

A Study on a Novel Tool Temperature Measurement Method in High-Speed Machining of Titanium

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INTRODUCTION

Due to their superior mechanical properties, heat resistance and exceptional corrosion resistance, titanium alloys are widely used in the aerospace, chemical and ship building industry [1]. However, during the machining of titanium alloy, tool wear progresses rapidly because of the high cutting temperature and strong adhesion between the tool and the work material owing to their low thermal conductivity and high chemical reactivity. Therefore, it is not easy to achieve productive machining with good cost performance rate of 400-600 cubic millimeters in roughing. But, when finishing, a long, small diameter cutting tool is needed, hence a low material removal rate of only 40-60 cubic millimeters. Since it is difficult to apply the heavy-duty cutting to a finishing operation because of its slender tool application, the high-speed cutting is expected to be an alternative approach to enhance the productivity of titanium cutting. There are many advantages to high-speed machining, however, cutting speed strongly affects the cutting temperature and high cutting temperature increases the excessive tool wear [2-4]. Therefore, it is important to measure and control the cutting temperature to enhance the efficiency in titanium machining.

On the other hand, end milling is intermittent cutting process, and tool engages both material and air during a single revolution. This cycle seems to be closely connected with tool wear. Several methods can be used to measure cutting temperature. Thermo-couple method is often used for cutting temperature measurement. Meanwhile, there are two types of methods using thermo-couple. One method is that thermo-couple is put into cutting tool or workpiece. For this method, a small hole must be drilled in the tool or workpiece. Another method is to use the tool-workpiece interface as a thermo-couple. This method is practical for measuring cutting temperature for turning process. However, it is difficult to build the measuring circuit of the thermo-couple in end milling.

The research focused on developing a novel method to measure the cutting temperature in high-speed end milling of titanium alloys by PCD (Polycrystalline Diamond) cutting tools. Meanwhile, it also tried to find some relation between machining conditions and cutting temperature. In the proposed method, the infrared radiation pyrometer was selected to measure the temperature under the various cutting conditions, which is able to measure the temperature without contact to measuring object. Through the experiments, we found the proposed method can meet the requirement of accuracy.

CONCEPTUAL AND MEASURING PRINCIPLE

End milling process

End milling process is one of typical intermittent process. In the process, since the cutting tool repeats cutting material and air cutting, the temperature of cutting tool repeats heat up and cooling down, shown in Figure 1.

Measuring principle and concept

Since it is difficult to directly measure the temperature of the contact point between the tool and the workpiece, we can use certain non-contact measurement method to measure the temperatures at different position of the tool during air cutting, like every other 90-degree of the whole cutting process. Then, based on the temperature tendency of the tool in the air cutting, we can estimate the actual cutting temperature of the tool. That is the major principle of the temperature measurement method.

As we know, all objects on the earth radiate infrared according to the temperature. By measuring the radiate infrared of an object using an infrared radiation pyrometer and converting it to voltage value by photo conductor, the temperature of an object can be measured. And one of the greatest merits of infrared radiation pyrometer is that temperature measurement can be carried out without contacting the measuring object.

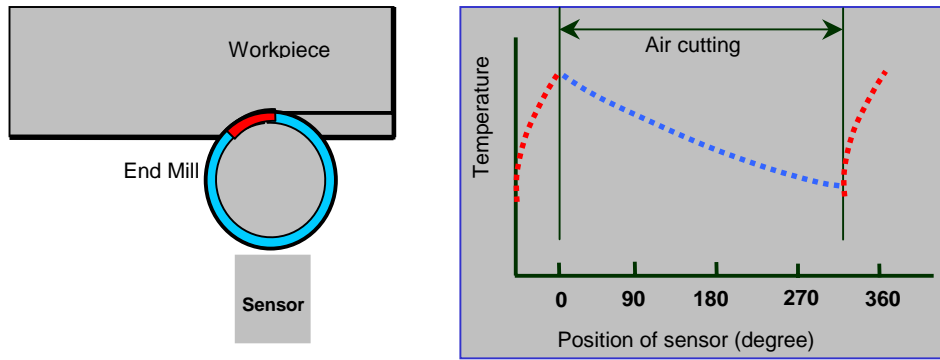


Fig.1: End mill process

Therefore, owing to the feature of end mill process, infrared radiation pyrometer was selected as a sensor to measure the temperature of tool. Thus tool temperature in air cutting can be measured in this method. After the temperatures are obtained, the temperature at cutting contact point can be derived through extending the temperature curve. The measuring system is easy to build compared to the thermocouple method. This also means that the measuring system is flexible and applicable to actual manufacturing.

