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Measurement of Cutting Temperature during Machining

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Abstract : *In metal cutting, heat generated on the cutting tool tip is important for the performance of the tool and quality of the finished product. The effect of the cutting temperature, particularly when it is high, is mostly detrimental to both tool and work piece. The machining and tool life can be improved by the knowledge of cutting temperature on the tool tip. In this mini project we are evaluating the variation of different parameters on cutting temperature. We are setting up an experiment to measure the temperature developed on tool tip, during turning operation in a center lathe, under different parameters. The metal cutting parameters considered are cutting speed, feed rate and depth of cut. In this experiment we are using an assembly of k-type thermocouple and multimeter for measuring the temperature. The tool used is of high carbon tip, cast iron shank and work piece is mild steel cylindrical rod. Mild steel work piece is used because it has large variety of applications like worms, gears, machine parts, components of tool die set, tool holder etc. From the data collected during the experiment, we can understand the effects of different turning parameters on temperature developed on tool tip and suitable turning conditions for obtaining maximum material removal rate at lower temperature. The results obtained are tabulated and analyzed graphically.*

Keywords : *Cutting tool, Depth, Feed rate, Machining, Parameters, Speed, Thermocouple*

I. Introduction

It is known that during the transformation of work piece into chips, because of energy transformations in the cutting zone, it releases significant quantities of heat. The temperature developed is an important factor which has a dominant influence to the mechanism of transformation of the work piece machined layer into chip. Also it has effect on the phenomenon that occur in the process of cutting tool wear (abrasive, adhesive, diffusive), The development of temperature influence the magnitude of the cutting force components, it also cause residual stresses in various part of work piece. Therefore, in the machining process it is important accurately to know the magnitude of the temperature that occurs in the cutting zone. The temperature developed in the tool can be measured in different ways. We are using artificial thermocouple to measure the temperature because it is simple and reliable to use and is the most widely using method.

1.1 Sources Of Heat Generation During Machining

During machining heat is generated at the cutting point from three sources. Those sources and causes of development of cutting temperature are:

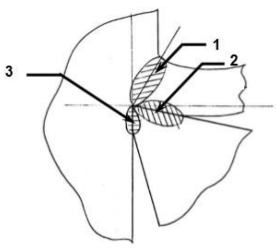

Fig. 1 Sources of heat generation in machining

- Primary shear zone (1) where the major part of the energy is converted into heat
- Secondary deformation zone (2) at the chip – tool interface where further heat is generated due to rubbing or shear
- At the flanks (3) due to rubbing between the tool and the finished surfaces.

1.2 Effect Of High Cutting Temperature

The effects of the high cutting temperature, particularly when it is high, are mostly detrimental to both the tool and the job. The major portion of the heat is taken away by the chips. But it does not matter because chips are thrown out. So attempts should be made such that the chips take away more and more amount of heat leaving small amount of heat to harm the tool and the work piece. The possible detrimental effects of the high cutting temperature on cutting edge are

- Rapid tool wear, which reduces tool life
- Plastic deformation of cutting edges if the tool materials is not enough hard and strong
- Thermal flaking and fracturing of cutting edges due to thermal shocks
- Built up edge formation

The possible detrimental effects of cutting temperature on the machined work piece are

- Dimensional inaccuracy of the job due to thermal distortion and expansion-contraction during and after machining
- Surface damage by oxidation, rapid corrosion, burning etc.
- Induction of tensile residual stresses and micro cracks at the surface and sub surfaces

However, high cutting temperature helps in reducing the magnitude of the cutting force and cutting power consumption to some extent by softening or reducing the shear strain.

In metal cutting, the magnitude of the temperature at the tool-chip interface is a function of the cutting parameters. This temperature directly affects production. Therefore, increased research on the role of cutting temperatures can lead to improved machining operations. In this study, tool temperature was estimated by employing K-type thermocouple to measure the tool-tip temperature. Due to the complexity of the machining processes, the integration of different measuring techniques was necessary in order to obtain consistent temperature data. Experiments were carried out in cylindrical mild steel work piece material. The information from the journals showed that with increase in cutting speed, feed rate and depth of cut, the tool temperature increases. The cutting speed was found to be the most effective parameter in assessing the temperature rise. Thus, machinability can be improved by monitoring the cutting temperature of the tool.

Temperature estimation is one of the most difficult and complicated procedures in metal cutting operations. Due to the complexity of the various events taking place at the point of contact between the tool and work piece, developing a model for measuring the temperature is an extremely difficult process. Consequently, accurate and repeatable temperature prediction still remains a challenge due to this complexity of the contact phenomena. It is quite difficult to measure the temperature because the heat in the region is very close to the cutting edge.

Temperature measurement techniques include thermocouple method, method with an embedded tool-chip pair, measurement of infrared radiation (pyrometers, infrared photography, etc.) and the use of thermo-sensitive paint, as well as metallography based on metal microstructure or micro-hardness variations, and the use of thermal cameras. Each technique has its own advantages and limitations depending on the physical measurement. Thermocouples are one of the most widely used experimental methods for measuring the temperature in machining. Thermocouples are conductive, inexpensive, can be operated over a wide temperature range and can be easily applied. However, they only measure the mean temperature over the entire contact area of the tool and the work piece.

1.3 Temperature Levels In Metal Cutting

In the cutting process, nearly all of the energy dissipated in plastic deformation is converted into heat that, in turn, raises the temperature in the cutting zone. Heat generation is closely related to plastic deformation and friction. Three main sources of heat can be specified when cutting. They are

- plastic deformation by shearing in the primary shear zone;
- friction on the cutting face;
- friction between the chip and the tool on the tool flank;

Temperature causes dimensional errors on the machined surface. The cutting tool elongates as a result of the increased temperature, and the position of the cutting tool edge shifts toward the machined surface, resulting in a dimensional error of approximately 0.01–0.02 mm. Because the processes of thermal generation, dissipation, and solid body thermal deformation are all transient, sometime is required to achieve a steady-state condition. Heat is mostly dissipated by the discarded chip, which carries away approximately 60%–80% of the total heat. The work piece acts as a heat sink drawing 10%–20% of the heat away, and the cutting tool draws away nearly 10% of the heat.

