Investigation of Cutting Tool Temperature in Turning

氏　　　名	MAHFUDZ AL HUDA
生　年　月　日	
本　　　籍	インドネシア
学 位 の 種 類	博士（工学）
学 位 記 番 号	博甲第305号
学位授与の日付	平成11年3月25日
学位授与の要件	課程博士（学位規則第4条第1項）
学位授与の題目	Investigation of Cutting Tool Temperature in Turning(旋削加工における工具刃先温度の解析)
論文審査委員	（主　査）上田　隆司 （副　査）黒部　利次，北川　正義，米山　猛，細川　晃

学位論文要旨

Abstract In present study, the measurement technique for determining the temperature of cutting tool edge in turning is established. A new type of infrared radiation pyrometer is developed in which an optical fiber accepts the infrared rays and transmits it to two infrared detectors (Ge and InSb) through a fused fiber coupler. The pyrometer is applied to the temperature measurement of the tool-chip interface and of the flank side of tool edge. A translucent alumina (Al_2O_3) tool is used as a cutting tool, in order to measure the temperature of tool-chip interface from inside of the tool. A CBN tool is used as a cutting tool, to measure the temperature of flank side of tool edge in turning of high hardness steels.

The temperature measurement method developed in this study is suitable to measure the temperature at the tool-chip interface of translucent tool, either in dry or wet cutting condition. This method is also suitable to determine the temperature of the cutting edge at the tool flank. The temperature of the cutting edge is highly affected by cutting speed, but the influences of depth of cut and feed rate are not so great. There is a close relation between the tool temperature and the hardness of the work material.

Temperature distribution around the cutting edge is analysed using finite element method. The calculated temperatures are compared with experimental results. Good agreement is obtained between the analytical results and experimental ones.

Chapter 1　　Introduction

It is well known that the temperature around the cutting edge has a great effect on the machinability of the cutting process. The primary shear zone temperature affects the mechanical properties of work material, and high temperature along the tool-chip interface greatly influences the tool wear, i.e. the tool life. Tool becomes softer and wear becomes more rapidly by abrasion as temperature increases. While the heat generated in the friction zone between tool flank and workpiece will conduct into the tool and work material. The surface integrity and machining accuracy are influenced by these temperatures as they will cause thermal expansion during machining and perhaps metallurgical changes. In addition, these temperatures also cause the generation of tensile residual stress in the surface layer of work material. The tensile residual stress should be avoided since it reduces the fatigue strength of work material.

Therefore, it is not surprising that considerable efforts have been made to assess the interface temperature by both experimental and theoretical means. However, it is not easy to determine the temperature at the cutting edge, either experimentally or analytically. The distinguishing characteristics of temperature measurement at the cutting edge are as follows: access to the measuring point is limited, the area to be measured is very small, the measuring point is the moving area, and an extremely steep gradient of temperature exist in it.

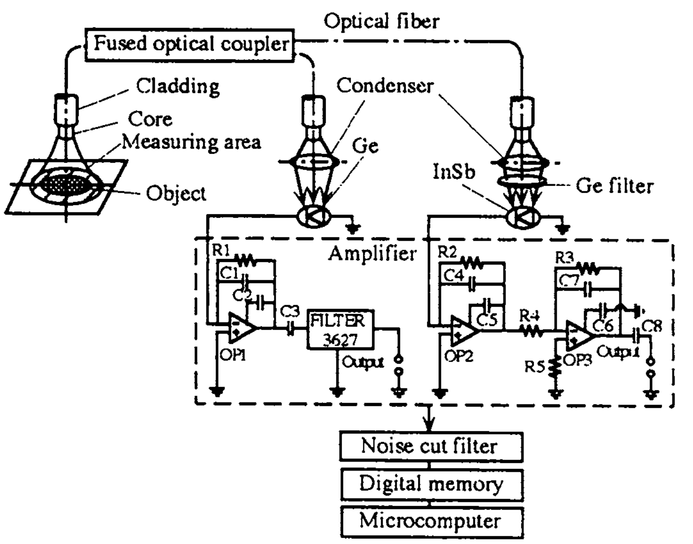


Fig. 1 System of two color pyrometer.

