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The effect of oil mist supply on cutting point temperature and tool wear in driven rotary cutting

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ABSTRACT

We examined cutting point temperature and tool wear in driven rotary cutting. Cutting tests under dry and minimum-quantity-lubrication (MQL) conditions of stainless steel (SUS304) were carried out. Cutting point temperature was measured using a tool-work-thermocouple method at various cutting speeds. Cutting point temperature tends to increase with increased cutting speed. In driven rotary cutting, cutting point temperature was lower than that of non-rotation cutting. At high-speed cutting of 500 m/min, cutting point temperature was over 1200 °C in the non-rotation tool, but 1000 °C with driven rotary cutting. In addition, when driven rotary cutting was used with MQL, cutting point temperature was decreased to 900 °C. The magnitude of tool wear corresponded almost precisely to cutting point temperature. Severe adhesion on the rake face was observed and resulted in progressive wear on the rake face in rotary cutting at a cutting speed of 100 m/min. The appropriate cutting speed range passively shifts higher from the viewpoint of cutting temperature with rotary cutting.

1. Introduction

The superheat alloys used for airplane and gas turbine engines have superior mechanical properties at high temperatures. However, this causes excessive wear of cutting tools during machining for several reasons. The poor heat conductivity of these kinds of metals leads to higher cutting temperatures and severe tool failure. In addition, as the hardness and thickness of the affected layer is large, the boundary wear is often severe. Higher affinity causes adhesive tool wear. Especially on turning, as the tool continuously contacts the work material under high cutting temperature conditions, it is often necessary to employ rather low cutting speed. In order to realize higher cutting speeds, cBN tools and ceramics tools have been applied to the cutting of superheat alloys [1–3]. Although these kinds of tools have higher hardness, their toughness is poor. Sudden tool failure then becomes a risk, and a stable high-speed cutting technique is required.

As a possible solution, rotary cutting tools have been proposed [4] and have received a great deal of attention from researchers over the past few decades [5–13]. Their fundamental principle is a turning operation with an end face that is a cylindrical tool that rotates. Fig. 1 is a schematic of driven rotary cutting. As the round tool rotates, the cutting edge is cooled during periods of non-cutting, and this is effective in decreasing the temperature of the tool. In addition, as tool wear is distributed over the entire cutting tool, notch wear does not occur, and thus tool life is expected to increase.

A large quantity of flood coolant is usually effective in decreasing cutting temperature. Olgun et al. [11], however, reported that a dry condition was better than the flood coolant condition for the rotary turning of AISI 1050. The report suggested that excessive cooling could lead to decreased tool life. The minimum quantity lubrication (MQL) technique, which supplies a small amount of oil with compressed air, is expected to offer better lubrication and to have a moderate cooling effect on the rotary cutting tool. This is because in rotary cutting, if the lubricant is delivered to the cutting edge during the non-cutting period, it enters the tool-chip interface with the tool rotation during cutting. This lubricant supply action is totally different from that on the conventional turning. Capillary effect at elastic tool-chip contact area is the main action to supply the lubricant on the conventional turning process with MQL [14]. Yamamoto et al. [12] reported that when the MQL was supplied to the opposite side of the cutting point of the rotary tool,

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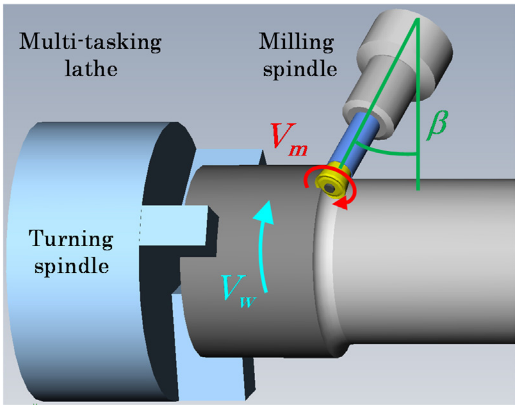

Fig. 1. Schematic model of driven rotary cutting tool.

tool chipping was decreased, as well as adhesion of the chips on the machined surface. Meanwhile, Hosokawa et al. [13] clarified that there are optimum tool rotational speeds to decrease cutting point temperature.

Based on this background, we investigate the effect of MQL on the cutting temperature in this study. Our objective is to clarify the effect of the amount of MQL on cutting temperature and tool wear by the tool life test in driven rotary cutting.

