# Study of Machining with Diamond Tool

## Measurement of Cutting Temperatures

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### Abstract

The cutting temperatures on the tool face are very important factors in machining as well as cutting force and chip formation. But the measurement of cutting temperatures of diamond tool is impossible with the conventional work-tool thermocouple technique, because diamond is an electrically non-conductive material.

In this report, a calibration equation is firstly obtained from the relation between the cutting temperatures with work-tool thermocouple technique and the cutting temperatures with chip-chip breaker thermocouple technique using cemented carbide tools which are the electrically conductive materials. And the cutting temperatures of diamond tool are estimated by substituting the value obtained from the chip-chip breaker thermocouple technique with diamond tools into the calibration equation. The results show that this method is useful to suggest the cutting temperatures of diamond tool.

## 1 Introduction

The machining characteristics of diamond tool are to be able to expect finely finished surfaces and very long tool life for machining of soft non-ferrous metals[1) such as brass and aluminium alloys. Those metals are difficult to obtain the fine surfaces by the grinding process.

The cutting temperatures affect the tool life and the welds on the tool face such as built up edge[2) in various ways. Tool life decreases at high cutting temperatures in most common cases. While the welds increase commonly the finished surface roughness up to twice of theoretical one, the other times the welds decrease the surface roughness. While the studies on the cutting temperatures of diamond tool have been scarcely reported, the reason may be in the fact that the cutting temperatures of diamond tool are virtually impossible to measure by conventional work-tool thermocouple technique.

In this report, the temperatures of flowing chip undersurface are measured by chip-chip breaker thermocouple technique with diamond tools and cemented carbide tools which are conductive material. The cutting temperatures in machining aluminium alloy with diamond tools are suggested by the compensating of both results, and the performances of diamond tool are estimated with respect to cutting temperatures.

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## 2 Experimental method

The cutting tools used in the chip-chip breaker thermocouple technique are shown in Fig. 1. This technique is a method to measure a mean cutting temperature at the position A of chip breaker at which the chip undersurface contacts. It is needed to compensate these results for corresponding with the mean cutting temperature of the position B which is measured by work-tool thermocouple technique most commonly used. In this report, it is also aimed to measure the temperature of position B. The temperatures are firstly measured by work-tool thermocouple technique and chip-chip breaker thermocouple technique with cemented carbide tools which are the conductive materials. The equation of compensation between both results is introduced and the cutting temperatures of diamond tool at the position B are calibrated with the equation and the temperatures at the position A.

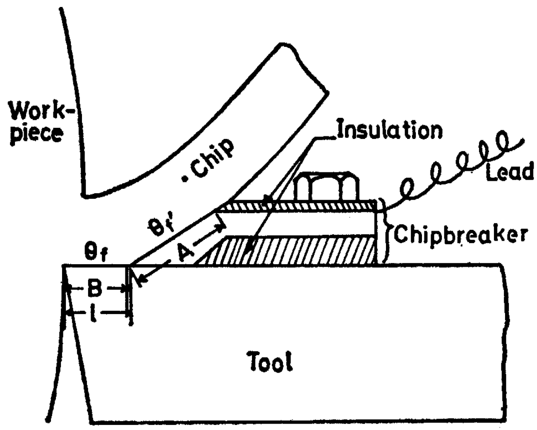

Fig. 1 The positions where the cutting temperatures are measured.

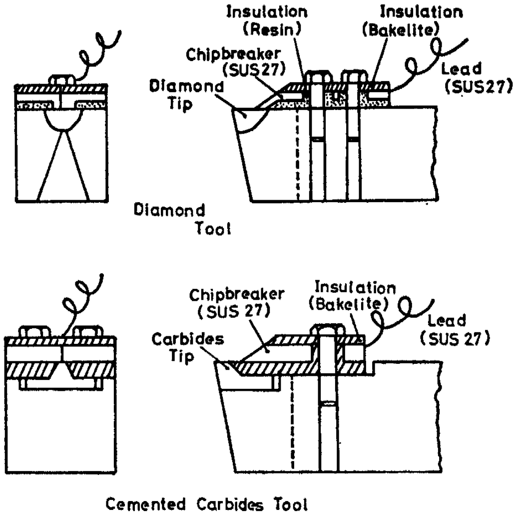

Fig. 2 Tools used in chip-chip breaker thermocouple technique.

