# Measurement of Temperature of Drill Point during Drilling

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Cobalt high speed steel drills brazed with sheathed thermocouples were utilized in measuring the cutting temperature of the drill face, and the relationship between cutting temperature and calorific values was investigated during both low frequency vibratory drilling and conventional drilling.
Compared with conventional drilling, the cutting edge temperature, cutting force and calorific values for low frequency vibratory drilling were substantially low.

## 1. Introduction

Cutting temperature has a direct influence on tool wear and the frictional phenomenon between the tool face and chips. Thus, a standardized and accurate cutting temperature measuring technique is been called for. There are several techniques in use to measure cutting temperature such as, surface thermometers[1)], temperature-sensitive chemicals[2)], calorimetric technique[3)], workpiece-tool thermocouple[4)], workpiece-constantan and tool-constantan[5)] techniques. We have in the past employed various methods to measure the temperature of the cutting edge during drilling, such as burying thermocouples in the workpiece, inserting alumel-chromel thermocouples in drills etc. However, the three dimensional geometry of the cutting edge makes the cutting mechanism of the cutting edge complicated.

The above mentioned methods have the following shortcomings, contact between chips and the thermocouple result in a short-circuit, and temperature measurements cannot be carried out arbitrarily. Thus, these methods portrayed a lot of scatter in the results obtained. In short, the above methods fall short of being satisfactory. The limited data on cutting temperature during drilling operations reflects the difficulty associated with measuring the drill face temperature.

Taking into consideration the shortcomings of the above methods, in this study a

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sheathed thermocouple was coupled to insulated magnesium oxide and then brazed on to the face of the cutting edge to investigate the temperature during both low frequency vibratory drilling and conventional drilling of aluminum. And the relation between cutting energy and calorific value for vibratory drilling was investigated and the results obtained were compared with those for conventional drilling.

## 2. Experimental Apparatus and Method

### 2.1 Experimental apparatus

The block diagram for the experimental procedure employed in this study is shown in Fig. 1. The drilling tests were conducted on a NC vertical milling machine. The electromotive force from the sheathed thermocouple was amplified with a temperature sensitive amplifier and then passed through an A/D voltage converter to a personal computer for processing. A piezo electric dynamometer was utilized to measure cutting forces (torque, thrust), and a model indicating the measured forces is shown in Fig. 2. As can be seen in the figure, the average fluctuation of the cutting force is shown as the static component and the standard deviation of the fluctuation as the dynamic component. The data obtained was processed by a personal com-

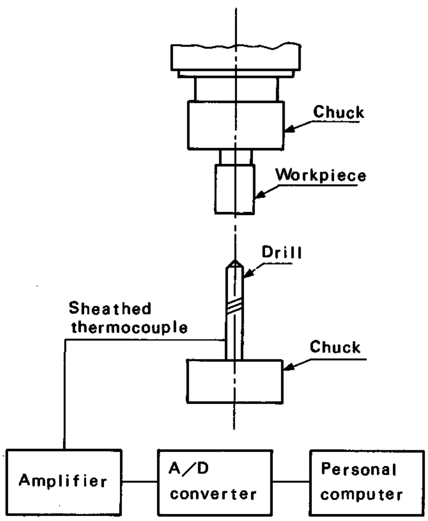



Fig. 1 Block diagram used for the measurement of cutting temperature.

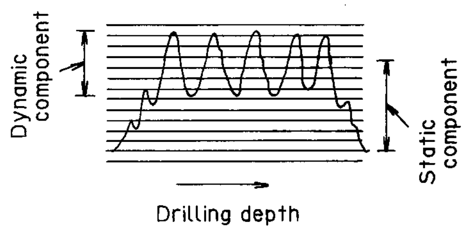



Fig. 2 Static and dynamic components of cutting forces.

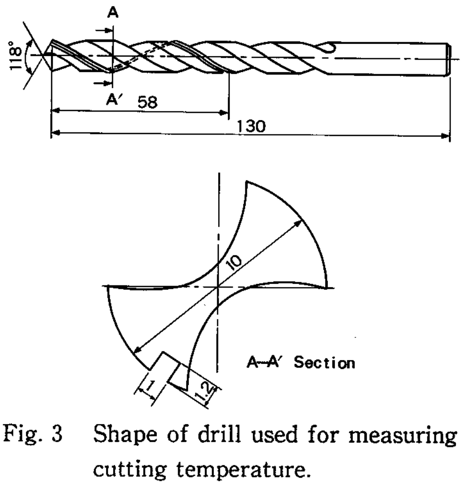



Fig. 3 Shape of drill used for measuring cutting temperature.

puter.