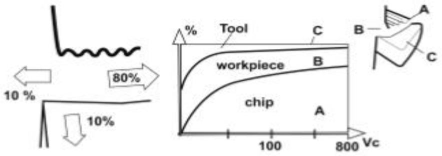

Fig. 2 The dissipation of heat

Tool-work thermocouple has 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, depth of cut and the tool parameters on the temperature.

1.4 Thermocouple Method

The principle of temperature measurement by a thermocouple is that when two different metals come in contact, if these parts, called the hot and the cold junctions, are maintained at two different temperatures, an electromotive force (emf) is produced across these two junctions. The emf generated is a function of the materials used for the thermocouple as well as the temperatures of the junctions. In machining applications, a thermoelectric emf is generated between the tool and the work piece. For this study, the tool temperature was measured using a K-type thermocouple.

II. Literature Survey

L.B.Abhang et. al[1] did work on prediction of temperature at chip tool interface during turning process. In this research, the metal cutting parameters considered are cutting speed, feed rate, depth of cut and tool nose radius. It can be seen that the cutting speed, feed rate and depth of cut are the most significantly influencing parameters for the chip-tool interface temperature followed by tool nose radius. The results show that increase in cutting speed, feed rate and depth of cut increases the cutting temperature while increasing nose radius reduces the cutting temperature.

Temperature on the chip-tool interface is important parameters in the analysis and control of machining process. Due to the high shear and friction, energies get dissipated during a machining operation and the temperature in the primary and secondary shear zones are usually very high, hence affect the shear deformation and tool wear. In a single point cutting, heat is generated at three different zones i.e. primary shear zone, chip tool interface and the tool work piece interface. The primary shear zone temperature affects the mechanical properties of the work piece-chip material and temperatures at the tool- face chip and tool-work piece interfaces influence tool wear at tool face and flank respectively. Total tool wear rate and crater wear on the rake are strongly influenced by the temperature at chip-tool interface.

Fig. 3 Setup for temperature measurement using thermocouple

Therefore, it is desirable to determine the temperatures of the tool and chip interface to analyze or control the process. To measure the tool temperature at the tool chip interface many experimental methods have been developed over the past century.

Much research has been undertaken into measuring the temperatures generated during cutting operations. The thermocouple methods are based on the thermocouple principle that states that two contacting materials produce an electromotive force (emf) due to difference in temperatures of cold and hot junctions.

Tool-work thermocouple has 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, depth of cut and the tool parameters on the temperature. In tool-work thermocouple the chip-tool interface forms the hot junction, while the tool end forms the cold junction. The tool and work piece need to be electrically insulated from the machine tool. This cutting temperature measurement technique is easy to apply for the measurement of chip-tool interface temperature during metal cutting over the entire contact area.

Sushil D. Ghodam et. al[2] did work on Temperature measurement of a cutting tool in turning process by using tool work thermocouple. Temperature at the cutting point of the tool is a crucial parameter in the control of the machining process. Due to advancement in the machining processes, a special attention has been given on the life of a tool. The importance of knowledge of temperature measurement at the cutting point of the turning tool occurred due to the changes in the cutting condition is well known due to severe effects on the tool and work piece materials properties . During machining heat is generated at the cutting point from three sources i.e. primary, secondary and tertiary zones . A standard K-type thermocouple embedded in the work piece was used to convert measured emf's to the interfacial temperatures.

The Tool-Work thermocouple can also be used to measure the temperature at the cutting point of the tool. The tool-work thermocouple is work on the principle of seebeck effect which states that if there is a temperature difference between any two junctions then there will be a development of emf in between the two junctions.

The objective of this experiment was to compare the temperature generated during machining at uncoated and CVD coated tungsten carbide cutting tool. As feed rate increases from the temperature at the uncoated tool is increases at high amount as compared to the coated tool. The dissipation of heat during machining operation is shown below.

The results of this experiment show that:

- With the increase in a cutting speed or a feed rate, the temperature at the tool rake face also increases as found in the machining tests
- Due to the advancement in machining processes, generation of high temperature at the tool rake face takes place. This generation of heat can be resisted by using a coated tool. Reduction in the temperature of the tool improves the tool strength and also improves the surface roughness of work piece.
- From the experimental data, it is found that as compared to uncoated tool the coating of the tool increases the life of a tool for the same cutting velocity or for the same tool life, coated tool can be used at higher cutting speed as compared to uncoated tool.

Ajay Goyal et. al[3] did work on A Study of Experimental Temperature Measuring Techniques used in Metal Cutting. From the beginning of machining of materials, rise in tool, chip, and work piece temperature remains a problem for engineers. The excessive rise in temperature severely affects the tool life and the quality of the work piece. To check this issue, engineers and scientists are continuously investing their efforts. Measurement of the tool, chip, and work piece temperatures takes a vital breakthrough in this direction. Several methods are developed and tested from time to time. But none is found perfect, some are better at a certain situation but fails at another. The appropriate technique for a given problem depends on the situation under consideration, such as the ease of accessibility, situation dynamics, desired accuracy.

During metal cutting, cutting parameters like optimum cutting speed, subsurface deformation, metallurgical structural alterations in the machined surface, and residual stresses in the finished part, each depends on maximum temperature, temperature gradient, and the rate of cooling at various points of tool and work piece. Not only this, the tool life, the development of new tool material, and other advances in manufacturing technology also depend on temperature rise and heat generation at three zones of heat generation. Thereby, it is often desirable to have an estimation of the generation of heat and the temperature rise at various points of tool, chip, and work piece, so that various parameters can be adjusted optimally beforehand to improve machinability.