The objective of this study is to establish a measurement technique for determining the temperature of cutting tool edge in turning operation. A new type of infrared radiation pyrometer is developed by combining a fused fiber coupler and two infrared detectors in order to perform a two-color measurement. The pyrometer is applied to the temperature measurement of the tool-chip interface and of the flank side of tool edge. The numerical analysis of temperature distribution in orthogonal cutting with coolant is done using finite element , in order to investigate the effect of the coolant on the temperature distribution. The calculated temperatures are compared with experimental results.

Chapter 2 Basic Principles and Characteristics of Two-Color Pyrometer

In this chapter, the system of two-color pyrometer is introduced (see **Fig. 1**). This pyrometer is used to measure the temperature of a body based on its emitted radiant energy. The infrared rays emitted from the object are accepted by an optical fiber, and divided into two channels by a fused fiber coupler. Each channel is linked to two infrared detectors, which have a different spectral sensitivity, respectively. Ge and InSb cells are used for high speed response. The electric signals converted from infrared energy by these cells are amplified and stored in a digital memory. The temperature is obtained by the ratio of the output voltages from these two cells, subsequently, the influence of the object emissivity on the temperature measured can be eliminated. Therefore, a precise calibration can be performed easily, and enable us to make a quantitative measurement without the knowledge of the object emissivity. A graded-index quartz (SiO_2) fiber is used as an optical fiber, hence, the pyrometer is proper for measuring temperature higher than 500 °C.

The influence of temperature distribution of the object at the temperature measured

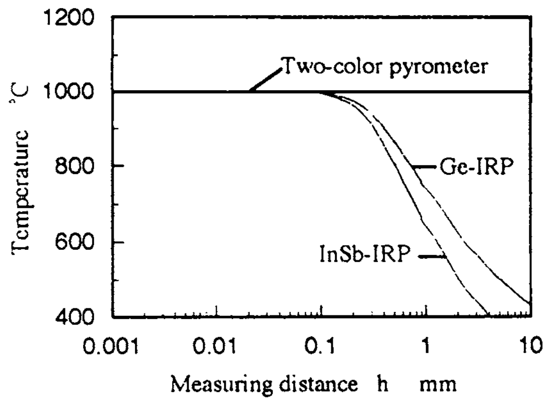


Fig. 2 Influence of measuring distance on temperature measured when object has uniform temperature.

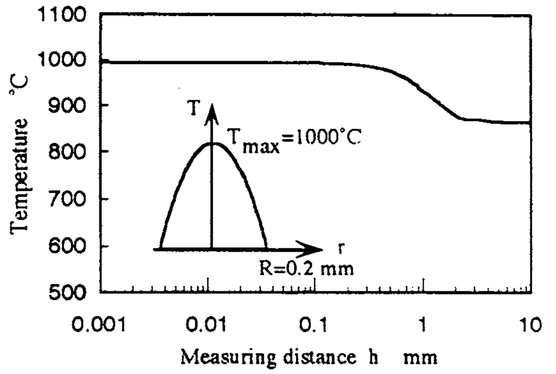


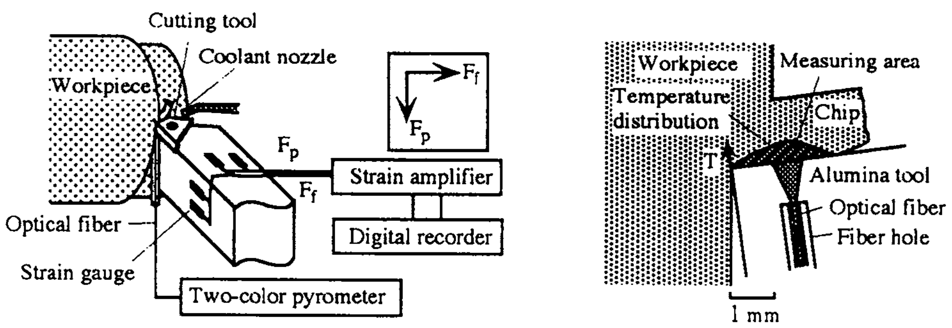
Fig. 3 Influence of measuring distance on temperature measured when object has 2nd power temperature distribution.