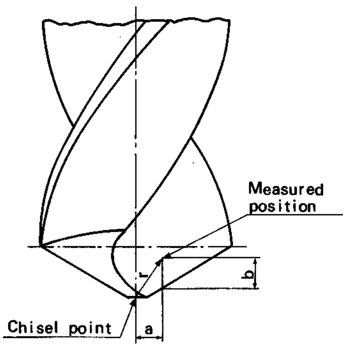
## 2.2. Drills buried with sheathed thermocouple

In this study, sheathed thermocouples were brazed on cobalt high speed steel drills HSCO (JIS SKH 56) for the measurement of the drill face temperature. The grooving for the brazing as well as the brazing process was carried out as follows. First of all, a groove was created along the margin of the HSCO drill testpieces as shown in Fig. 3. To have the sheathed thermocouple protrude on the drill face, a through hole of diameter 1mm was created by electrospark machining from a point on the flute to the drill face as shown in Fig. 4. For all the drills, the following points C-1, C-2 and C-3 were chosen for measuring the cutting temperature.

The sheathed thermocouples were then brazed on the groove or shallow flute created as explained above. The sheathed thermocouple consisted of insulated alumel-chromel thermocouple and magnesium oxide coupled together, thus the thermocouples had a high thermal conductivity and excellent response to change in temperature. The drills utilized in this study were reusable due to the high finish of the grooves.

## 2.3 Workpiece

In this investigation, annealed aluminum of high purity (A1050-0) was utilized. In order to have it attached to the spindle shaft of the NC milling machine, the workpiece was machined to the shape shown in Fig. 5. The protruding part of diameter 10mm was fitted to a collet chuck and then clamped to the spindle. To minimize the walking phenomenon of the cutting edge during drilling the workpiece was drilled to a depth of 3mm with a center drill of diameter 3mm.




| Drill | a (mm) | b (mm) | r (mm) |
|---|---|---|---|
| C−1 | 1.3 | 1.7 | 2.7 |
| C−2 | 1.7 | 2.2 | 3.5 |
| C−3 | 3.2 | 3.1 | 5.9 |

Fig. 4 Measured positions at drill face.

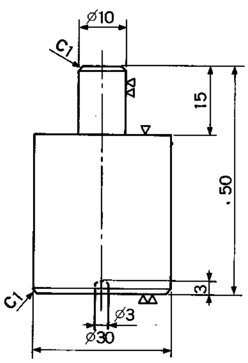



Fig. 5 Workpiece used for measurement of cutting temperature.

### 2.4. Cutting conditions

The low frequency vibratory drilling tests were carried out by fitting the drill to a chuck mounted on the table of the NC milling machine and by the up and down movement of the table, low frequency vibration was realized. A water soluble coolant (JIS W 2-3) supplied at a rate of 3.2$l$/min was used in this investigation. The cutting conditions are shown in Table 1.

Table 1 Cutting conditions.

| | |
|---|---|
| Drill dia. d (mm) | 10 (SKH 56) |
| Revolution N (rpm) | 440 |
| Feed rate S (mm/rev) | 0.15 |
| Frequency ratio $W_f$ (cycle/rev) | $W_f=0$ Conventional<br>$W_f=0.1$ Vibratory |
| Amplitude a (mm) | 0.1 |

## 3. Experimental Results and Discussion

### 3.1. Measurement of cutting edge temperature

The cutting edge temperatures (drill face temperature) at a cutting depth of 20mm for both low frequency vibratory drilling abbreviated (vibratory drilling) and conventional drilling are shown in Fig. 6. As the figure shows, the temperature of the drill face during vibratory drilling is approximately 20% lower than when drilling conventionally. In both drilling methods the drill face temperature is higher in the vicinity of the chisel edge (C-1) and margin (C-3) compared to the central portion of the face (C-2). Figure 7 shows the relation between drill face temperature and cutting depth. It can be observed in the figure that in both drilling methods, the cutting edge temperature increases linearly with depth. However, up to a cutting depth of 5mm, both cutting methods show no difference in cutting temperature. After a cutting depth of 5mm, the cutting edge temperature during vibratory drilling is lower than that of conventional drilling. During vibratory drilling, at a cutting depth of 10−

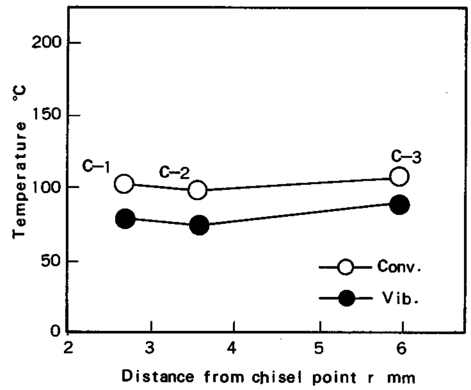



Fig. 6 Influence of distance from chisel point on cutting temperature for $W_f=0.1$ and $W_f=0$.