Foundation of estimation of heat generation due to mechanical work was laid by Rumford further strengthened by Joule by finding the mechanical equivalent of heat. While the application in metal cutting was first reported by Taylor, since then scientists and researchers have been developing various methods and techniques to estimate the temperature variations at various points of tool, chip, and work piece. These methods can be categorized in three broad categories, namely experimental, analytical, and finite element analysis-based methods. Each one has its own merits and demerits. In this paper all the experimental techniques for the measurement of heat generation (temperature rise) during metal cutting at tool and work piece, available in the relevant literature, are studied critically and presented in a user-friendly concise manner under the following subtitles: (i) Thermal paints technique; (ii) Thermocouple techniques -Tool-work thermocouple technique, Transverse thermocouple technique, and Embedded thermocouple technique; (iii) Infrared radiation pyrometer technique; (iv) Optical infrared radiation pyrometer technique; (v) Infra-red photography; (vi) Fine powder techniques; and (vii) Metallographic methods.

Study of Various Techniques temperature rise at various points of tool, chip, and work piece, so that various parameters can be adjusted optimally beforehand to improve machinability. Foundation of estimation of heat generation due to mechanical work was laid by Rumford ; further strengthened by Joule by finding the mechanical equivalent of heat. While the application in metal cutting was first reported by Taylor , since then scientists and researchers have been developing various methods and techniques to estimate the temperature variations at various points of tool, chip, and work piece. These methods can be categorized in three broad categories, namely experimental, analytical, and finite element analysis-based methods. Each one has its own merits and In 1798, Rumford's boring cannon experiment for detection of frictional heat generation proved that mechanical work can be converted into heat. This experiment laid the foundation of experimental analysis of mechanical equivalent of heat. However no attempt was made to measure the mechanical equivalent of heat numerically. Over more than half a century later the mechanical equivalence of heat was successfully established by Joule by envisioning a calorimetric method. Taylor and Quinney's study of the generation of heat accompanied by plastic strain strengthened the concept of mechanical equivalence. They measured the temperature of various specimens under tensile test during the formation of creep and they found that the major amount of plastic energy, used for deforming the specimen, gets converted into heat. In metal cutting application, Taylor studied the relation between cutting velocity and tool life, and developed a tool life equation. He also invented a tough, wear resistant, heat resistant, and hard tool material (HSS) which is still in use. Since then, scientists and researchers have been developing various methods and techniques to estimate the temperature variations at various points of tool, chip, and work piece. These methods can be categorized in three broad categories, namely experimental, analytical, and finite element analysis-based methods. Here, developments in the experimental techniques for the measurements of the temperature rise (heat generation) during metal cutting are explained.

Thermal Paint Technique

This is one of the simplest and most economical techniques used for the measurement of temperature at various points of tool. The technique was used by Schallbroach and Lang , Bickel and Widmer among others. Particularly, Okushima and Shimoda used this technique to determine the temperature distribution at joints of the tool. Rossetto and Koch investigated the temperature distribution on the tool flank surface and developed the isotherms of temperature at various points with respect to flank surface distance in x and y direction at a specified cutting variable. The results obtained with this technique are generally considered approximate and confirmation of results from any other technique is recommended.

Thermocouple Techniques

The technique is based on Seebeck effect. According to this effect, temperature difference produced between hot and cold junctions of two dissimilar metals produces voltage difference between the junctions . This voltage difference is calibrated to measure temperature rise at cutting zones. This method is useful to relate various cutting parameters (speed, feed, and depth of cut) to the variation of temperature. Advantages of using thermocouples for the measurement of temperature include its simplicity, easiness of measurement, flexibility, and low cost. Stephenson predicts that this method gives very good results when tungsten carbide tool insert is used in single point tool operations. Moreover, Stephenson mentions that this method is inappropriate for rough cutting at high speeds.

Transverse Thermocouple Technique

The tool-work thermocouple technique is used to measure the average temperature at tool work interface, but the temperature variation at different points and faces of the tool is difficult to analyse with this method. To overcome this problem, transverse thermocouple technique was developed by Arndt and Brown , which is capable of notifying temperature at various points on the tool with the help of a moving. In probe this technique, a high speed steel tool and cemented carbide probe or vice versa are used.

Tool-Work Thermocouple Technique

The arrangement of this technique is very simple; setup is illustrated in following figure . Shaw predicts that the method is easy to determine the temperature variation on tool work piece interface during metal cutting. Accurate calibration of the tool and work piece materials as a thermocouple pair is difficult. The temperature rise at single point tool can be observed by this technique. Further, the technique is widely used in case of tool inserts. In order to find the temperature rise distribution at various points of the tool, this technique could not be used in single setup.

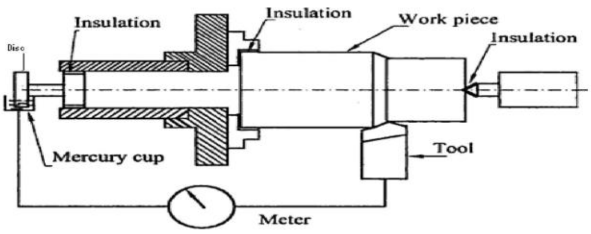

Fig. 4 Schematic setup for measuring interface temperature using tool work thermocouple

Embedded Thermocouple Technique

In operations like milling, grinding, etc., where other two thermocouple techniques do not work, embedded thermocouple can serve the purpose. This type of thermocouple minimizes chances of fire hazards and measuring errors in high speed dry cutting of magnesium alloys. Hirao devised a wire thermocouple setup to measure the temperature Embedded Thermocouple Technique is using in operations like milling, grinding, etc. where other two thermocouple techniques do not work, embedded thermocouple can serve the purpose. Yangused 9 K type thermocouples along all three surfaces of the tool for temperature measurement. Kitagawa created a micro thermocouple between an alumina- coated tungsten wire and the carbide inserts. Sullivan and Cotterell measured the temperature in the turning of aluminum 6082-T6 by using two thermocouples in the work piece and tool.