is examined, theoretically . In the case when temperature distribution of the object is uniform, the temperature measured by the pyrometer is not influenced by the measuring distance, and therefore, it could be measured accurately (see **Fig. 2**). In the case when the object has temperature distribution, the temperature measured is slightly affected by the measuring distance, and the temperature is obtained very close to the maximum temperature of the object (see **Fig. 3**).

Chapter 3 Measurement of Temperature of Tool-Chip Interface in Turning

In this chapter, the two-color pyrometer with a fused fiber coupler is applied to the temperature measurement of the tool-chip interface. The experimental arrangement is illustrated schematically in **Fig. 4**. A translucent alumina (Al_2O_3) tool is used as a cutting tool. The optical fiber is inserted into a fine small hole (the diameter is approximately 0.6 mm) at the tool, which extends nearly to the rake surface of the tool. During the cutting process, the infrared rays radiated from the tool-chip interface and transmitted through the translucent tool are accepted by the optical fiber, and led to the two-color pyrometer. Temperatures are measured in dry and wet cutting condition, in order to investigate the effect of coolant on the temperature.

Fig. 5 shows the interface temperature as a function of cutting speeds for dry and wet cutting conditions. The tool-chip interface temperature is highly affected by cutting speed, and the temperature increases rapidly with the increase of cutting speeds. With common method of overhead jet cooling, the tool-chip interface temperature reduces only about 30°C at temperature about 950 °C, compared with the temperature in dry cutting.



(a) Experiment set-up. (b) Optical fiber setting.

Fig 4 Schematic illustration of experimental set-up (1).

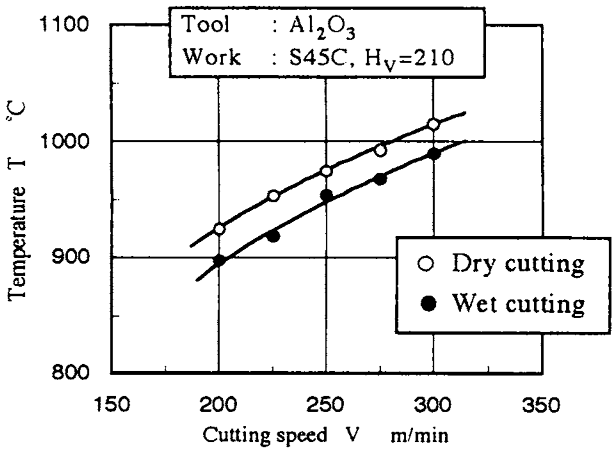
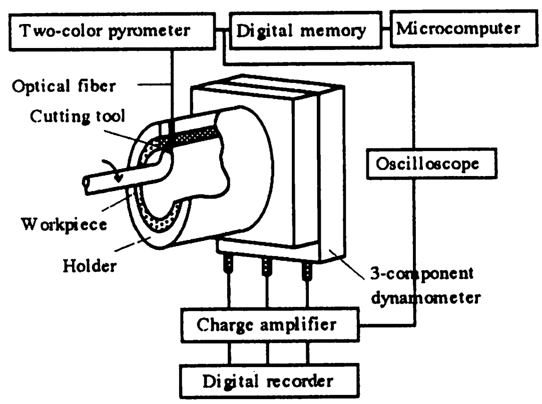