EXPERIMENT SETUP AND CONDITIONS

Figure 2 shows the schematic view of temperature measuring system with infrared radiation pyrometer. Sensor head of pyrometer is fixed on a spindle unit of machine tool with fixture. Infrared radiated from flank face of insert is caught by the sensor head and conveyed to the infrared radiation pyrometer through an optical fiber. The photo-conductor in the pyrometer converts radiation energy from the infrared to a voltage value. The output voltage is captured in the PC by way of A/D converter. Then the temperature data can be obtained by software designed for data processing.

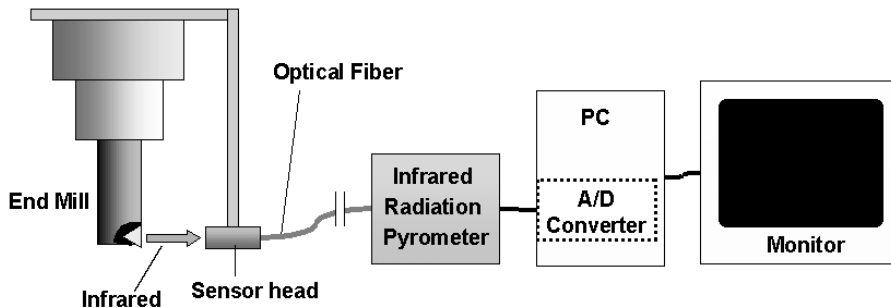


Fig.2 Schematic view of temperature measurement system

Specification of End Mill

The specification of end mill is shown in Table 1. Here, two different insert materials, Polycrystalline Diamond (PCD) and Cemented Carbide, have been utilized to compare the temperature of different tool insert materials. All the other parameters are the same.

Tab.1 Specification of end mill

Manufacturer	Sumitomo Electric Inc.
Type	Throw away end mill
Diameter	30 mm
Axial rake angle	15°
Radial rake angle	-3°
Insert materials	Polycrystalline Diamond (PCD) Cemented Carbide

Experiment conditions

Experiment conditions are shown in Table 2. A vertical machine tool was used for machining of titanium alloys and a software, Labview is used for data acquisition. Figure 3 shows the sensor head setup. The sensor head is rigidly attached to the spindle with a aluminum plate fixture. The sensor head can be fixed at three positions around end mill.

Tab. 2 Experiment conditions

Workpiece	Titanium Alloy (Ti-6Al-4V)
Machine Tool	Vertical type machine center
Cutting speed	300m/min, 400m/min, 500m/min
Feed rate	0.06-0.14mm/tooth
Radial depth of cut	0.06-0.14mm
Axial depth of cut	3.0mm
Measuring distance	50mm
Sensor position	90°, 180°, 270°
Cutting direction	Down cutting

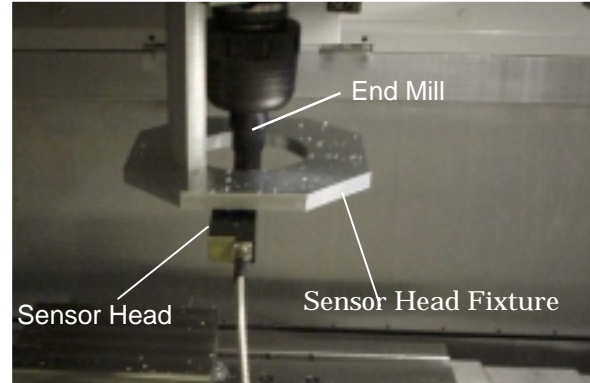


Fig.3: Setup of the sensor head

Measurement of emissivity

Since each object has different emissivity, the emissivity of cutting tools must be measured in advance. Figure 4 shows the measurement setup of emissivity of cutting tools. Cutting tool is put in electric furnace. And atmosphere is kept to particular temperature. Meantime, temperature of specimen was measured by infrared radiation pyrometer.

