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The Measurement of chip-tool interface Temperature in the Turning of steel

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Abstract- In metal cutting, the heat generated on the cutting tool is important for the performance of the tool and quality of the work piece. Maximum heat is generated on the tool –chip interface during machining. The machining can be improved by the knowledge of cutting temperature on the tool. In this study, the temperature generated on the cutting tool and experimental methods for the measurement of temperatures are reviewed. Special attention has been paid to tool- work thermocouple method and an experimental setup fabricated to measure the temperature on the cutting tool and work piece junction during metal cutting is described. With this method, the average temperature at the tool-chip interface is measured. The output of the thermocouple is in the mill volt range and measured by a digital milli- voltmeter. The voltmeter is basically current sensitive device; hence the meter reading will be dependent on the emf generated by tool-work-thermocouple. The thermoelectric power of the circuit is usually small and estimated by calibrating the circuit against a reference thermocouple (Alumel-Cromel K type). The setup for calibration and the procedure is described in this work.

Keywords-Cutting temperature, tool-work thermocouple,Calibration of tool-work thermocouple, Metal cutting

1. INTRODUCTION

When cutting metals and alloys most of the energy required to form the chips is converted into heat. Therefore, the temperatures generated in the cutting zone are an important factor to take into consideration. This factor is of a major importance to the performance of the cutting tool and quality of the work piece[1].Temperature in the cutting zone depends on contact length between tool and chip, cutting forces and friction between tool and work piece material. A considerable amount of heat generated during machining is transferred into the cutting tool and work piece. The remaining heat is removed with the chips. The highest temperature is generated in the flow zone. Therefore, contact length between the tool and the chip affects cutting conditions and performance of the tool and tool life [2-3].

For the improvement of cutting performance, the knowledge of temperature at the tool-work interface with good accuracy is essential. Several experimental and analytical techniques have been developed for the measurement of temperatures generated in cutting processes. Due to the nature of metal cutting, it is not possible to measure temperature precisely in the cutting zone and thus it is difficult to verity the theoretical results in a precise manner. Because of nature of the metal cutting, determination of internal temperatures on the cutting tool are very difficult. For measuring of this temperatures generated in the cutting zone, several methods have been developed. Calorimetric method, thermocouple method, infrared photographic technique, thermal paints and PVD technique are some of them [4].

Tool-work thermocouple has always become a popular tool to be used in temperature measurements during metal cutting. This method is very useful to indicate the effects of the cutting speed, feed rate and cutting parameters on the temperature. Thermocouples are conductive, rugged and inexpensive and can operate over a wide temperature range. In machining applications, a thermo electric emf is generated between the tool and the work piece. With these method, the entire tool is used as a part of the thermocouple and the work piece as the other part. The cutting zone forms the hot junction while a cold part of the tool and the work piece forms the cold junction. This technique is easy to apply but only measures the mean temperature over the entire contact area of tool and work piece.

Based on these measurements using the thermocouple method, Stephenson [5] stated that the average emf is in tool -work piece interface.

K.J. Trigger[6] investigated the tool-work interface temperatures using the thermocouple technique. This work differs from the earlier work in that cemented carbide tools were used in machining steels instead of the HSS tools. Both the elements of tool-work thermocouple comprised of iron base alloys of similar basic lattice structure, a factor which can influence the tendency of the chip to form a built up edge on the tool and consequentlycause erratic results. W.Grzesik [7] investigated the influence of tool-work interface temperature when machining an AISI 1045 and an AISI 304 with coated tools. A standard k-type of thermocouple inserted in the work piece was used to measure the interface temperature. The friction on the flank face had a big influence on the heat generated at about 200 m/min cutting speed. O' Sullivan and Cottrell [8]measured the machined surface temperatures two thermocouples inserted into the work piece when machining aluminum 6082-T6. The results indicated that an increase in cutting speed resulted in a decrease in cutting forces and machined surface temperatures. This reduction in temperature was attributed to the higher metal removable rate which carried more heat being carried away by the chip. Trent and Wright, P.K [9],during the machining process, a considerable amount of the machine energy is transferred into heat through plastic deformation of the work piece surface , the friction of the chip on the tool face and the friction between tool and the work piece.Trent and Wright [9] suggest that 99% of the work done is converted into heat. This results in an increase in the tool and work piece temperatures. Muller-Hummed and Lahres, M. [10] the temperature distribution depends on the heat conductivity and specific heat capacity of the tool and the work piece and finally the amount of heat loss based on radiation and convection. The maximum temperature occurs in the contact zone between the chip and the tool [11]. Herbert [12], (quoted in (E M Trent, 1989) used a technique with tool-work thermocouple to analyze chip-tool interface temperature variation under different cutting conditions, such as the cutting speed and depth of cut, as well as with different cutting fluids. His results showed that temperatures increased with increase in speed from 0.1m/s to 1m/s. Similarly, temperatures were high when cutting dry, followed by cutting with an oil lubricant, and finally with water as the cutting fluid. Since water is the best conductor of heat among the three choices, it gave the lowest temperature, reinforcing water’s ability as a good coolant. Who achieved up to 30 to 40 % increase in cutting speed when machining steel with high speed steel tools using water as coolant. Despite its excellent cooling ability water lacks lubricating properties and causes serious corrosion problems on the machine tool components as well as on the work piece.