Infrared Radiation (Ir) Pyrometer Technique

It is a photo electric effect based technique, designed and developed by Schwerd and Kraemer, respectively. It can measure the temperature along the shear zone and tool flank accurately. The technique was further modified by Lenz by reducing the exposure time of radiations to PbS cell, so that measurement could be taken along clearance face. Since the resistance of the PbS cell is sensitive to the changes in its ambient temperature as well as to the infrared radiation, to take care of this, the cell was kept at a constant temperature in an ice bath.

Optical Infrared Radiation Pyrometer Technique

This method is similar to IR pyrometer technique explained with the difference of an optical mechanism. The optical mechanism collects radiation instead to direct impingement of radiations to PbS cell, thus producing better results and reducing the exposure time. This technique is also implemented with the use of tool inserts.

M.Cotterell et. al[4] did work on Temperature and strain measurement during chip formation in orthogonal cutting conditions. Temperature and normal stress generated at the tool-chip interface are critical parameters for the tool wear and the work piece material damage . The primary effect of temperature is on tool wear. Although there are various tool wear mechanisms, it is generally known that increases of temperature produce progressive tool wear. Apart from the tool, the maximum temperature and the temperature gradient influences subsurface deformation, metallurgical structural alterations in the machined surface, and residual stresses in the finished part . Another well-known problem occurs in the cutting of low thermal conductivity materials such as titanium, where the heat generated during the cutting process flows much more in the tool than the chip due to the low conductivity of the work piece material and this causes thermal stresses to occur in the tool. As a result of the thermal stresses, tool fatigue, failures due to fracture and wear occur more frequently.

The metal cutting is a coupled thermo-mechanical process. During the process, the heat generation occurs as a result of plastic deformation and friction along the tool–chip and the tool-work piece interface. It is a comprehensive assumption that almost all the energy required for cutting is converted to heat in the cutting domain . It is difficult to develop a precise temperature prediction model in machining due to the complicated contact phenomenon. Metal cutting is very highly localized and non-linear, occurs at high temperatures, high pressures and strains. Therefore, accurate and repeatable temperature prediction still remains challenging due to the complexity of the contact phenomena in the metal cutting process . Apart from the temperature prediction, temperature measurement is even more challenging in this research area, because it is very difficult to make temperature measurement very close to the cutting edge. Numerous attempts have been made to measure the temperature in the machining operations. One of the most extensively used experimental techniques to measure the temperature in machining is the use of thermocouples. In addition to thermocouples, the infrared (IR) radiation techniques are probably the second most used method for temperature measurement in machining. In the IR technique, the surface temperature of the body is measured based on its emitted thermal energy. The IR technique is applied for the temperature field measurements with the use of cameras with films or chips sensitive to IR radiation.

The maximum temperature in the two zones increases with speed. With the increase on feed rate, section of chip increases and consequently friction rises. This involves the increase of temperature. From these experiences is clear that the maximum temperatures reached during the simulation are produced in primary and secondary areas of cutting. The largest contributor to uncertainty in temperature is the work piece emissivity.

Bogdan P. Nedic et. al[5] did work on Cutting Temperature Measurement And Material Machinability. Cutting temperature is very important parameter of cutting process. Around 90% of heat generated during cutting process is transferred by sawdust, and the rest is transferred to the tool and work-piece. In this research cutting temperature was measured with artificial thermocouples and metal machinability from aspect of cutting temperature was analyzed. For investigation of material machinability during turning, artificial thermocouple was placed just below the cutting top of insert, and for drilling, thermocouples were placed through screw holes on the face surface. In this way simple, reliable, economic and accurate method for investigation of machinability during cutting is obtained.

Heat phenomena occurring both in narrow and broad area of cutting zone, are directly related to the wear rate of tool, to the machinability of work-piece material, to the tool stability and to many other characteristics of the machining process experimental observation show that almost all work of cutting forces is turned into the thermal energy. Generated heat goes from the cutting zone into the chips, tool, work-piece and into the environment, causing decrease of hardness of tool's cutting elements, cutting wedge deformations, loss of tool cutting ability and its bluntness. Generated heat distribution in work-piece, in tool and in chips, i.e. the temperature level at working elements of tool at processed surface and at chips depends on: work-piece material (its mechanical and chemical characteristics), cutting speed, feed rate, depth of cut, tool geometry, lubricants type and other relevant parameters. Beside the influence on tool wear, heat generated in the cutting process has influence on: the machining process productiveness, processed surface quality, accuracy of machining and other output parameters of the machining process. Due to this, the investigation, measurement and knowledge of levels and distributions of the cutting temperature within the tool and work-piece are of the utmost importance.

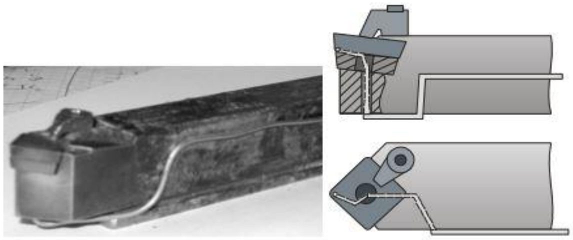

Fig. 5 Measuring spot for artificial thermocouple for turning tool

For turning, specially formed artificial thermocouple was placed between shim and insert on the spot below cutting zone. . Optimum conditions for working , quality, productiveness and economy of process and tool stability can be determined on basis of this knowledge.