Thermal measuring method

Figure 5 shows the overview of thermal measurement method. A tool temperature was measured at three different positions during machining which are 90°, 180° degree and 270° around the end mill.

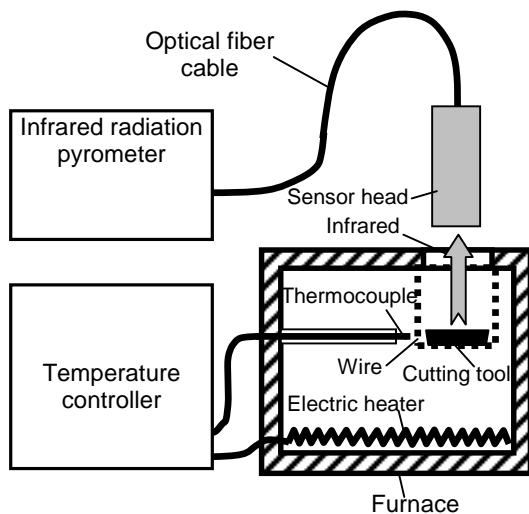


Fig.4: Measurement setup of emissivity of cutting tools

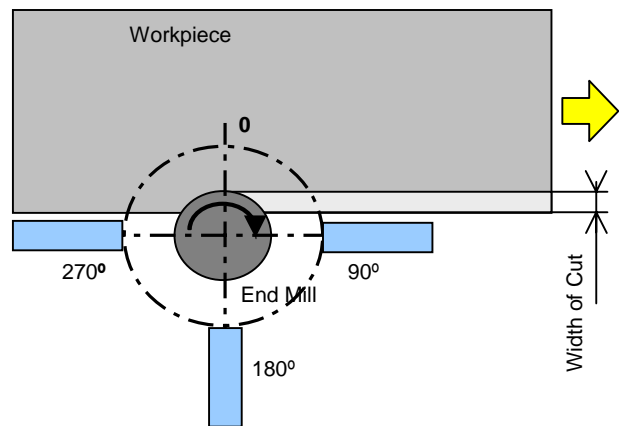


Fig.5: Experiment method

RESULTS AND DISCUSSIONS

Figure 6 shows the data sample results from experiment. Figure 6 (a) shows the raw data gathered by computer system based on the basic setup. The data in Figure 6 (b) is the conversion from raw data to temperature. Figure 6 (c) is a cloud of peak points of the signal and the average value was defined as cutting temperature. Using the method, tool temperature with different cutting tools at different sensor positions can be obtained as shown in Figure 6 (d).

From Figure 6 (d), it can be seen that the tool temperature at high speed machining such as feed rate 0.1 mm/tool gradually decreases during air cut. The tool temperature at 90 degree is the highest and the tool temperature at 270 degree is the lowest. Though cutting the titanium by the PCD tools, the tendency of thermal variation during the air cut is almost same as that of thermal variation of the carbide tools. However, the absolute value of the tool temperature is 150~300 degree C lower compared with the tool temperature of carbide tools. This tendency shows the good thermal conductivity of PCD tools same as original [3]. From this result, it can be concluded that the new sensor system with infrared radiation pyrometer have a reasonable measurement accuracy for the purpose of easy-to-use in an actual machining in real time manner. Actually, experiments at different conditions have been conducted to investigate the relation between machining conditions and cutting temperature, but the results will not be presented because of page limit. Moreover, thermocouple method (tool-workpiece interface) is to be used to measure the temperature at the same condition for the comparison purpose.