Diamond tool and carbide tool used in chip-chip breaker thermocouple technique are shown in Fig. 2. These chip breakers made of SUS27 stainless steel are electrically insulated by bakelite from the tool tips and tool shanks. And then the lead wires made of the same material as chip breaker are used to prevent the bias voltage which are introduced by the temperature rise in the cold junction.

The temperatures measured with chip-chip breaker thermocouple technique are also influenced by the location of chip breaker. When the position of chip breaker is too near to the cutting edge, the measured temperatures become higher than that in normal. When the distance from the cutting edge to the chip breaker is too wide, the measured temperatures become lower than that in the normal condition. As the same temperatures of chip undersurface are measured for the distance between the cutting edge and the chip breaker from 0.7 mm to 1.2 mm, this distance of 1.0 mm is selected in this experiment. Although the cutting speed was changed in this experiment, this suitable distance is not influenced by the changing of cutting speed.

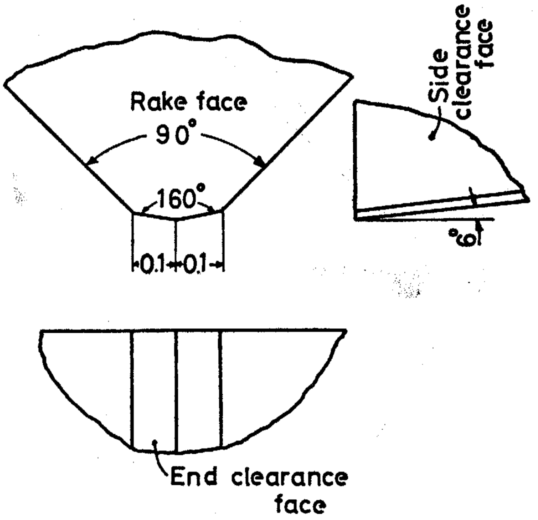

Fig. 3 Tool geometry.

Cutting speed is varied from 15 m/min to 600 m/min. Depth of cut and feed are respectively 0.3 mm and 0.0125～0.125 mm/rev. The cemented carbide tools made of a micro-crystalline material (symbol M.A.) are used to compare with the diamond tools. The tool geometry is as shown in Fig. 3. The material cut is an aluminium alloy (JIS 5056) containing 5% magnesium. The machine tool used is an engine lathe made by Shoun Manufacturing co..

## 3 Experimental result and cosiderations

### 3–1 Calibration between the heated temperature and electromotive force

In order to measure the electromotive forces (EMF) generated by work material/tool material and work material/chip breaker, the thermocouples consisted of these materials are heated to several known temperatures in a furnace.

Fig. 4 shows the electromotive force having generated in case of these thermocouples. It is seen that the relations between heated temperature and the electromotive force are almost linear in the thermocouples used. Although very small electromotive force was measured in a SUS27 stainless stell-aluminium alloy thermocouple, the measurement is assisted by increasing the sensitivity of the potentiometer. Hence, the electromotive force of tool in machining is also measured with this potentiometer. The cutting temperatures of each tool are calibrated from the electromotive force shown by the curves of Fig. 4.