S.R.Carvalhoa et. al[6]did work on Temperature determination at the chip–tool interface using an inverse thermal model considering the tool and tool holder. During a cutting process the mechanical energy due to the plastic deformation enveloped at the primary shear plane and at the chip–tool interface is converted into heat. Studies have shown that the chip and the environment dissipate a great deal of this heat while the rest of heat is conducted both into the work piece and into the cutting tool. However this small quantity of heat conducted into the tool (10% of the total heat rate) is enough to create high temperature near the cutting edges, in which same cases can reach the level of 1100^0C. As a result of the high temperatures developed at the tool surfaces critical tool wear, short tool life and poor work piece surface integrity will generally impair productivity. This fact makes the cutting temperature field identification fundamental on the quality of the finished product. However, direct measurements of temperatures at the tool–chip–work piece interfaces are very difficult due to the cutting movement and the small contact is as involved.

Conventional experimental methods such as infrared pyrometer, embedded thermocouple and tool–work piece thermocouple usually present problems. The infrared pyrometer can represent a good solution if some limitations, like sensor resolution and chip interference near the cutting zone, are alleviated. In the other hand the use of the tool–work piece thermocouple are limited to tools that can conduct electricity. In addition, the thermocouple does not measure the temperature at a specific point, but an average temperature at the heat affected zone between the tool and the work piece.

The success of any experimental technique depends on the physical model used. In this case, in spite of the application of one-dimensional model in ellipsoidal coordinates, a three-dimensional model is more appropriated to describe heat transfer in machining. The temperature field in any region of the tool set is calculated from the heat flux estimation at the cutting interface. The determination of the temperature and heat flux at the chip–tool interface is done by using the inverse heat conduction problem technique.

Trajcevski.N et. al[7] did work on Investigation of temperature during machining process by high speed turning. It is known that during the transformation of work piece machined layer into chips, because of energy transformations in the cutting zone it is released significant quantities of heat. Created heat in the cutting process is directly dependent on the applied processing parameters, work piece material characteristics. Therefore, in the machining process it is important accurately to know the magnitude of the temperature that occurs in the cutting zone as function of machining parameters. The temperature in the cutting process can be determined in an analytical and experimental way, which is condition and cutting tool. The heat reflected through the maximum temperature is an important factor which has a dominant influence to the mechanism of transformation of the work piece, the phenomenon that occur in the process of cutting tool wear (abrasive, adhesive, diffusive, heat, oxidative), the magnitude of the cutting force components, which is in close correlation with thermal model of creation residual stresses; and thus to the creation of the resultant developed many methods . From the experimental methods, the most widespread is the method of natural thermocouple, where the natural thermocouple consists of the cutting tool and the work piece. Methods of natural thermocouple are simple to implement, but require knowledge of the thermoelectric characteristics of the natural thermocouple, and its determination is only by experimental way. The emergence of modern cutting materials, especially cutting ceramics, creates conditions for the application of significantly higher cutting speeds.

J. W. Jung et. al[8] did work on Cutting Temperature and Laser Beam Temperature Effects on Cutting Tool Deformation in Laser-assisted Machining. Laser-assisted processing is one of the emerging fields in advanced manufacturing. The advantages that make the lasers increasingly attractive in industrial production include coherence, focus ability, attractive, very high power intensity, power shaping capability and ease of automation with in-process sensing. It also offers the potential to realize innovative design with high flexibility, a high processing speed, and good quality in many manufacturing processes. The capital investment may be higher, but this is offset by the benefits gained in many applications. Increasing demand for advanced difficult-to-process materials and the availability of high-power lasers have stimulated interest in research and development related to laser machining. Increasing interest in the use of lasers for manufacturing can be attributed to several unique advantages, which are generally applicable to the entire range of materials processing applications, such as high productivity, noncontact processing, elimination of finishing operations, adaptability to automation, reduced processing cost, improved product quality, greater material utilization, minimal heat-affected zone (HAZ). Materials processed by laser beam machining, range from metals and alloys to inorganic as well as organic non-metals, composites and rocks, etc. Pulsed Nd:YAG laser beam can be effectively used for cutting of silicon nitride ceramics and proper selection and controlling of laser beam machining process parameters can generate good quality cut surface during cutting of engineering ceramics. Nd:YAG laser machining system can be continuously operated from a few watts to several hundred watts, but in most applications pulsed operation is preferred. Taper formation is the most important characteristics during laser micro-hole drilling operation due to the inherent focusing characteristics of the laser machining process. This paper presents the deformation errors caused by thermal effects in the laser-assisted machine tool. Laser assisted machine tool performs the localized heating and cutting process simultaneously. So, the heats generated by localized heating process as well as the cutting process are conducted into cutting tool. In order to predict deformation errors, the heats from the two heat sources have to be analyzed simultaneously and thermal distortion have to be calculated. The objective of this paper is prediction of thermal distortion by laser power and cutting temperature.

