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DEVELOPMENT OF TEMPERATURE MEASUREMENT OF CUTTING TOOL USING INFRARED RADIATION WITH OPTICAL FIBER

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DEVELOPMENT OF TEMPERATURE MEASUREMENT OF CUTTING TOOL USING INFRARED RADIATION WITH OPTICAL FIBER

MOHAMMAD ZULHAFIZ BIN JENUREN

A dissertation submitted in partial fulfilment

of the requirement for the degree of

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Dedicated to my beloved families for their unconditional love and encouragement.

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ABSTRACT

A review of machining with high speed (HSM) in use nowadays shows that it is one of the modern technologies that replaced conventional machining due to efficiency, accuracy and machining time. In metal cutting process, the heat generated is acts as important factor that influences the performance of cutting tool. The high temperature zones resulting wear to the cutting tool that leads to flank wear and crater wear. Therefore, it reduces tool life and affects dimensional accuracy. This study is focus on cutting performance of carbide cutting tool towards temperature using infrared radiation. These methods include calibration, pyrometer and tool wear analysis. The use of a pyrometer has been examined in detail using a sensor of indium arsenide (InAs) and indium antimonide (InSb). The experiment involved an analysis of the effect of changing the feed rate, varying the radial depth and varying the axial depth against tool wear. The results showed that increasing the feed rate, radial depth and axial depth increases the cutting temperature and tool wear. An important factor in measuring temperature of cutting tool is calibration process of heated cutting tool and position of the optical fiber towards cutting tool. A tool wear analysis has been conducted that shows that increasing the radial depth and axial depth with respect to feed rate increases the wear length which will increase the temperature. The results of this experiment and tool wear analysis are presented such that can be used as an aid to improve the design of dry cutting.

ABSTRAK

Hasil kajian *High Speed Machining* (HSM) yang digunakan pada masa kini menunjukkan bahawa ia adalah salah satu teknologi moden yang menggantikan pemesinan konvensional kerana kecekapan, ketepatan dan masa pemesinan. Dalam proses pemotongan logam, haba yang dihasilkan akan bertindak balas sebagai faktor penting yang mempengaruhi prestasi memotong alatan. Zon suhu tinggi menyebabkan kehausan pada alatan pemotongan yang membawa kepada *flank wear* dan *crater wear*. Oleh kerana itu, suhu tinggi ini akan mengurangkan hayat alatan pemotongan dan memberi kesan kepada ketepatan dimensi. Kajian ini menumpukan kepada prestasi alatan pemotongan karbida ke arah suhu menggunakan sinaran inframerah. Kaedah ini termasuk penentukuran, pengukur api dan analisis alatan penggunaan. Penggunaan pengukur api yang telah diperiksa secara terperinci menggunakan sensor *indium arsenide* (InAs) dan *indium antimonide* (InSb). Eksperimen ini melibatkan analisis kesan perubahan kadar suapan, yang berbeza-beza kedalaman jejarian dan berbeza-beza kedalaman paksi terhadap alatan penggunaan. Hasil kajian menunjukkan bahawa peningkatan kadar suapan, kedalaman jejarian dan paksi kedalaman meningkatkan suhu pemotongan dan kehausan alatan penggunaan. Satu lagi faktor penting dalam mengukur suhu alatan memotong adalah proses penentukuran alatan pemotong dipanaskan dan kedudukan gentian optik ke arah alat memotong. Analisis alatan penggunaan telah dijalankan yang menunjukkan bahawa peningkatan kedalaman jejarian dan paksi mendalam berkenaan dengan kadar suapan meningkatkan panjang kehausan yang akan meningkatkan suhu. Keputusan eksperimen ini dan analisis alatan penggunaan dibentangkan itu boleh digunakan sebagai bantuan untuk memperbaiki reka bentuk pemotongan kering.