Kurimoto et al [13] cut low alloy engineering steel using cemented carbide tool over a range of speeds and feeds in air and using different cutting lubricants (water). They indicate an increase in temperature with increments in speed and feed, and a small lowering of temperature when water was used as a coolant. Vieira, J. m. et al [14] studied the cooling ability of the cutting fluids, the cutting fluids were used emulsion of mineral oil, semi-synthetic and synthetic cutting fluids, cutting temperatures were measured by tool work thermocouple technique during turning of AISI 1020 steels. The results showed that the chip-tool interface temperature increased with increasing cutting speed during machining. Cutting fluids reduced the mean chip-tool interface temperatures in relation to the dry cutting. Out of these cutting fluids the semi-synthetic cutting fluids exhibited the best cooling ability during machining, followed by the emulsion -based mineral oil, and the 5% concentration and 10% concentration of synthetic fluids. Khan, M. M et al. [15] reported the effects of MQL by vegetable oil based cutting fluid on the turning performance of low alloy steel AISI 9310 as compared to completely dry and wet machining in terms chip-tool interface temperature, chip formation, tool wear and surface roughness, chip-tool interface temperature were measured by tool-work thermocouple technique during turning of AISI 9310 steels. The results showed that chip-tool interface temperature were reduced by MQL and wet machining as compared to dry machining under different cutting condition with uncoated carbide inserts.

During metal cutting, the heat generated is significant enough to cause local ductility of the work piece material as well as of the cutting edge. Although softening and local ductility are required for machining hard materials, the heat generated has a negative influence on the tool life and performance. Therefore, the control of cutting temperature is required to achieve the desired tool performance.

In this study, the methods of temperature measurement during machining were reviewed and a temperature measurement set-up based on tool work thermocouple method is prepared.

2. TEMPERATURES IN METAL CUTTING

During the metal cutting process, a considerable amount of the machine energy is transferred into heat through plastic deformation of the work piece surface, the friction of the chip on the tool face and the friction between the tool and the work piece. Trent and Wright [9] suggest that 99 per cent of the work done is converted into heat. This results in an increase in the tool and work piece temperatures.

The temperature distribution depends on the heat conductivity and specific heat capacity of the tool and the work piece and finally the amount of heat loss based on radiation and convection. The maximum temperatures occur in the contact zone between the chip and the tool. There are three main sources of heat generation during the process of cutting metal with a machine tool. Heat is produced in the primary shear zone as the work piece is subjected to large irreversible plastic deformation (Shear- zone).(b) Heat produced by friction and shear on the tool rake face, or secondary shear zone. The chip material is further deformed and some adheres to the tool face. In this region the last layer of atoms of the chip material are stationary. The velocity of the adjacent layers gradually increases until the bulk chip velocity is attained. Thus there are both sticking and sliding friction sections. This combined shear and friction action produces heat (friction zone). © Heat produced at the tool-work interface, where the tool flank runs along the work piece surface and generates heat through friction. Under normal cutting conditions, a thin layer of work piece material is extruded below the cutting edge, thus establishing contact with the clearance face for a distance of approximately 0.2 mm below the cutting edge of a sharp tool with a flank angle of 6°. This is a part of the third heat source that can be thought of as a part of the total heat pattern (work tool contact zone).

As the cutting action proceeds and the heat has been generated most of the heat is dissipated in the following manners (chip, work piece, cutting tool and cutting fluid).

(a)The discarded chip carrying away the heat. The temperature decays along the length of the chip. Also, due to head convection and radiation at the outer surface of the chip, the temperature gradient is higher across the chip cross section than along the length of the chip. (b)The work piece acts as a heat sink. (c)The cutting tool acts as a heat sink. (d)Coolant, where used, will help to draw away heat from all areas. There are different estimations of the amount of heat dispersed into the tool, chip and work piece. Any coolant will reduce the actual temperature of all three heat sinks.

