Experimental conditions

Tool	Material	Single crystal diamond		
	Nose radius mm	5 (R5)	0.8 (R0.8)	2 (R2)
Workpiece	Material	JIS A5056		
	Diameter mm	30 (, 197)		
	Heat treatment	As rolled		Annealed
	Hardness Hv	90		63
Feed rate	f μm/rev	50	30	40
Depth of cut	d μm	30		
Spindle speed	rpm	1000		
Cutting fluid		Kerosene		

2. Experimental results

Figure 1 shows a schematic diagram of cutting cross section and direction of observation of the cutting edge. Figure 2 is an electron micrograph showing typical features of cutting edge observed at cutting distance of 1997 km close to its tool life. The points represented by P and Q in the electron micrograph correspond side ends of cutting cross section shown in Fig. 1, respectively. Wear land of cutting edge is surrounded by the two curves, and rake and flank wear lands are separated by the boundary between the upper dark area and the lower bright area. Consequently, width of flank wear land w_f is defined as distance between the lower curve and the boundary in vertical direction. Width of rake wear land w_r is defined as distance between the upper curve and the boundary. Distance from top end P along with cutting edge is represented by l_w.

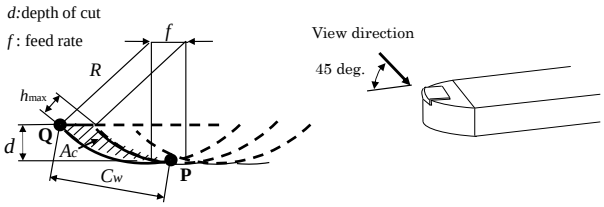

Figure 1. Cutting cross section and view direction of cutting edge

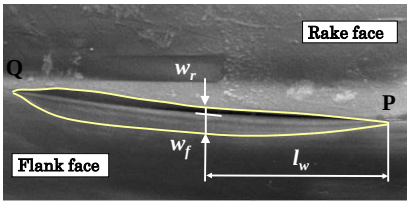

Figure 2. Electron micrograph of cutting edge (R2, L = 1997 km)

2.1. Flank wear

Figure 3 shows width of flank wear land w_f and uncut chip thickness h corresponding to distance from top end of wear land l_w in case of cutting conditions R0.8, R2, R5 when area of flank wear land A_{wf} normalized by area of cutting cross section A_c is about 5. It can be seen that maximum width of flank wear land depends on the nose radius since maximum uncut chip thickness h_{max} expressed by height of triangle in Fig. 3 and width of cutting cross section C_w shown in Fig. 1 are determined by cutting conditions. Figure 4 shows relation between the width of flank wear land w_f normalized by uncut chip thickness h and the distance from top end of wear land l_w normalized by the width C_w and it demonstrates that normalized widths w_f /h obtained under different cutting conditions are approximated by a logarithmic function of normalized distance l_w/C_w less than 0.8.

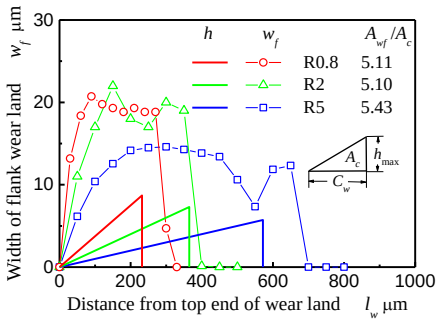

Figure 3. Width of flank wear land and uncut chip thickness

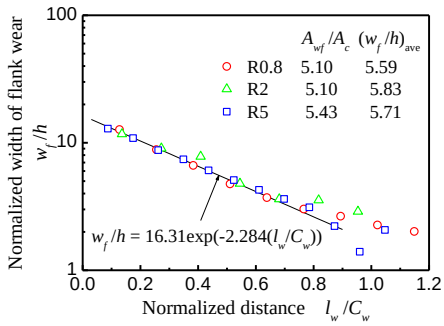

Figure 4. Normalized width of flank wear land with normalized distance

2.2. Rake wear

Figure 5 shows width of rake wear land w_r and uncut chip thickness corresponding to distance from top end of wear land l_w in case of cutting conditions R0.8, R2, R5 when area of rake wear land A_{wr} normalized by area of cutting cross section A_c is about 1. It can be seen that maximum width of flank wear land depends on maximum uncut chip thickness h_{max}. However, local width of flank wear land w_r does not depend on local uncut chip thickness h. Figure 6 shows relation between the width of rake wear land w_f normalized by maximum uncut chip thickness h_{max} and normalized distance l_w/C_w at normalized area of flank wear land A_{wr}/A_c of about 2 near tool life of the cutting tool. It demonstrates that local normalized widths w_r /h_{max} obtained under different cutting conditions are approximately same at local normalized distance l_w/C_w.

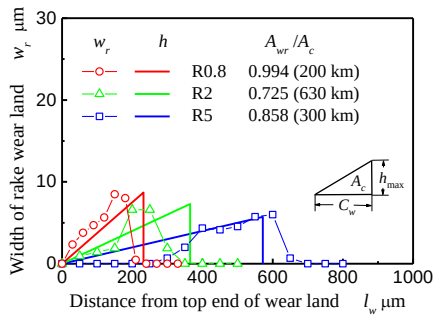

Figure 5. Width of rake wear land and uncut chip thickness

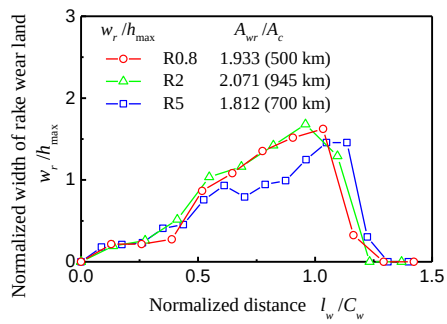

Figure 6. Normalized width of rake wear land with normalized distance

3. Conclusions

1) The normalized widths obtained under different cutting conditions were approximated by a logarithmic function of the normalized distance when local width of flank wear land was normalized by local uncut chip thickness, distance from top end of wear land was normalized by width of cutting cross section, area of flank wear land was normalized by area of cutting cross section, and the normalized area of flank wear land was same.

2) The local normalized widths obtained under different cutting conditions were approximately same at the same normalized distance when local width of rake wear land was normalized by maximum uncut chip thickness, area of rake wear land was normalized by area of cutting cross section, and the cutting tool was close to its tool life.

3) Maximum width of flank wear land was approximately twice and a half times of maximum uncut chip thickness and maximum width of rake wear land was approximately one and a half times of maximum uncut chip thickness.

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