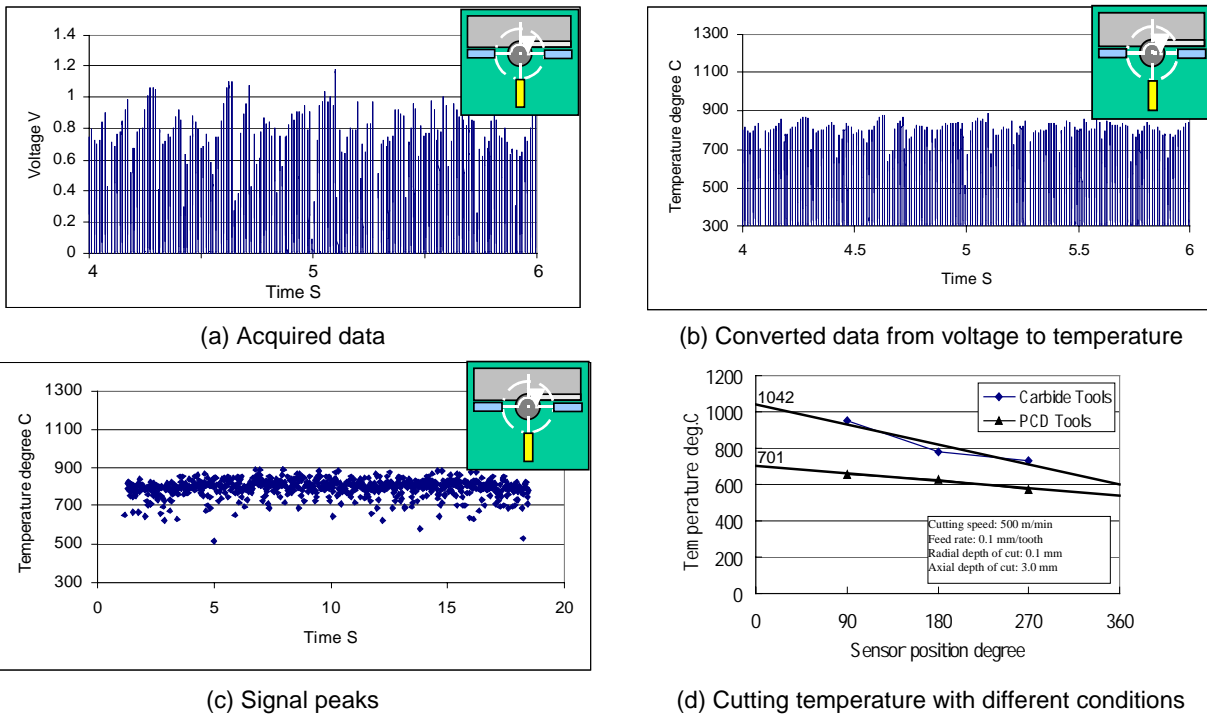


Fig. 6: Measurement results

CONCLUSIONS

- (1) The novel temperature measurement method has been proposed based on the concept of the easy-to-use in an actual machining condition in order to investigate the high-speed machinability of titanium Ti-6Al-4V by polycrystalline diamond (PCD) cutting tools.
- (2) The measurement results of the sensor system show the reasonable tendency of the thermal conductivity during air cutting. The Tool temperature of PCD tools is 150~300 degree C lower than that of carbide tools in titanium end milling.

REFERENCES

- [1] Ezugwu E. O., Wang Z. M., 1995, "Titanium Alloys and Their Machinability – A Review", Journal of Materials Processing Technology Vol. 68, p. 262 – 274.
- [2] Bhaumik S. K., Divakar C., Singh A. K., 1995, "Machining Ti-6Al-4V Alloy With a wBN-cBN Composite Tool", Materials & Design Vol. 16, No. 4, p. 221 – 226.
- [3] Liu J., Yamazaki K., Nakai T., Fukaya T., Mori M., Furuta M., 1999, "High-Speed Machining of Titanium by New PCD Tools", Society of Automotive Engineers, Inc.
- [4] Dowe S.J., Rahle, B., 1997, "Performance Analysis of Coated Tools in Real-life Industrial Experiments Using Statistical Techniques", Surface & Coating Technology Vol. 99, p.213 - 221.