Abdil Kus et. al[9] did work on Thermocouple and Infrared Sensor-Based Measurement of Temperature Distribution in Metal Cutting. During metal cutting, the magnitude of the temperature on the cutting edge is a function of the cutting parameters. This temperature directly affects the production. Heat generated during machining is affected by many events, including tool life, chip formation, surface quality, cutting forces, etc. Maximum heat occurs at the tool-chip interface. Thus, machinability can be improved by monitoring the cutting temperature of the tool. Temperature estimation is one of the most difficult and complicated procedures in metal cutting operations. Due to the complexity of the various events taking place at the point of contact between the tool and work piece, developing a model for measuring the temperature is an extremely difficult process. Consequently, accurate and repeatable temperature prediction still remains a challenge due to this complexity of the contact phenomena. It is quite difficult to measure the temperature because the heat in the region is very close to the cutting edge. Due to the lack of sufficient experimental data, it is not possible to verify a mathematical model. However, numerous attempts have been made to measure the temperature in machining operations. They concluded that the cutting temperature is the function of cutting speed and feed rate. Temperature measurement techniques include thermo coupling with an embedded tool-chip pair, measurement of infrared radiation (pyrometers, infrared photography, etc.) and the use of thermo-sensitive paint, as well as metallography based on metal microstructure or micro hardness variations, measurement of temper colour, and the use of thermal cameras. Each technique has its own advantages and limitations depending on the physical measurement .Thermocouples are one of the most widely used experimental methods for measuring the temperature in machining. Thermocouples are conductive, inexpensive, can be operated over a wide temperature range and can be easily applied; however, they only measures the mean temperature over the entire contact area of the tool and the work piece A standard K-type thermocouple inserted into the work piece was used to measure the interface temperature. The friction on the flank face had a great influence on the heat generated at a cutting speed of approximately 200 m/min. The results indicated that an increase in the cutting speed led to a decrease in the cutting forces and the machined surface temperatures. This reduction in the temperature was attributed to the higher metal removal rate that resulted in more heat being carried away by the chip.

A. A Sri Rama Krishna et. al[10] did work on Temperature Prediction in Orthogonal Machining. In machining operation the cutting process involves severe plastic deformation in primary and secondary deformation zones. The work done in affecting plastic deformation reappears in the form of heat. The rise in temperature leads to early wear of the tool and dimensional inaccuracy of the finished product. Hence estimation of temperature in machining new materials is essential. A metal matrix composite being a new material it is essential to note the temperature while machining these materials. Hence a turning test on aluminium 6061-based metal-matrix composites (MMCs) (aluminium-30% SiC) was performed with K-20 carbide tool material to assess the temperature which occurs in machining. The experiments were conducted to measure the temperature along the cutting tool edge using thermocouple at various cutting speeds and depth of cuts keeping feed rate constant while turning with K-20 carbide cutting tool. A complex micromechanical process for a normally loaded particulate reinforced metal matrix composite against a tungsten carbide cutting tool has been modeled using FEA. The MMC considered for the present work is made up of Al-6061 aluminium alloy as matrix materials in which SiC particles are uniformly dispersed. The heat generation at the chip tool interface, frictional heat generation at the tool flank and heat generation at the work tool interface were calculated analytically and imposed as boundary conditions. The analysis of steady state heat transfer was carried out and the temperature distribution at cutting edge, shear zone, and interface regions has been reported.

III. Project Description

In our experiment we are setting up a temporary arrangement for measuring temperature at the tool tip during turning operation in centre lathe. Temperature measuring device consists of an assembly of K type thermocouple and multimeter .The tool being used in the experiment is high carbon steel tip with cast iron shank. A hole of diameter 4mm is drilled on the shank of the tool and probe of the thermocouple is inserted in the hole such that it touches the tool tip. The negative and positive end of the thermocouple is connected to the corresponding terminals of the multimeter . In this arrangement the temperature at the tip of the tool will develop an emf in the thermocouple which will be displayed in the multimeter. The tool is fixed on the tool post and the work piece is fixed on the four jaw chuck. The multimeter reading is taken for different machining conditions by varying the cutting parameters like cutting feed, depth of cut, cutting speed etc.

3.1 Components

3.1.1 Centre Lathe

The experimental apparatus to measure the cutting temperature on the tool is built on the centre lathe; lathe is the name of machine tool used for turning process. Turning is a metal cutting process in which the work piece is rotated and a single point cutting tool of hard material is brought to the surface of work piece resulting in removal of excess material in the form of chip.

3.1.2 Work Piece

Mild steel rod of cylindrical shape is selected as the work piece for the experiment. The Mild steel work material is selected because it has wide application in the field of manufacturing of worms, gears, machine parts, components of tool die set, tool holder etc. and also because of its availability at cheap cost.

3.1.3 Cutting Tool

In this project we are measuring the temperature on the cutting tool during turning operation. The tool used for this experiment is the right hand tool with high carbon tip and cast iron shank.

3.1.4 Artificial Thermocouple

Nickel-Chromium V/s Nickel-Aluminium K-Type thermocouple is used for the measurement of temperature in this experiment. It is capable of measuring temperature ranging from -200 to 1250 degree Celsius. The thermocouple measures temperature and generates corresponding emf. This emf generated is converted to temperature by using reference table.

3.1.5 Multimeter

The readings from thermocouple are in the form of voltages and for measuring these voltages we are using a multimeter with digital display. At it has an accuracy of .1 milli voltage.

3.2 Schematic Diagram

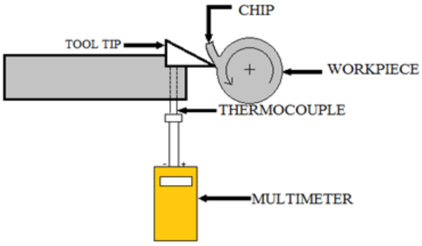

Fig. 6 Arrangement of thermocouple

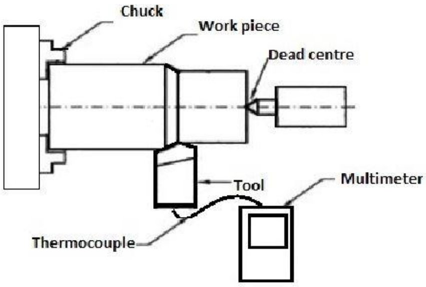

Fig. 7 Schematic diagram of experimental setup

3.3 Procedure

- The diameter of thermocouple probe is measured
- A hole is drilled in the same diameter on the most adjacent point of the cutting tool tip for inserting the thermocouple probe
- The tool is fixed on the tool holder
- The work piece is centred on the lathe chuck properly by adjusting the jaws of the chuck
- The one end of thermocouple is fixed in the hole in the tool and the other end is connected to the multimeter
- The parameters considered are feed rate, depth of cut and speed of rotation in rpm
- Calculations were carried out to find the values, for making the feed rate constant.
- The pitch values are adjusted by changing the gears
- Rpm can also be varied by changing the gears
- Depth of cut is adjusted by using cross slide
- Values from multimeter are taken for different values of depth of cut at constant rpm and feed rate
- The same procedure is repeated at different values of feed rate and rpm
- Five minute time were allowed to bring the tool to cool back to initial state of atmospheric temperature after each turning operation
- The chip produced were collected and its features were noted for every operation
- The values of temperature were found out from the multimeter readings by using reference chart
- Graphs were plotted to obtain the relationship between the temperature and the various parameters