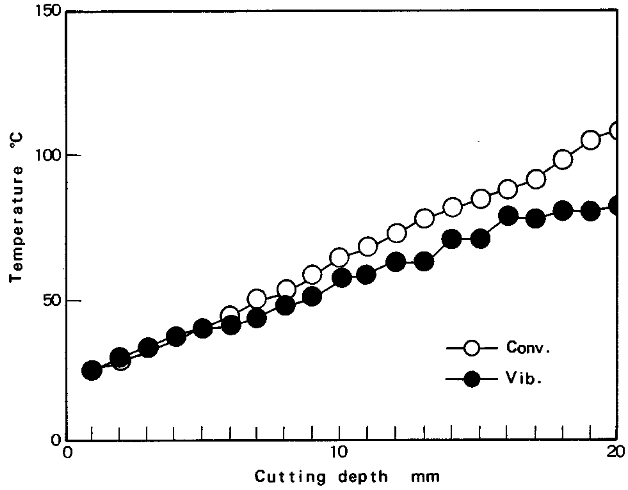



Fig. 7 Relation between cutting temperature and cutting depth for $W_f=0.1$ and $W_f=0$.

15mm, the cutting edge temperature rise was found to be ununiform at a certain range, whereas during conventional drilling this tendency was not observed. At a cutting depth of 20mm, the cutting edge temperature during vibratory drilling was roughly 25% lower than that during conventional drilling. The relatively low temperature and the ununiform nature of the cutting edge temperature during vibratory drilling is due to a reduction in frictional heat at the tool-chip interface, and this in turn comes about, as a result of the pressure effect on the dynamic pulse generated and the effect of periodic vibration, consequently resulting in the formation of shorter chips that are easily eliminated.

### 3.2. Relation between cutting energy and calorific value

It was pointed out that the drill face temperature associated with vibratory drilling were lower than those in conventional drilling. In this study, calorific values were calculated from frictional heat due to friction between the workpiece and tool and heat conducted into the tool from chips.

Work during machining consists of work required for metal removal, frictional work at the tool and chip interface and work due to metal shearing. The work due to metal shearing is considerably small. It is believed that ninety percent of the work required for metal removal and the frictional work at the tool and chip interface is converted into heat and transfered to the chips. Thus, the rate at which chips are eliminated greatly influences the performance of a drill. By calculating the work per unit time from the static components of thrust and torque and by comparing it with the heat eliminated through chips, the degree of heat removal by chips was investigated.

The cutting force (thrust, torque) during vibratory drilling is shown in Fig. 8. In the figure, the cutting forse data is compared with that of conventional drilling. In vibratory drilling, due to the periodic fluctuation of the depth of cut, the cutting force

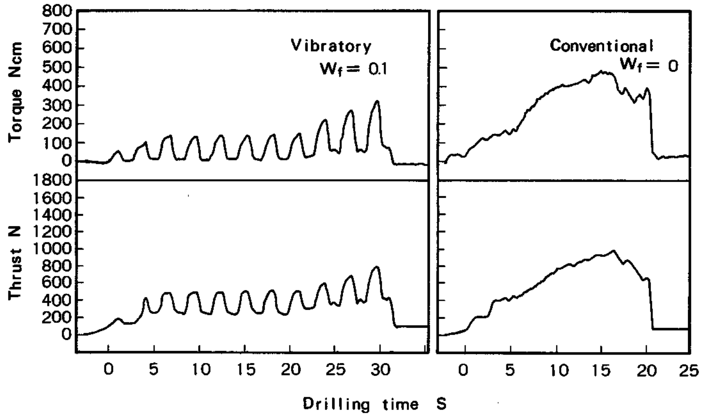



Fig. 8 Measured results of cutting forces (thrust, torque).

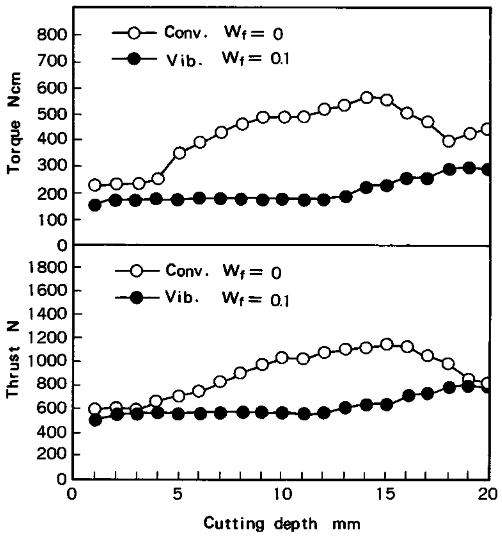



Fig. 9 Comparison of cutting force (static component) for $W_f=0.1$ and $W_f=0$.