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LIST OF ABBREVIATIONS

HSM	High Speed Machining
N	Rotational Speed
RPM	Revolution Per Minute
^{O}C	Degree Celcius
μm	Micrometer
mm	Millimetre
f	Feed rate
R_d	Radial Depth
A_d	Axial Depth
%	Percentage
ISO	International Standard Organization
HP	Horse Power
Hz	Hertz

CHAPTER 1

INTRODUCTION

1.1 Background

Machining is one of the most widely used processes in manufacturing and has undergoes the focus of research and development for many years. In metal cutting or chip type machining process, heat is generated during cutting act as an important factor that influences the performance of cutting tool. The productivity of machining lies with increasing in metal removal rate .This desired can be achieved by increasing the input of cutting variables like the cutting speed, the feed rate and the depth of cut.

According to Schulz & Moriwaki (1992), machining with high speeds (HSM) is one of the modern technologies which in comparison with conventional cutting where it enables to increase efficiency, accuracy and quality of workpiece and at the same to decrease costs and machining time. Bhaumik et al (1995), Liu et al. (1999) & Dowey & Rahle (1997) reported that 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 which affect tool life. Therefore, it is a crucial things to measure and control the cutting temperature to enhance the efficiency in machining.

In metal cutting, there are two types of technique that is commonly used for temperature measurement which are thermocouple and infrared radiation pyrometer. Thermocouple is a simple temperature sensor which consisting of two dissimilar metals in thermal contact and the contact point produces a small open circuit voltage as a function of temperature. Then, infrared radiation pyrometer is the current method for measuring temperature. This technique is based on the surface temperature of the body that is measured according to emitted thermal energy from tool, workpiece and chip.

1.2 Problem Statement

One of the most common phenomena occurs in machining process is the heat generated in the cutting zone. Shaw (1984), Komanduri-Hou (2001), and Stephenson (1993) agree that most of the energy applied to the cutting process is converted into heat in the main zone of plastic deformation, the shearing plane. This is where the workpiece material turns itself into chip and in the secondary zone of plastic deformation, chip slides on the rake face. Last but not least, some heat also arises on the tertiary zone where the tool relief face slides on the newly machined surface. However, the heat generated is very small in this last source where it is not considered in most cases when using sharp cutting tool.

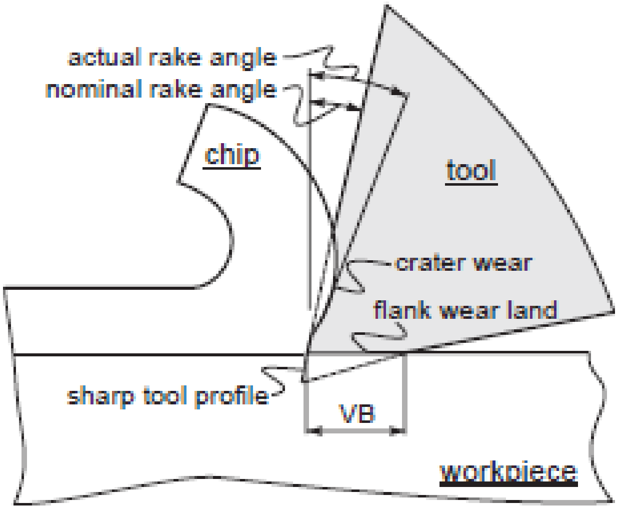

Figure 1.1: Heat generated in cutting zone

The heat that is generated during metal cutting process gives high temperature to the cutting tool. Thus high temperature zones resulting wear to the cutting tools that leads to flank wear and crater wear (rake face). Therefore it reduces tool life for the cutting tool. As a result the surface of workpiece become rough and it affects dimensional accuracy.

Thermocouple is one of a simple temperature sensor technique consisting of two dissimilar metals in thermal contact. The contact point produces a small open circuit voltage as a function of temperature. However, this technique requires that both tool material and work material has to be electrically conductive. Limitation to this technique is cutting fluid cannot be used, calibration is tedious and laborious, secondary voltages may occurs and many tool-workpiece where combinations do not form an ideal thermocouples setup.

Infrared radiation pyrometer is the latest method in measuring temperature during metal cutting. It is because there is no direct contact with the heat source and high temperatures can be captured easily. This technique is based on emitted thermal energy from the tool, the workpiece and the chip. However, temperature measurement from metal cutting using this method could be misleading if an incorrect emissivity value is chosen based from incorrect position of optical fiber.