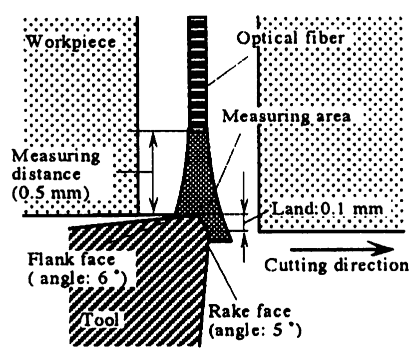
Fig. 5 Interface temperatures measured by two-color pyrometer.
(Cutting conditions: d = 0.8 mm, f = 0.2 mm/rev)

Chapter 4 Measurement of Temperature at Flank Side of CBN Tool Edge in Turning of High Hardness Steels.

In this chapter, the two-color pyrometer is applied to the temperature measurement of flank side of CBN tool edge in turning of high hardness steels. A high carbon chromium bearing steel (JIS-SUJ2), a chromium molybdenum steel (JIS-SCM415), and a quenched 0.55 % carbon steel (JIS-S55C) are used as work materials. The experiment arrangement is illustrated schematically in **Fig. 6**. A single point cutting tool is gripped by a chuck mounted on the end of the main spindle of the lathe, and rotates at various cutting speeds. A cylindrical workpiece is placed at the work holder and the inner surface of the workpiece is generated by cutting. A small fine hole (diameter is approximately 0.6 mm) was drilled at the work material perpendicular to the machined (inner) surface. The optical fiber is inserted into this fine hole from the outer surface and is fixed at the point that the distance between the incidence face of the fiber and the machined surface is 0.5 mm. The infrared



(a) Experiment set-up.



(b) Optical fiber setting.

Fig 6 Schematic illustration of experimental set-up (2).

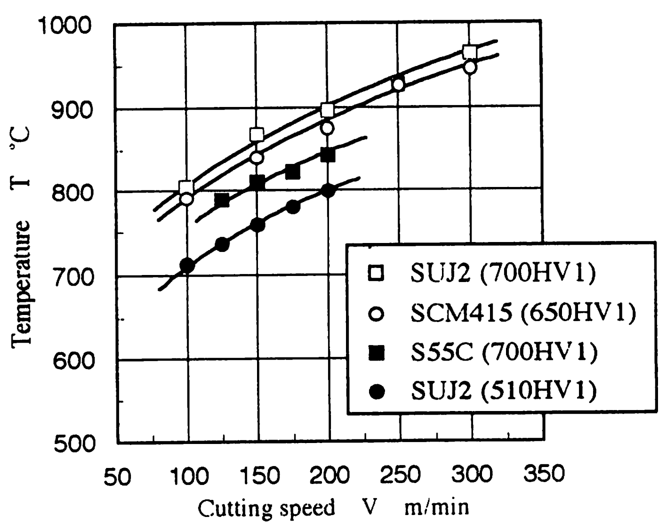


Fig. 7 Influence of work materials on tool edge temperature. (Cutting conditions: $d = 0.1$ mm, $f = 0.1$ mm/rev)

rays radiated from the flank side of the tool edge during the cutting are accepted by the optical fiber, at the time when the tool passed above the hole.

Fig. 7 shows the cutting edge temperatures as a function of cutting speed for various work materials. It is found that there is close relation between the temperature and the hardness of the work material. The highest temperature is obtained for a high carbon chromium bearing steel (JIS-SUJ2), which is the hardest material used in present experiment.

The width of flank wear is measured in order to investigate the influence of cutting speed on tool wear. The influence of cutting speed on tool wear is great and the width of flank wear at cutting speed of 300 m/min is about twice as large as that at 100 m/min.