is shown as the dynamic component. While, fig. 9 is the static component of the force. As can be seen in the figure, the cutting force for vibratory drilling is almost constant throughout the drilling process, whereas that for conventional drilling increases with cutting depth. After drill penetration, at a cutting depth of about 10mm, the thrust and torque for vibratory drilling are respectively 560N and 175Ncm. While, for conventional drilling the thrust and torque are respectively 1000N and 480Ncm. A comparison of the above results shows that the thrust and torque for vibratory drilling are respectively 44% and 63% lower than that for conventional drilling. The shorter chips produced during vibratory drilling, thus easy chip ejection are responsible for the lower cutting forces in vibratory drilling as compared with conventional drilling.

Work $N_{FX}(J/\text{sec})$ per unit time due to the torque component of cutting force $F_x(N \cdot m)$ is given by

$$N_{FX} = 2\pi n F_x / 60 \tag{1}$$

where $n$(rpm) is the rotational speed of the spindle.

Work $N_{Fz}$($J$/sec) per unit time due to the thrust component of cutting force $Fz$($N$) is given by

$$N_{Fz} = nsF_z / 60 \times 1000 \tag{2}$$

where $s$(mm) is the feed rate..

Total work ($J$/sec) on the workpiece is given by

$$N = N_{FX} + \mathrm{N}_{Fz} \tag{3}$$

Volume of chip $V_c$(m$^3$/sec) produced per unit time is given by

$$V_c = (\mathrm{d} \times 10^{-3})^2 / 2^2 \cdot \pi ns / 60 \times 1000 \tag{4}$$

where $d$(mm) is the diameter of the drill.

Amount of heat $N_c$($J$/sec) removed by chips per unit time is given by

$$N_c = \rho C T V_c \tag{5}$$

where $\rho$(kg/m$^3$) is the density of the workpiece, $C$($J$/kg $\cdot$ $K$) is the specific heat of the workpiece and $T$($K$) is the temperature of chips.

The measured values of cutting forces $Fx,Fz$ and face temperature at a cutting depth of 20mm were substituted in the above equations. The values for $Fx$ and $Fz$ are respectively the static components of the torque and thrust. For both drilling methods, chip temperature $T$ was measured at position C-2 as shown in Fig. 4.

At position C-2 of the margin and chisel of the drill, the effect of the heat source is hardly felt. Thus, the measured temperature was very close to that of the chips. The density and specific heat capacity of the workpiece are respectivity 2710kg/m$^3$ and 523$J$/kg $\cdot$ $K$. As the result in Table 2 shows, the $N$, $N_c$ for vibratory drilling are lower than that for conventional drilling.

The work ratio $Nc/N$ for vibratory drilling is 52.7%, while it is 20.8% for conventional drilling. The difference in work ratio $Nc/N$ can be attributed to the lower absolute temperature and lower cutting forces associated with vibratory drilling. With this method, it is possible to determine the cutting temperature under different cutting conditions from measured values of cutting forces with high degree

Table 2 Calculated results of cutting energy and Calorific value.

| | n (rpm) | S (mm/rev) | $F_x$ (N·m) | $F_z$ (N) | $N_{FX}$ (J/sec) | $N_{FZ}$ (J/sec) | N (J/sec) | T (K) | $V_C \times 10^{-9}$ (m$^3$/sec) | $N_C$ (J/sec) | NC/N (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Vib. | 440 | 0.15 | 1.75 | 560 | 80.6 | 0.62 | 81.2 | 351 | 86.10 | 42.8 | 52.7 |
| Conv. | 440 | 0.15 | 4.8 | 1000 | 221.2 | 1.1 | 222.3 | 380 | 86.10 | 46.3 | 20.8 |

of accuracy.

## 4. Conclusions

In order to measure the temperature of the drill face during both low frequency vibratory drilling and conventional drilling of aluminum, sheathed thermocouples brazed on the drill face was used. And Calorific values were obtained by correlating cutting forces with drill face temperature.

The following conclusions are drawn.

(1) The temperature of the drill face during low frequency vibratory drilling was found to be lower as compared with that for conventional drilling. In low frequency vibratory drilling, at a certain range, the increase in temperature was observed to be unperiodic in nature. Futhermore, at a cutting depth of 20mm the cutting edge temperature was approximately 25% lower than in conventional drilling.

(2) The cutting energy, frictional heat and heat conducted into tool from chips were lower during low frequency vibratory drilling compared with those for conventional drilling.

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