Table 1 Value of Parameters

	FEED RATE (cm/sec)	**CUTTING SPEED (rpm)**	**DEPTH OF CUT(mm)**
SLOW	1.2	455	0.5
			1.0
MEDIUM	3	685	1.5
HIGH	5.5	1025	2

IV. Result And Discussion

The experiment of measuring cutting temperature during machining was completed successfully using artificial thermocouple and multimeter. The feed rate and cutting speed is made constant and the values of voltages were measured from multimeter at four different depths of cuts, the feed rate is made constant by adjusting the pitch values. The experiment is repeated at three different feed rate and cutting speed and the obtained values are tabulated below

Table 2 Obtained values

FEED (cm/min)	**CUTTING SPEED (rpm)**	**DEPTH OF CUT (mm)**	**TEMPERATURE(^{0}C)**
3	1025	0.5	70.5
3	1025	1	90
3	1025	1.5	109.5
3	1025	2	141.5
3	685	0.5	49.5
3	685	1.0	73.5
3	685	1.5	104.5
3	685	2.0	125
3	455	0.5	49
3	455	1.0	68
3	455	1.5	83
3	455	2.0	95
5.5	1025	0.5	47
5.5	1025	1.0	63.5
5.5	1025	1.5	68.5
5.5	1025	2.0	93
5.5	685	0.5	49
5.5	685	1.0	75.5
5.5	685	1.5	83
5.5	685	2.0	98
5.5	455	0.5	66
5.5	455	1.0	73.5
5.5	455	1.5	67
5.5	455	2.0	105.5
1.2	1025	0.5	70.7
1.2	1025	1.0	99.5
1.2	1025	1.5	118.9
1.2	1025	2.0	125
1.2	685	0.5	42.8
1.2	685	1.0	61.2
1.2	685	1.5	97.8
1.2	685	2.0	90.4
1.2	455	0.5	39.2
1.2	455	1.0	58.8
1.2	455	1.5	67.8
1.2	455	2.0	70.7

The graphs were plotted using these values to obtain the relationship between the temperature and the various parameters.

3.3 Temperature v/s Cutting Speed at Varying Feed Rate

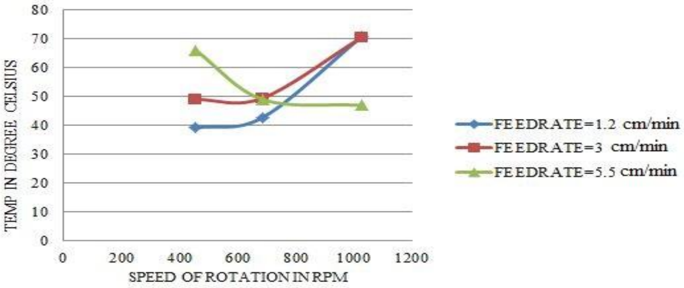

Fig. 8 Temperature v/s cutting speed at varying feed rate on depth of cut = 0.5mm

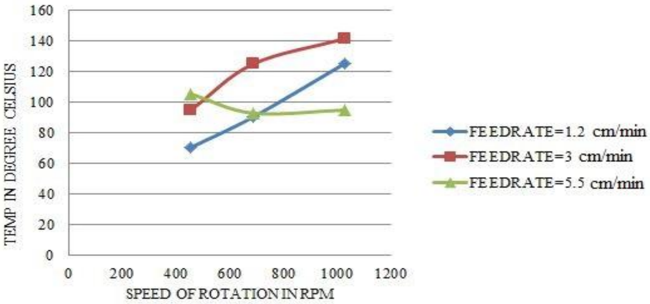

Fig. 9 Temperature v/s cutting speed at varying feed rate on depth of cut = 1.0mm

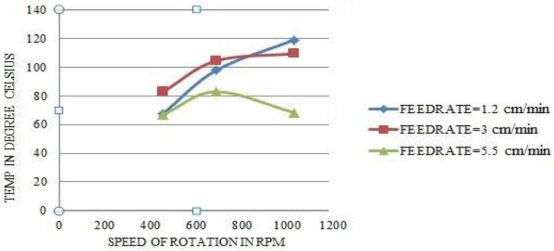

Fig. 10 Temperature v/s cutting speed at varying feed rate on depth of cut = 1.5mm

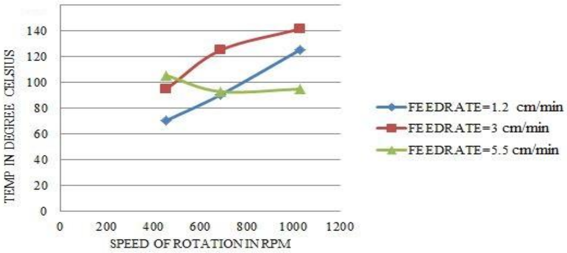

Fig. 11 Temperature v/s cutting speed at varying feed rate on depth of cut = 2.0mm