### 3–2 Electromotive force curves in machining

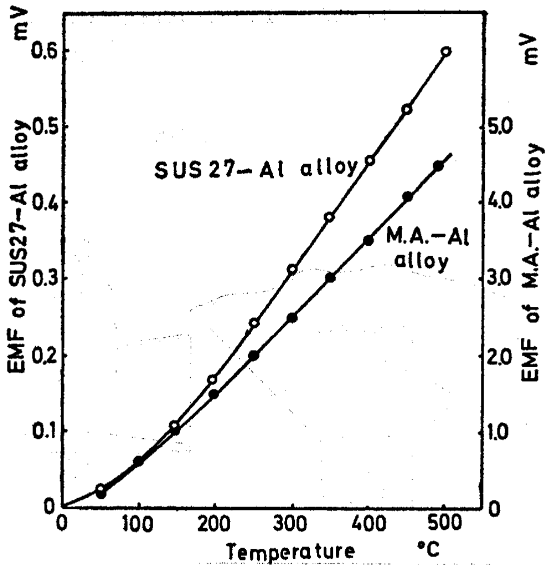

Fig. 4 Electromotive force at various temperatures.

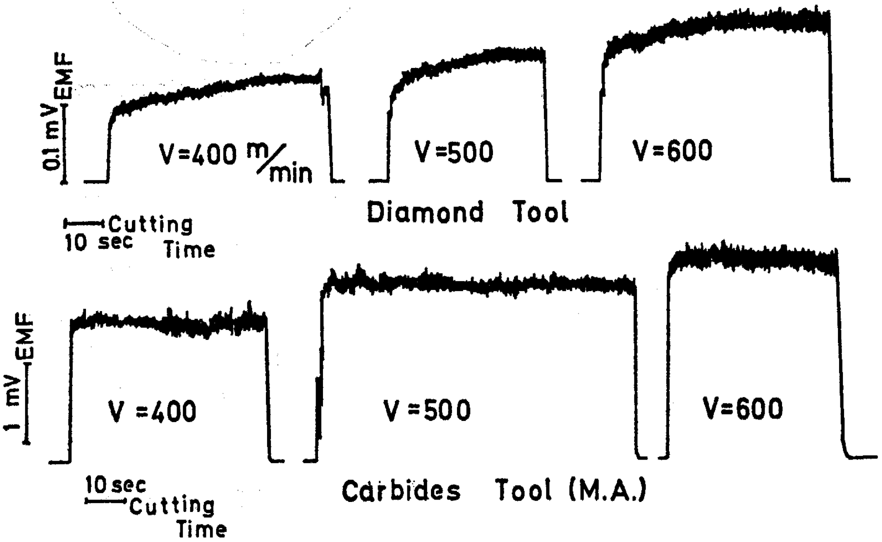

Fig. 5 Electromotive force curves on chart paper with chip-chip breaker thermocouple technique. Depth of cut 0.3 mm Feed 0.075 mm/rev

The tools and the workpieces in this experiment are electrically insulated from machine tool to preclude the troubles such as noises and errors which are introduced by a small laekage current. The degree of this insulation is confirmed with an ohmmeter.

Typical examples which are measured by chip-chip breaker thermocouple technique in various cutting speeds are shown in Fig. 5. While the electromotive force curves of carbide tools increase quickly to a steady value in short cutting time of about 5 sec, about thirty seconds of cutting time are required to attain the steady value in case of diamond tool with the same chip-chip breaker thermocouple technique. This long measuring time is often needed in case of measurement with conventional work-tool thermocouple technique at the low cutting speeds. This long measuring time is considered not to show the abnormal cutting condition, but to mean that the undersurfaces of flowing chips are at the situations of low temperature or of low contact pressure. The measurement time is defined as fifty seconds in this experiment.

### 3–3 The equation of calibration and the consideration of the results

The results which are obtained by the measurement with work-tool thermocouple technique and chip-chip breaker thermocouple technique with carbide tool are shown respectively with solid line and dotted line in Fig. 6. From the Fig. 6, it is seen that their differences are a large amount in the range of high cutting temperatures and a small amount in the range of low cutting temperatures. Therefore, the following equation including an exponential term is assumed to calibrate the cutting temperatures of position B from the results of position A.

$$\theta_f = a(\theta'_f)^b + \theta'_f$$

where $\theta'_f$ is the temperature of position A measured by chip-chip breaker thermocouple technique, $\theta_f$ is the cutting temperature of position B. The symbols a and b are constants.