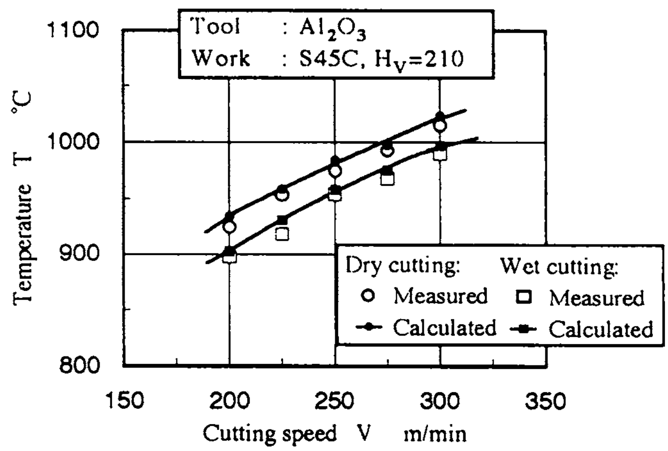


Fig. 8 Comparison of calculation results with experimental values.
(Cutting conditions: d = 0.8 mm, f = 0.2 mm/rev)

Chapter 5 Analysis of Temperature Distributions in Orthogonal Cutting with Coolant

In this chapter, the finite element method is applied to determine the temperature distributions in the chip, workpiece and the tool. The problem considered is the two-dimensional steady state cutting process. Heat is generated by plastic deformation flow in the chip and by friction between the chip and the tool. Commonly used cooling methods, overhead and flank jet cooling method,are modelled as boundary conditions.The influence of the coolant on temperature distributions is investigated. The calculated temperatures are compared with experimental results.

Fig. 8 shows the comparison of the calculated temperatures with the temperature measured by two-color pyrometer. It is found that the experimentally measured temperatures coincide well with the calculated results. Good agreement is obtained between the analytical results and the experimental ones.

It is also found that the influence of coolant is small on the tool-chip interface temperature, in which the maximum temperatures are reduced only about 30 °C at temperature about 1000 °C. However, the coolant decreases the depth of the hot zone below the rake surface of the tool.The temperature distributions in the tool are varies with the various heat transfer coefficient. For heat transfer coefficient higher than 10^3 W/(m^2·K), the cooling is effective in reducing temperature away from the tool zone. The flank jet cooling is more effective than overhead jet cooling in reducing the tool-chip interface temperature, and the combination of these two method is the most effective.

Chapter 6 Conclusions

This chapter summarises this thesis with conclusions for our study work in developing the measurement technique for determining the temperature of tool edge in turning.

学位論文審査結果の要旨

平成11年1月27日に第1回学位論文審査委員会を開催し，平成11年2月3日に口頭発表ならびに第2回審査委員会を開催して慎重に審査した結果，以下のように判定した。

本論文は，施削加工において，工具寿命や加工材料仕上げ面性状に大きく影響する，切削時の工具刃先温度について研究している。光カプラーとInSb素子・Ge素子を組み合わせた新しいタイプの2色温度計を製作し，工具すくい面温度を測定している。すなわち，透光性のあるアルミナ工具を用いて，工具－切りくず接触面から輻射され工具内を透過してきた赤外線を受光し，光カプラで分岐して2つの素子に伝送している。また，有限要素法による熱伝導解析を行い，加工液の有効な供給方法についても検討している。

この温度計を活用して，高速切削中のCBN工具の刃先温度計測を行っている。生産性の向上にもっとも有効な手段として高速切削が注目されているが，軸受け鋼やクロムマンガン鋼といった高硬度鋼を，従来の数倍の速度で高速切削しようとするときの工具刃先温度を計測する事に成功している。ダイヤモンドに次ぐ硬度を持つCBN工具は従来の超硬工具などにないすぐれた特性を有しているが，1300℃近辺で酸化する弱点があり，工具温度はCBN工具の性能を引き出す際に最も重要なファクターの1つである。さらに，工具摩耗との関連についても検討している。

以上のように，本論文は高速切削における工具寿命を考える上で不可欠な工具刃先温度を計測することに成功して多くの新しい知見を得ており，博士(工学)論文に値するものと判定した。