1.3 Objectives

In this study, our main objective is to determine the best configuration and setup for thermocouple and infrared radiation pyrometer to measure the temperature during cutting process. At the same time, this study also helps to relate the effect of cutting parameters with the temperature that has been measured.

- To apply infrared radiation technique in measuring cutting temperature
- To develop cutting temperature measurement device
- To measure temperature at cutting tool edge
- To analyze the effect of cutting parameters on temperature and wear

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to High Speed Machining

According to Schulz (1996), high speed machining (HSM) is one of the advanced manufacturing technologies with a great potential in industries. One definition that describes the process is it involves machining at considerably higher cutting speeds and feed rates than those used in conventional machining. However, it is most common used to describe metal cutting at high rotational speeds. This process has been adapted to a wide range of applications. The significance for high speed machining and especially high speed milling in production has increased since new machines and tools enable the possibility to reduce process time on one hand and to improve surface quality on the other hand.

Korkut et al. (2007), Kulenovic et al. (2007), Chen et al. (2013) & Vijay et al. (2013) states that number of studies have researched the effects of the cutting speed, feed, depth of cut, nose radius and other factors on the surface roughness. The surface quality is one of the most specified by customer requirements and the major indicator of surface quality on machined is surface roughness. The surface roughness is mainly a result of various controllable or uncontrollable process parameters and it is harder to be detected than physical dimensions.

2.2 Milling Operation

Milling operations are one of the most common machining operations in industry. It is used for face finishing, edge finishing, material removal and etc. There are several parameters that can influence the forces acting on the cutting tool. Due to these parameters, the forces are unpredictable and resulting in larger dimensional variations when products being produced.

The milling process is a highly non-linear plastic deformation process with many independent and dependent variables process parameters change such as functions of the feed rate, tool rotation angle and the position angle of a point along the cutting edge. As a result from using constant process parameters, the measured force components are underestimated during the engagement and disengagement periods.

2.3 Tool Materials

There are many types of tool materials with range from high-carbon steels to ceramics and diamonds used as cutting tool materials in industries nowadays. According to Davis (2005) it is important to be aware that differences exist among tool materials, what these differences are and the correct application for each type of material

The three properties of a tool material:

i. Hardness: It is defined as the resistance to indenter penetration. According to Isakov (2004) it is directly correlates with the strength of the cutting tool material. The ability to maintain high hardness at elevated temperatures is called hot hardness. Figure 2.1 shows the hardness of typical tool materials as a function of temperature.