$a(\theta'_f)^b$ means the compensation between both lines of carbide tools in Fig. 6. The constants a and b obtained from experimental results with the method of least squares are respectively 2.88 and 0.5. In wide range of cutting speed, these results (symbol ×) calibrated by equation (1) agree considerably with the cutting temperatures of work-tool thermocouple technique which are

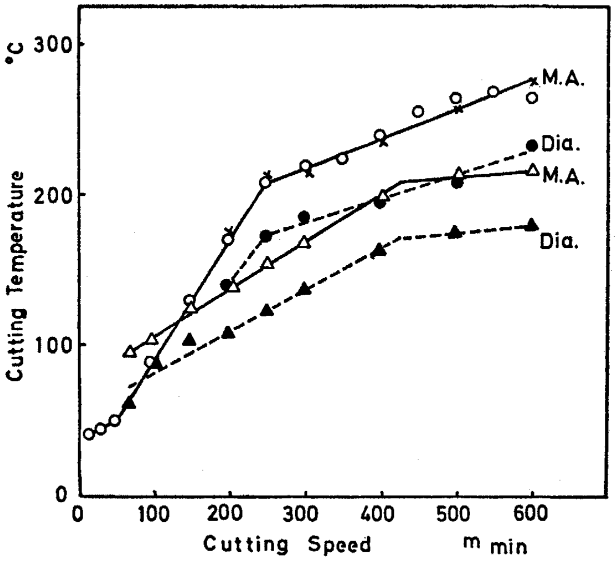

Fig. 6 Relation between cutting speeds and cutting temperatures
Depth of cut 0.3 mm, Feed 0.075 mm/rev
○ Results by work-tool thermocouple technique
△ ▲ Results by chip-chip breaker thermocouple technique
● × Results calibrated by the equation (1)

experimental values.

In order to calibrate the cutting temperatures of diamond tool corresponding with the position B, the cutting temperatures of diamond tool in position A obtained from chip-chip breaker thermocouple technique are substituted in equation (1). The results are shown as solid line in Fig. 6. The qualitative trend of the curve of this diamond tool is similar to that of solid line of carbide tool. The cutting temperatures of diamond tool are only slightly lower than that of carbide tool. These phenomena correspond to thinner chips than the chips of carbide tool[1)].

The solid line of diamond tool bends at 400 m/min of cutting speed. The temperature of this bending point is about 220°C which corresponds with that of carbide tool measured by the work-tool thermocouple technique, and then these temperatures corrspond almost to recrystallization temperature of the aluminium alloy used in this experiment. From these points of view, it is considered that this equation is useful to calibrate the cutting temperatures of diamond tool.

### 3–4 Relation between cutting speed and cutting temperature

The cutting temperatures increase with the increasing of cutting speed as shown in Fig. 6. The remarkable differences of the cutting temperatures between diamond tool and carbide tool can not be found below the cutting speed of 150 m/min, however, the cutting temperatures of diamond tool become lower than that of carbide tool above 150 m/min. These low cutting temperatures are one of excellent properties of this tool in machining aluminium alloy.

It is considered as the reasons that the cutting edge of diamond tools are more sharp and the welds on the cutting edges are less than in case of the carbide tools. Cutting action of diamond tools is consequently very smooth, the cutting force of diamond tool is also less than that of carbide tool[3)].

## 4 Conclusion

From the above experiments, the following conclusions are obtained.

1 The temperature of chip undersurface can be successfully measured by chip-chip breaker thermocouple technique.

2 The cutting temperatures of diamond tools can be calibrated with an equation formed with experimental results of carbide tools.

3 The cutting temperatures of diamond tools are sligthly lower than that of carbide tools in the range of high cutting speed.

## Acknowledgment

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