When a material is deformed elastically, the energy required for the operation is stored in the material as strain energy, and no heat is generated. In metal cutting the material is subjected to extremely high strains and the elastic deformation forms a very small proportion of the total deformation whereas plastic deformation forms large proportion of the total deformation. Therefore; it may be assumed that all the energy is converting into heat. Heat generated tool-work interface is of importance to the tool performance.

The heat generated is shared by the chip, cutting tool and the work piece. Figure1 shows that maximum amount of heat is carried away by the flowing chip. From 10 to 20% of the total heat goes into the tool and some heat is absorbed in the work piece. With the increase in cutting velocity, the chip shares heat increasingly.

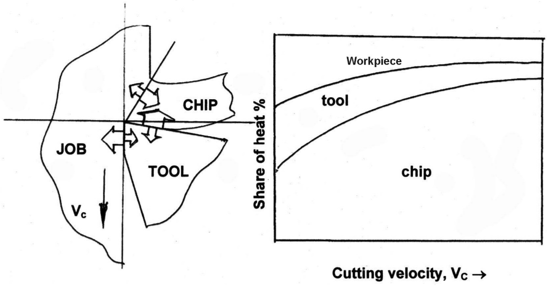


Figure1.Distribution of heat amongst chip, tool and work piece

The effect of cutting temperature, particularly when it is high, is mostly detrimental to both the tool and the job.

3. EFFECT OF CUTTING TEMPERATURE ON TOOL AND JOB

(a) The possible detrimental effects of high cutting temperature on cutting tool (edges) are: Rapid tool wear, which reduces tool life, Plastic deformation of the cutting edges if the tool material is not enough hot-hard and hot-strong, Thermal flaking and fracturing of the cutting edges due to thermal shocks, Built-up-edge formation.

(b) The possible detrimental effects of cutting temperature on the produced jobs are:Dimensional inaccuracy of the job due to thermal distortion and expansion contraction during and after cutting, Surface damage by oxidation, rapid corrosion, burning etc and Induction of tensile residual stresses and micro cracks at the surface/subsurface.

4. EXPERIMENTAL SETUP: TOOL WORK THERMOCOUPLE

There are number of methods for measuring the chip tool interface temperature: Tool work thermocouple, Radiation pyrometers, embedded thermocouples, temperature sensitive paints and indirect calorimetric technique.

Of all these methods, the tool work thermocouple technique is the most widely used technique for the measurement of the average chip tool interface temperature. The other methods suffer from various disadvantages such as slow response, indirectness, and complications in measurement.

Thermocouple: Thermocouple is a temperature sensor based on the principle that a voltage is produced when two dissimilar metals. The junction produces a voltage in proportion to the difference in temperature between the measuring junction and the reference junction.

An experimental setup designed, fabricated and calibrated in mechanical engineering workshop to measure the temperature on cutting tool and work piece junction during metal cutting on precision lathe (HMT,LTM-20 heavy duty lathe machine) as shown in Figure2.

This method of tool temperature measurement employs the tool (carbide tool) and the work material (alloy steel) as the two elements of a thermocouple. The thermoelectric emf generated between the tool and work piece during metal cutting is measured using a sensitive mill voltmeter. The hot junction is the contact area at the cutting edge, while an electrical connection to a cold part of the tool forms one cold junction. The tool is electrically insulated from the machine tool (usually a lathe). The electrical connection forming the cold junction with the rotating work piece is more difficult to make, mercury cup with rotating disc at the end of the work piece through the spindle bore is a convenient method for completing the emf circuit. A form of mercury slip ring connection being used, the emf can be measured and recorded during metal cutting, and, to convert these readings to temperatures, the tool and work materials, used as a thermocouple, It has been calibrated against a standard as Chromel-Alumel (as shown in Figure3 Each tool and work material used must be calibrated.