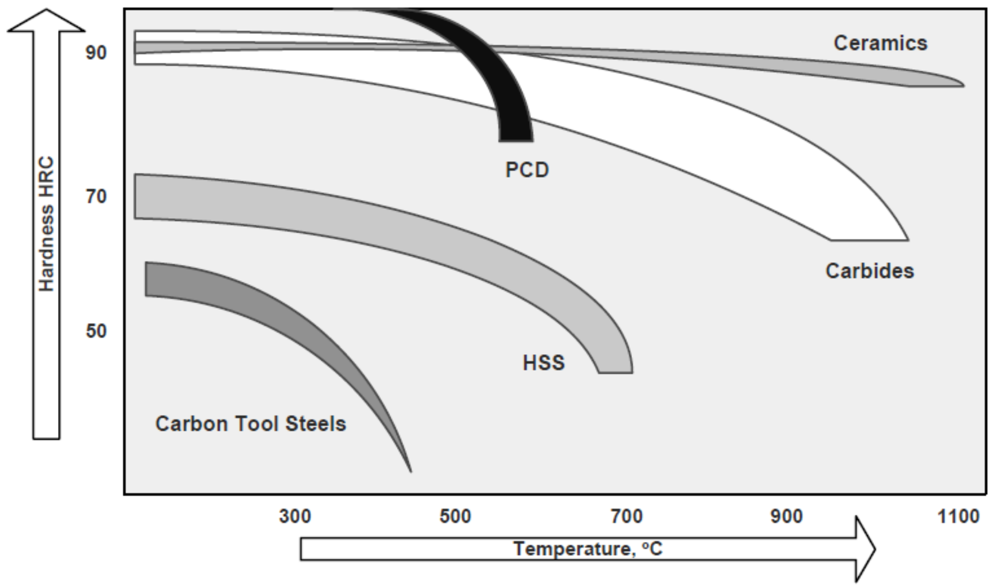

Figure 2.1: Hardness of tools against temperature

ii. Toughness: It is defined as the ability of a material to absorb energy before fracture. The better it resists shock load, chipping and fracturing, vibration, misalignments, run outs and other imperfections in the machining system the greater the fracture toughness of a tool material. Figure 2.2 shows that, tool materials, hardness and toughness change in opposite directions. A major trend in the development of tool materials is to increase their toughness while maintaining hardness.

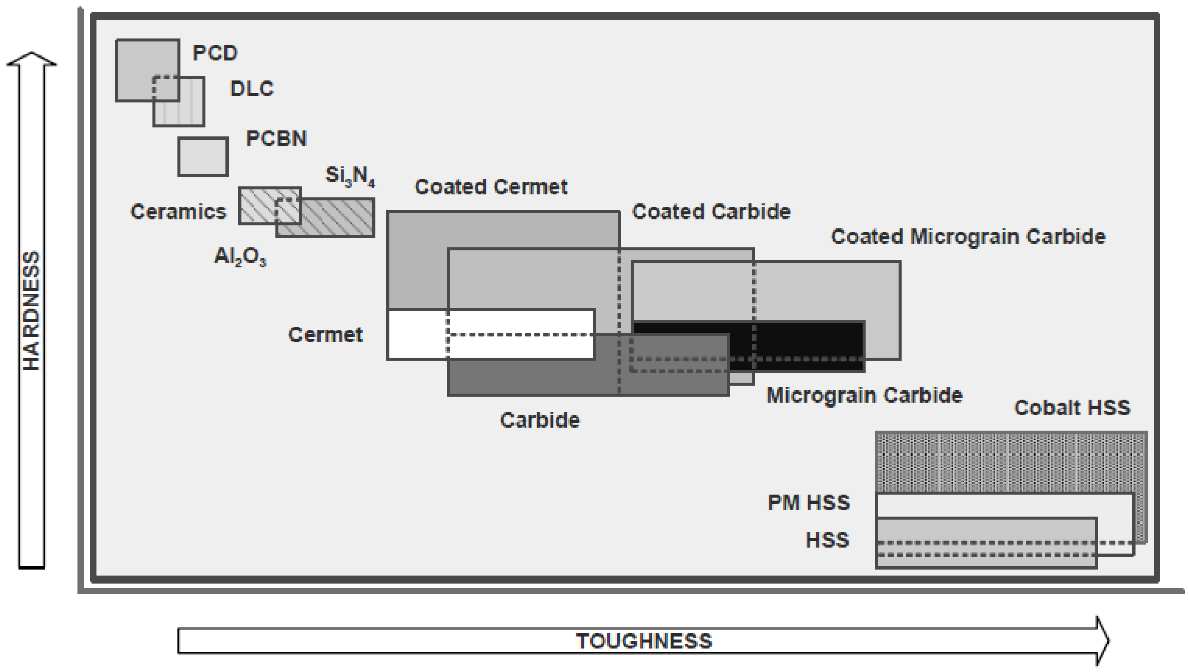

Figure 2.2: Hardness and toughness of tool materials

iii. Wear resistance: It is defined as the attainment of acceptable tool life before tools need to be replaced. Although it is very simple, this understanding of characteristic is the least understood.

2.4 Wear Profile

Tool wear is a result from complicated physical, chemical, and thermo-mechanical phenomena. This is due to various simple mechanisms of wear such as adhesion, abrasion, diffusion, oxidation and *etc* act simultaneously with a predominant influence of one or more in different situations. The identification of the dominant mechanism is harder and most interpretations are subject personal opinion.

2.4.1 Types of Tool Wear

According to the standard ISO 3685 (1993), wear measurements is from the major cutting edge and considered to be divided in to four regions, as shown in Figure 2.3. Flank wear and crater wear are the most common form of tool wear. However, flank wear is most commonly used for wear monitoring in metal cutting.