2. Experiment

2.1. Driven rotary cutting on multi-tasking lathe

Fig. 1 shows a schematic of driven rotary cutting on a multi-tasking lathe (MAZAK INTEGREX i-200). A rotary tool is attached to the milling spindle, and the milling spindle head moves linearly along the longitudinal direction of the workpiece. The rotational speed of the rotary tool can be controlled because it is driven by the milling spindle. The inclination angle β can be changed by swiveling the B-axis. Therefore, various machining conditions can be set for one tool. Cutting speed Vw, tool peripheral speed Vm, and tool inclination angle β can affect the cutting tendency; the following dimensionless circumferential velocity ratio V^* is defined as:

$$V^* = \frac{V_m}{V_w \sin\beta} \quad (1)$$

When V^* is 0, it means cutting is conducted with a fixed tool. When V^* is 1, the tool peripheral speed and tangential cutting speed component along the tool are the same; then, the frictional work on the cool flank face will be minimum.

Oil mist was supplied to both the tool rake face and the clearance face through a 1.6 mm diameter nozzle with 0.2 MPa compressed air.

2.2. Temperature measurement by tool-workpiece thermocouple method

Cutting point temperature was measured using the tool-workpiece thermocouple method [15]. Thermal electromotive forces were measured at the cutting point in a closed circuit comprised of the tool, workpiece, and data recorder. Basically, the method allows measurement of the average temperature on the tool-chip (workpiece) contact area. Fig. 2 presents a schematic of the method. A carbide bar and SUS304 bar were employed and pressed by a spring-load to minimize the thermal electromotive forces except at the tool-workpiece contact area. The workpiece was insulated from the chuck. The correlation between the temperature of the tool-chip junction and the thermal electromotive force

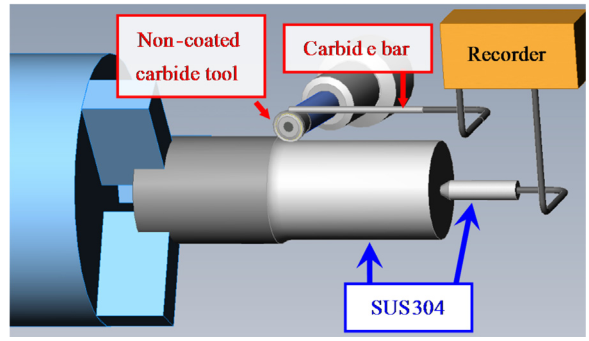

Fig. 2. Tool-workpiece thermocouple method.

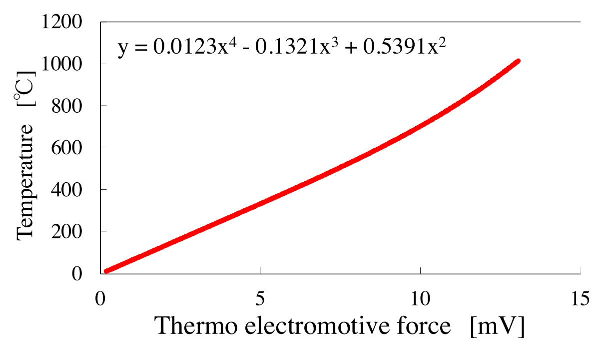

Fig. 3. Correlation of thermal electromotive force and temperature.

Table 1
Experimental conditions for dry and MQL rotary cutting.

Work material	SUS304
Tool material	Non coated carbide, CVD coated carbide
Feed rate	0.5 mm/rev
Depth of cut	0.5 mm
Cutting speed V_w	100–500 m/min
Velocity of tool V_m	0–86 m/min
Ratio of circumferential velocity V^*	0.0, 1.0
Inclination angle of tool β	10°
Normal rake angle	0°
Lubricant supply rate	10.4 ml/h

was clarified, as shown in Fig. 3 by measuring the average temperatures and thermal electromotive forces at the heated contact area of SUS304 and carbide.

3. Driven rotary cutting with MQL

3.1. Experimental conditions

We investigated the effect of the oil mist supply on cutting point temperature and tool wear during driven rotary cutting. Dry and MQL conditions were compared as cutting speeds were varied from 100 m/min to 500 m/min. Table 1 lists the cutting conditions. Stainless steel SUS304 was used as the workpiece material. A CVD-coated insert with TiN-Al_2O_3-TiCN and non-coated carbide insert were employed as tools. Tool diameter was 12 mm. A non-coated carbide insert was used for the temperature measurement using the tool-workpiece thermocouple method. A coated insert was used to test tool life.

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