3.4 Temperature v/s Feed Rate At Varying Rpm

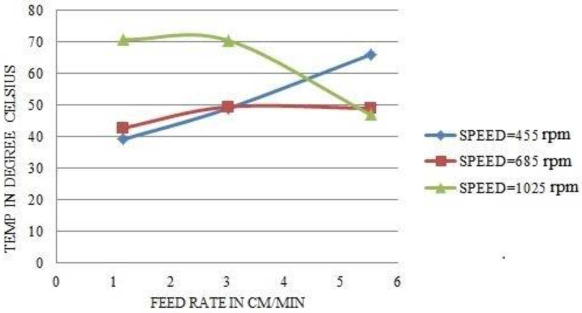

Fig. 12 Temperature v/s feed rate at varying rpm on Depth of cut = 0.5mm

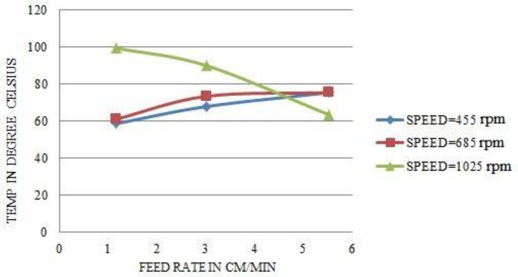

Fig. 13 Temperature v/s feed rate at varying rpm on depth of cut =1mm

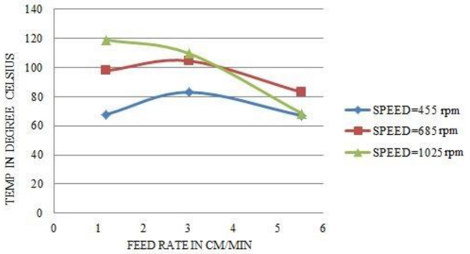

Fig. 14 Temperature v/s feed rate at varying rpm on depth of cut = 1.5mm

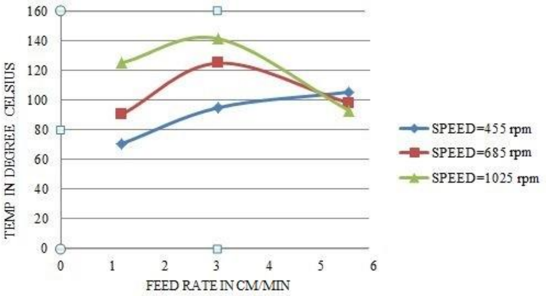

Fig. 15 Temperature v/s feed rate at varying rpm on depth of cut = 2mm

3.5 Temperature v/s Depth of Cut at Varying Rpm

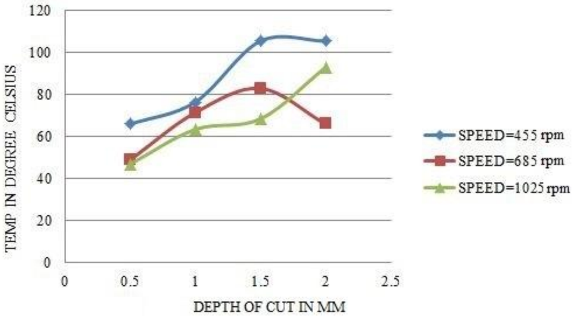

Fig. 16 Temperature v/s depth of cut at varying rpm on feed rate = 5.05 cm/min

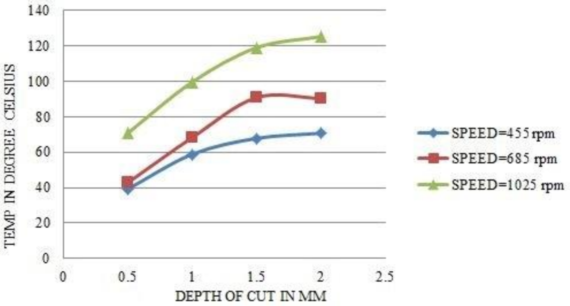

Fig. 17 Temperature v/s depth of cut at varying rpm on feed rate = 1.2 cm/min

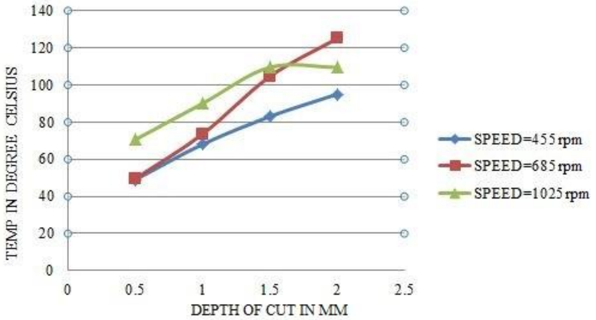

Fig. 18 Temperature v/s depth of cut at varying rpm on feed rate =3.03cm/min

V. Conclusion

Chip-tool interface temperature is closely connected to cutting speed. With increase of cutting speed, friction increases, this induces an increase in temperature in the cutting zone. With the increase in feed rate, section of chip increases and consequently friction increases this involves the increase in temperatures.

If the depth of cut increases, the section of chip increases and friction of chip-tool increases which leads to an increase in temperature. The maximum temperature developed in the cutting tool tip during machining was found to be 141.5°C. The optimum condition for obtaining maximum surface finish, with least rise in temperature at tool tip, is high cutting speed (RPM) with low depth of cut and medium feed rate. The optimum condition for least machining time (without considering surface finish) and least rise in temperature at tool tip is medium cutting speed (RPM) with medium depth of cut and high feed rate. By carrying out proper measuring and applying suitable methods to reduce the developed temperature during machining operation can improve the quality of the work piece and can enhance the life of the cutting tool

VI. Future Scope

- The process can be extended for the fabrication of an apparatus that can measure temperature during any machining operation.
- Optimum parameters can be found out for the machining operation (process optimization).
- The process can be used for comparing the effectiveness of different cutting fluids and cutting tool tips.
- The experiment can be used for the prediction of cutting temperature at various points of cutting tool.

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