Region C is the curved part of the cutting edge at the tool corner

Region B is the remaining straight part of the cutting edge in zone C

Region A is the quarter of the worn cutting edge length b farthest away from the tool corner

Region N extends beyond the area of mutual contact between the tool workpiece for approximately 1–2 mm along the major cutting edge. The wear is of notch type.

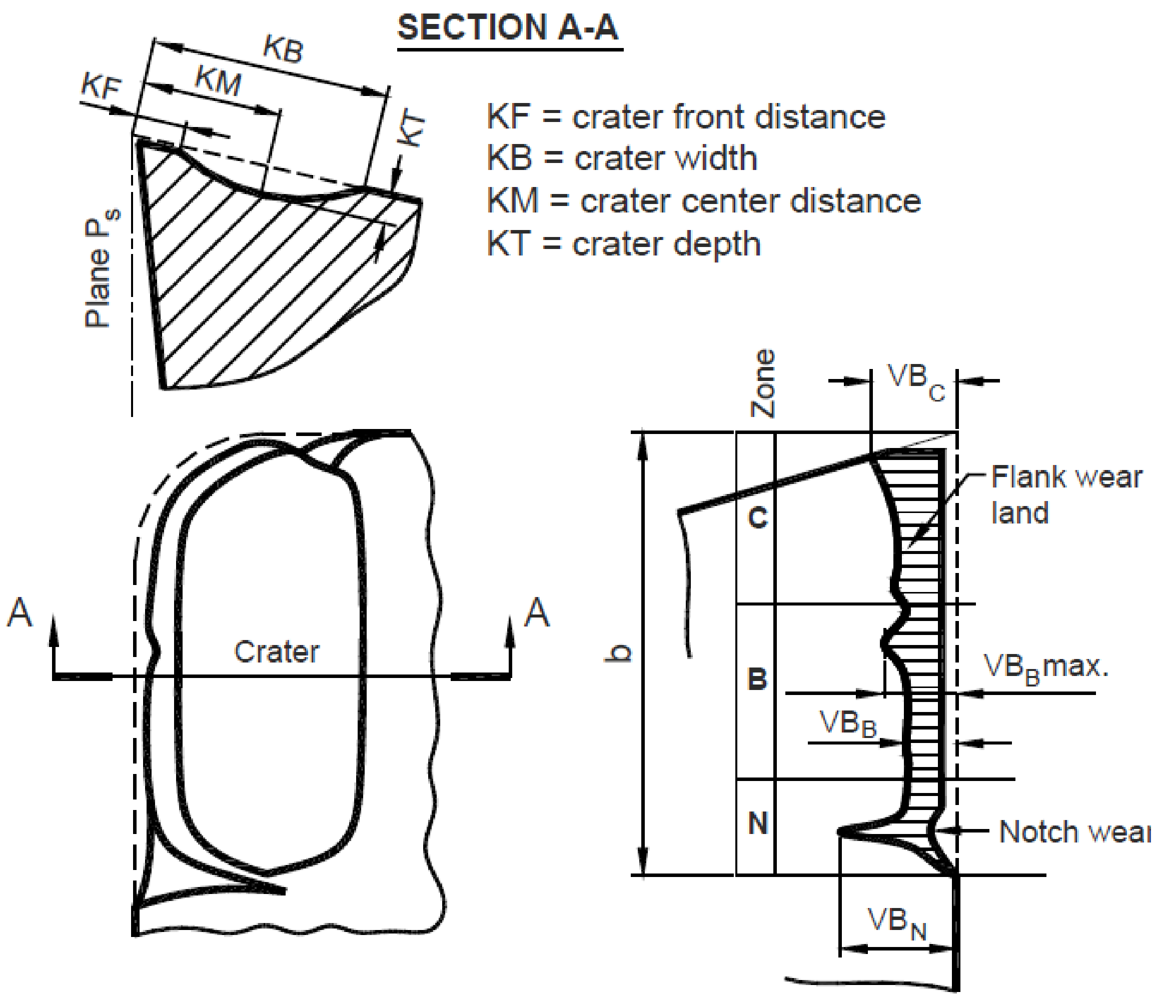

Figure 2.3: Types of tool wear according to standard ISO 3685:1993

The width of the flank wear land, VB_B is measured within zone B in the cutting edge plane Ps perpendicular to the major cutting edge. The width of the flank wear land is measured from the position of the original major cutting edge.

