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Effects of oil mist and air jet flushing on tool wear in milling of Ti6Al4V at high speed

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Abstract

Titanium alloys have been widely used in the aerospace, biomedical and automotive industries because of their good strength-to-weight ratio and superior corrosion resistance. However, it is very difficult to machine Titanium alloy materials due to their poor machinability, resulting in short tool life. The effects of oil mist and air jet flushing on tool wear in the milling of Ti6Al4V were investigated at a cutting speed of 300 m/min in this study. Tests with various flushing directions of oil mist and air jet during up, and down-cut were carried out. Tool wear and chip shape were measured and analyzed. As a result of these cutting tests and considerations, it was revealed that up-cut with oil mist flushed from any direction and air jet flushed from the side were desirable, and dry down-cut was also desirable.

Keywords: Milling, Tool, Wear, Titanium alloy, High speed

1. Introduction

Titanium alloys have been widely used in the aerospace, biomedical and automotive industries because of their good strength-to-weight ratio and superior corrosion resistance. However, it is very difficult to machine Titanium alloy materials due to their poor machinability resulting in short tool life, especially during high speed machining [1][2]. Consequently, the mechanisms of tool wear and tool lives have had serious problems during the end milling of Titanium alloy, and a lot of studies have been carried out to find solutions [3]-[9]. It was revealed in previous studies that cooling/lubricant conditions, cutting direction, and coating had a great influence on cutting temperature and tool wear. On the other hand, in the high-speed end milling of mild steel, it was reported that oil mist flushing on a portion of the end mill affects tool wear [10]. Consequently, it is expected that in the high-speed milling of titanium alloy, the flushing direction of oil mist on the end mill would affect tool wear during up and down-cuts.

The effects of oil mist and air jet flushing on tool wear in the milling of Ti6Al4V were investigated at a cutting speed of 300 m/min. Tests of various directions for oil mist and air jet flushing during up, and down-cut were carried out. Tool wear and chip shape were measured and analyzed.

2. Experimental Apparatus and Conditions

Cutting tests were carried out on a vertical machining center. The experimental apparatus used in this study is shown in Fig.1 and cutting conditions are shown in Table 1. The workpiece material is the typical titanium alloy Ti6Al4V. The upper square end face of the workpiece with an edge length of 25 mm was milled with a single cutting edge end

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mill using both up and down-cut. Cutting length was defined as 25 mm (the width of the workpiece) multiplied by the number of cuts, as shown in Fig. 2. Cutting tests were carried out at a cutting speed of 300 m/min in which the direction of oil mist and air jet flushing during up, and down-cut, were adopted as experimental parameters. In each cutting test ~~with~~ oil mist or air jet ~~flushing, it~~ was flushed from each direction as shown in Fig. 2: the rake face side or Front, the direction parallel to rake face or Side, and the flank face side or Rear. The nozzle hole is 2 mm in diameter. The distance from the nozzle for oil mist and air jet flushing to the chip was about 30 mm. Chips adhered to the cutting edge, just coming off the workpiece, were observed with a high-speed camera per spindle revolution. The width of cutting edge wear-land was measured off machine at constant cutting length intervals with a reading microscope. The hardness of the machined surface was measured with a Vickers hardness tester.

Table 1. Experimental conditions

Work-piece	Material	Ti-6Al-4V (as roled)
	Vickers hardness	340 (average)
	Width	25 mm
Cutting tool	Insert material	cemented carbide
	Coating	un-coated
	Rake angle	11 deg.
	Clearance angle	16 deg.
	Diameter	20 mm
	Corner radius	0.8 mm
	Number of inserts	1
Cutting speed		300 m / min
Spindle speed		4775 rpm
Feed speed		382 mm / min (0.08 mm/ rev)
Radial depth of cut		0.5 mm
Axial depth of cut		0.5 mm
Cutting length		0 – 4000 mm
Type of cut		up-, down-milling
Flushing conditions	Air jet	25 l/min
	Oil mist	air: 25 l/min, oil: 33cc/min
Flushing direction of oil mist and air jet		Front, Side, Rear

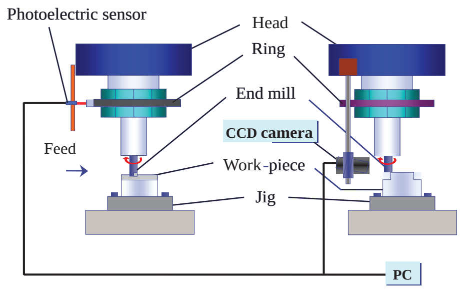

Fig. 1. Experimental apparatus

3. Down-Cut

3.1. Tool wear

Figure 3 schematically illustrates the cutting cross section of milling in this study. As shown in Fig. 3, since the depth of the cut was smaller than the corner radius of the insert, the workpiece surface was milled, creating around corner in the insert. Figure 4 shows photographs of typical cutting edge wear at a cutting length of 3750 mm during dry up-cut. Cuts are viewed from directions normal to rake face and flank faces respectively, and the width of flank wear-land is indicated in the upper right photograph.

Figure 5 shows the width of flank wear-land as machining progressed during down-cut with oil mist flushing. In Fig. 5, the width of flank wear-land at a cutting length of 400 mm in the case of all oil mist flushing directions is about 40 µm, which is less than the width for dry milling. However, flank wear in the case of Side and Front rapidly increased at a cutting length of about 1000 mm, and the 220 µm width in the case of Front was about 3 times as much as the 65 µm width of flank wear-land for dry down-cut at a cutting length of 3500 mm. In case of Rear, flank wear started increasing at a cutting length of about 1500 mm but it is ~~fairly~~ less than the width of wear in the case of the other flushing directions at a cutting distance of 4000 mm.

Figure 6 shows the width of flank wear-land as machining progressed during down-cut with air jet flushing. In Fig. 6, it can be seen that air jet flushing had no influence on flank wear since flank wear for milling with air jet at any cutting distance closely coincided with flank wear for dry milling.

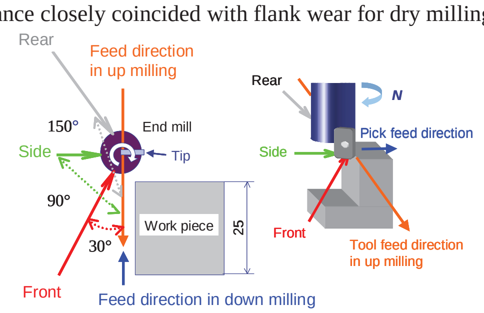

Fig. 2. Flushing directions of oil mist and air jet

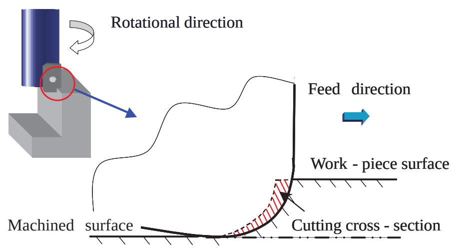

Fig. 3. Schematic diagram of cutting cross section

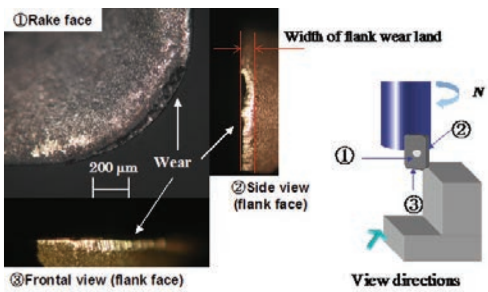

Fig. 4. Cutting edge at a cutting length of 3750 mm for dry up-cut