Development of Tool Edge Temperature Measurement Method in Wet Cutting*

(Application for CBN and Poly Crystalline Diamond Tools)

Hideto NISHIMOTO**, Ryutarou TANAKA***, Akira HOSOKAWA****, Takashi UEDA**** and Tatsuaki FURUMOTO****

** Graduate School of Natural Science and Technology, Kanazawa University
Kakuma-machi, Kanazawa-city, Ishikawa, Japan

*** Graduate School of Engineering, Hiroshima University
1-4-1 Kagamiyama, Higashi-Hiroshima, Hiroshima, Japan

**** Institute of Science and Engineering, Kanazawa University
Kakuma-machi, Kanazawa-city, Ishikawa, Japan
E-mail: ryu-tanaka@hiroshima-u.ac.jp

Abstract
In this paper, the measurement method of tool edge temperature using a two-color pyrometer with an optical fiber in wet cutting is proposed. Using the proposed method, the high pressure air supplied from the small hole where an optical fiber is inserted prevents coolant from adhering to the optical fiber edge and makes temperature measuring possible. The influence of this supplied air pressure on the tool edge temperature is negligible in the 0.05Mpa to 0.6MPa range. In this way, the temperature of CBN and PCD tool edge is measured in wet cutting of Ti-6Al-4V. As a result, the tool edge temperature increases rapidly with the increase of cutting speed. In dry cutting, PCD tool edge temperature is almost 100 ºC lower compared with CBN tool edge temperature. By coolant supply, PCD tool edge temperature decreases greatly. For example, when cutting speed is set at 300m/min, PCD tool edge temperature decreases by 350ºC, while CBN tool edge temperature decreases by only 70ºC.

Key words: Cutting Temperature, Turning, Coolant, Temperature Measurement, Two Color Pyrometer, Wet Cutting

1. Introduction
Titanium alloys are light weight and also have high heat and corrosion resistance property. These alloys are used as jet engine parts and structural member of aero-spaces. It is widely known that the tool edge runs a high temperature in cutting of difficult-to-cut materials such as titanium alloy due to their low-thermal conductivity. As a result, the tool wear progresses rapidly. In order to remove cutting heat from cutting tool, a large quantity of coolant is used in machining of difficult-to-cut materials. Therefore, the tool edge temperature during cutting need to be known to discuss the wear mechanism of cutting tool. The tool edge temperature during cutting is usually measured by a tool-work thermocouple method (1-3). However, there are some problems such as calibration method and electrical conductivity of tool material.

On the other hand, an infrared radiation pyrometer makes it possible to measure cutting temperature regardless of tool materials (4). Muller et al. investigated the temperature distribution on the rake face of a diamond coated tool using a thermo-graphic technique (5). Ueda et al. measured the temperature of alumina ceramic tool-chip interface by the two-color pyrometer (6). However, this method is only applicable for particular kind of tool.
In this study, the measurement method in cutting under coolant supply is proposed and CBN and PCD tools edge temperature are measured by this method in cutting of Ti-6Al-4V.

2. Experimental procedure

Figure 1 shows a schematic illustration of the experimental set-up. The two-color pyrometer with an optical fiber (4, 7) is used as a thermometer. This two-color pyrometer is composed of InAs photodetector and InSb detector, having different spectral sensitivities. Taking the output ratio of these two detectors, we can calculate the temperature of the object using the calibration curve which is obtained by the experiment. The cylindrical materials.

In this study, the measurement method in cutting under coolant supply is proposed and CBN and PCD tools edge temperature are measured by this method in cutting of Ti-6Al-4V.

2. Experimental procedure

Figure 1 shows a schematic illustration of the experimental set-up. The two-color pyrometer with an optical fiber (4, 7) is used as a thermometer. This two-color pyrometer is composed of InAs photodetector and InSb detector, having different spectral sensitivities. Taking the output ratio of these two detectors, we can calculate the temperature of the object using the calibration curve which is obtained by the experiment. The cylindrical materials.
workpiece is used. This workpiece has a fine hole which extends from the outer surface to the inner surface. The inner surface of workpiece is machined by cutting tool which is attached to a boring head. The infrared rays radiated from tool edge during cutting are transmitted to two detectors by an optical fiber which is inserted into small hole. The infrared rays is converted to the electric signal by these two detectors, it is recorded by an oscilloscope.

Figure 2 shows a schematic illustration of layout of an optical fiber setting. In the cutting experiment, the distance between the end face of the optical fiber and the flank face of the cutting tool is kept at 0.5 mm. The heated chip passes through measuring area of the pyrometer in advance of the high temperature tool edge heated during cutting. To discriminate between the output from chip and the output from tool edge, the acceleration pickup is used to sense the moment of tool-workpiece contact.

Table 1 shows the experimental conditions. CVD carbide tool is used as a cutting tool in cutting of AISI1045 and sintered steel SMF4040. CBN (CBN content: 80-95 volume percent) and PCD (diamond content: 80-95 volume percent) tools are used as cutting tool in cutting of Ti-6Al-4V. The cutting fluid (1:30 in water) is supplied from 15 nozzles to cutting area at the rate of 6 L/min.

Figure 3 shows the relation between output ratio of two inferred rays detectors and object temperature. The InAs photodetector and InSb detector has different spectral sensitivities within 1–3 mm and 3–5.5 mm, respectively. Taking the output ratio of these two detectors, we can calculate the temperature of the object using the calibration curve which is obtained by the experiment. The two-color pyrometer can measure the temperature of heat source accuracy regardless of its emissivity. So a SiC heating element is used as a heat source at calibration. Varying heat source temperature, the temperature of heat source is measured by two-color pyrometer and type K thermo-couple. Thus, the between output ratio of two inferred rays detectors and temperature is obtained. The obtained dates coincide well with the theoretical curve taking spectral sensitivity characteristic of an optical fiber and two-color detectors into consideration.