The crater depth, KT, is measured as the maximum distance between the crater bottom and the original face in region B.

2.4.2 Characteristics of Tool Wear

Flank wear - It occurs at the tool flanks due to work hardening where it contacts with the finished surface, as a result of abrasion and adhesion wear. The cutting force increases with flank wear. It affects the great extent of mechanics of cutting.

Crater wear – It happens on the tool face at a short distance from cutting edge by the action of chip flow over the face at very high temperature. The crater wear is mainly due to diffusion and abrasion. They are commonly observed where the continuous chip is formed (usually in the ductile material). The cutting edge may break from tool due to excessive cratering.

2.5 Heat Zones

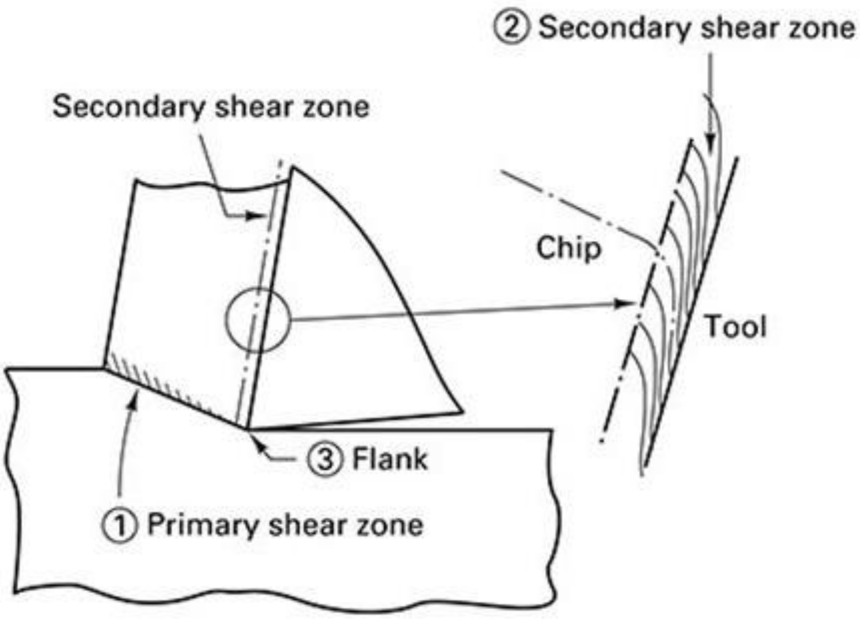

Figure 2.4: Heat generated zones

i. **Heat Generated in Primary Zone -** Heat generated within this zone is mainly due to plastic deformation and viscous dissipation. However, in classical machining theory, the rate of heat generated is the product of the shear plane component that from the resultant force and the shear velocity. The shear energy is converted into heat. This proves the intensity of shear plane heat when heat source is uniformly distributed along the shear plane.

ii. **Heat Generated in Secondary Zone -** Because of the complexity of plastic deformation in this region, this part of heat usually ignored in many previous theoretical researches. Boothroyd (1961) has shown that the secondary plastic zone is a roughly triangular in shape and that strain rate in this region varies linearly from an approximately constant value along the tool and chip interface. Thus, the maximum intensity of heat source in this zone is proportional to the strain rate.

iii. **Heat Generated at Interface between Tool & Chip -** Heat that is generated at tool or chip interface by friction. The intensity of the frictional heat source is approximately by the friction force, the sliding velocity of the chip along the interface, and the plastic contact length.

2.5.1 Heat in Metal Cutting

Types of heat sources from metal cutting are:

- Plastic deformation from workpiece converted to heat.
- Viscous dissipation transformed into heat if the cut material is viscoplasticity.
- Work done by friction from tool and workpiece converted to heat.
- Ambient heat source is concerned if there is thermal deformation.