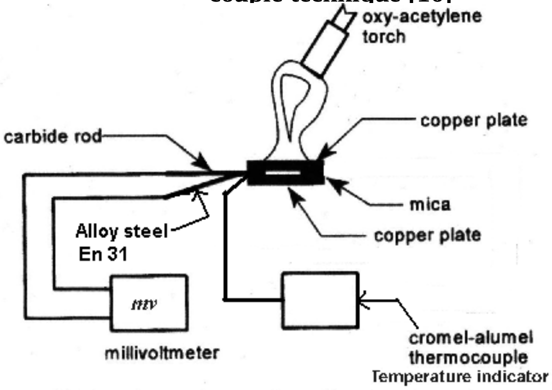
A. *Sample thermocouple calibration curve*

For the present investigation, the calibration of the tool-work thermocouple was carried out by external flame heating (as shown in Figure 3.The tool-work thermocouple junction was constructed using a continuous chip of (En31 alloy steel) work material and an uncoated carbide insert was used in actual cutting .A standard K-type thermocouple was mounted at the site of tool-work junction. The oxy-acetylene torch simulated the heat generation phenomena in metal cutting and rise the temperature at the chip-tool interface. Standard thermocouple directly monitored the junction temperature when a digital multimeter monitored the emf generated by the hot junction of the chip-tool. In the present case almost linear relationship is obtained between the temperature and emf. A linear model has the form T = aV+b where T is the temperature and V is the mill volt reading , and the parameters to find by least squares ,we write the equation in this form , with T being the dependent variable(X axis) , so that we can measure V and predict T. Hence the generalized equation is:

$$T = 20.44V + 34.158 \qquad (1)$$

A multiple correlation coefficient of model is 0.994 or **R^2 = 0.994**which tends to indicate a reasonable candidate model. Through the calibration develop a correlation between thermocouple voltage and standard k-type thermocouple temperature. This correlation may be represented by graph as shown in Figure4.

Figure2. Experimental setup for measuring average chip-tool interface Temperature using Tool-work thermo-couple technique [16]



tool-work

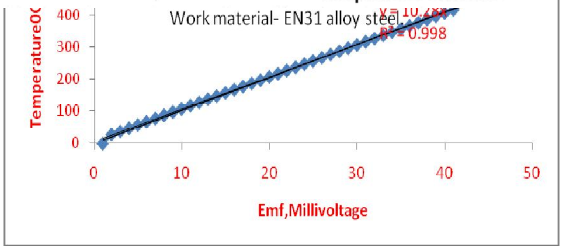


Figure 4.Tool-work thermocouple calibration curve

B. Application

The tool/work thermo-couple (Natural thermocouple) method has been used by many workers to investigate specific areas of metal cutting for example, to compare mach inability of different work materials, the effectiveness of coolants and lubricants or the performance of different tool materials. As an example cut a En31 alloy steel using cemented carbide tool over a range of speeds and feeds and different cutting lubricants Figure 5 shows the temperature values determined plotted against cutting speed for, feed rate (0.06mm/rev), depth of cut(o.2mm), tool nose radius(0.8mm) and with different cutting fluids, and a comparison of cutting in dry , soluble oil (wet) and 10% concentration of solid lubricant mixed with SAE-40 base oil by weight as a cutting fluid. The response indicates an increase in temperature with increments in speed from 50 rpm to 1200 rpm. Similarly cutting temperatures are high at dry machining, followed by cutting with wet machining and finally with 10% concentration of solid lubricants mixed with SAE-40 base oil by weight. Out of these lubricants 10% boric acid mixed with SAE-40 base oil performed best as coolant at all cutting speeds. Since boric acid with SAE-40 base provides better lubrication between tool and work piece, hence reduces the chip-tool interface temperature.

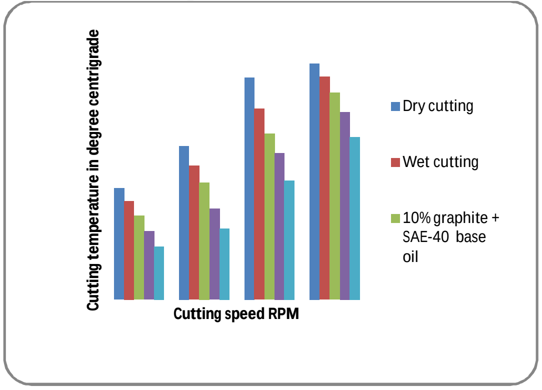


Figure5. Cutting temperature tool-work thermocouple (Feed rate 0.06mm/rev, Depth of cut 0.2mm and Tool nose radius 0.8mm) undr different lubricating conditions,(Tool material tungsten carbide and work material EN-31 steel alloy)

5. SUMMARY

In review the literature, there have been many experiments and a multitude of reports about temperature measurement while metal cutting. In this study average chip-tool interface temperatures have been experimentally studied using the tool-work thermocouple technique. However, the measurement methods the types of machines on which the measurements were made, the materials being cut and the positions of the temperature being measured are all varied. The tool-work thermocouple technique is the best method for measuring the average chip-tool interface temperature during metal cutting. The benefits of using the tool-work thermocouple are its ease of implementation and its low cost as compared to other thermocouples.

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