3. Experimental results

3.1 Output signals from the pyrometer and acceleration pickup

Figure 4 shows the output signals of two-color pyrometer and acceleration pickup in dry cutting. In this condition, calculated cycle time per revolution of output signals of the tool are 52ms. The output signal of acceleration pickup reacts in the same period. At this moment, the tool collides with a workpiece after air cutting of the fine hole. From the output signal of acceleration pickup, it is possible to find the moment when the tool edge passes above the hole. The diameter of hole which the optical fiber is inserted is 1.1mm,
and feed rate of cutting tools is 0.1mm/rev. In theory, the cutting tool edge passes above the hole 11 times. The tool edge temperature is calculated from output ratio when the tool edge passes above the hole where the optical fiber is inserted using theoretical calculation curve.

### 3.2 Measurement method of tool edge temperature in wet cutting

The measurement method of tool edge temperature with cutting fluid is reported in this chapter. Figure 5 shows the output of two-color pyrometer and acceleration pickup in wet cutting under non-air supply. It’s thought that cutting fluid adheres to an optical fiber edge, so the infrared rays from tool edge aren’t transmitted. In consequence, the output signal of two-color pyrometer isn’t shown up. In order to measure the tool edge temperature in wet cutting, it is necessary to prevent cutting fluid from adhering to optical fiber edge. Figure 6 shows the schematic illustration of workpiece and jig for measurement of tool edge temperature under coolant supply. The jig is inserted into the hole where workpiece has. The air is supplied to the jig with air tube. The air trends to the hole which the optical fiber is inserted, because the side of pyrometer is sealed up. The air pressure is adjusted with a regulator.

Figure 7 shows the output of two-color pyrometer and acceleration pickup in wet cutting under 0.3MPa supply. The output from pyrometer is shown up despite coolant supply. It’s though that the high pressure air supplied from small hole in which an optical fiber is inserted prevents coolant from adhering to the optical fiber edge and makes temperature measuring possible.

### 3.3 Influence of air pressure on the tool edge temperature

Figure 8 shows the influence of air pressure on the coated carbide tool edge temperature. In cutting of AISI 1045, the tool edge temperature decreases by 80ºC by coolant supply. The tool edge temperature in wet cutting is almost constant when the air pressure is changed. And the dry cutting of SMF4040, the tool edge temperature is almost constant regardless of air pressure. Therefore, the influence of the air pressure is negligible and the air pressure is kept 0.3Mpa in measuring tool edge temperature in wet cutting in this study.
3.4 Influence of cutting speed

The influence of the cutting conditions on the tool edge temperature is investigated. Ti-6Al-4V is used as a workpiece. Figure 9 shows influence of cutting speed on CBN tool edge temperature. The tool edge temperature is increase rapidly with the increase of cutting speed. In dry cutting, the CBN tool edge temperature is 680°C at a cutting speed of 100m/min and increases with the increase of cutting speed, reaching 770°C at a cutting speed of 300m/min. By coolant supply, the CBN tool edge temperature decreases by 70 ºC at a cutting speed of 300m/min.

In dry cutting, the PCD tool edge temperature is 570°C at a cutting speed of 100m/min and increases with the increase of cutting speed, reaching 650°C at a cutting speed of 300m/min. By coolant supply, the PCD tool edge temperature decreases by 350ºC at a cutting speed of 300m/min.
3.5 Influence of tool materials on the tool edge temperature

In dry cutting of Ti-6Al-4V, the PCD tool edge temperature is almost 100ºC lower compared with CBN tool edge temperature at each cutting speed. It is considered that cutting heat hardly concentrate PCD tool edge because the thermal conductivity of PCD tool is 400 W/(m·K) and higher thermal conductivity than that of CBN tool which is 105 W/(m·K). The PCD tool edge temperature is reduced about 350ºC by coolant supply, the CBN tool edge temperature is reduced only 70ºC. Under coolant supply, the PCD tool edge temperature shows only 440 ºC even when cutting speed is at 400 m/min.

4. Conclusions

This study is carried out to establish the tool edge temperature measurement method using a compact two-color pyrometer in wet cutting. In the experiment, titanium alloy Ti-6Al-4V are turned using a CBN and a PCD tool, the Influence of coolant supply on tool edge temperature is investigated on each condition. The main results obtained are as follows.

(1) In wet cutting, owing to cutting fluid adhere to the optical fiber edge, the measuring tool edge temperature is impossible. High pressure air supplied from small hole in which an optical fiber is inserted prevents coolant from adhering to the optical fiber.
edge and makes temperature measuring possible. The influence of the air pressure on tool edge temperature is negligible.

(2) The tool edge temperature linearly increases with the increase of cutting speed. PCD tool edge temperature is almost 100°C lower compared with CBN tool edge temperature in dry cutting of Ti-6Al-4V.

(3) By coolant supply, PCD tool edge temperature decreases greatly. For example, when cutting speed is at 300 m/min, PCD tool edge temperature decreases by 350 ºC, while CBN tool edge temperature decreases only by 70 ºC.

Acknowledgment

The authors are indebted to Sumitomo Electric Hardmetal Corp. for providing the cutting tools and workpiece.

References


