THERMAL ASPECTS IN MACHINING: A REVIEW

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***Abstract*: The study of heat has become prominent in metal cutting as it has very critical influence on machining processes. Any machining process involves three basic elements viz., chip, tool and workpiece. Heat developed among these three elements is vital and may cause considerable effect in the machining performance. The heat is generated due to several factors among which friction between the tool and the chip is one of the reasons. The effect of heat generation can be viewed in two forms, one from the workpiece and another form the cutting tool. In this paper a review has been done on the various sources of heat generation and its considerable effects on the life of cutting tool and the quality of the machined part. A study has also been conducted on the temperature distribution on the different regions. Generation of heat can be controlled by various machining parameters and cutting tool geometry, this paper also focuses on various factors that influences on the temperature generation. Although any amount of heat can be generated during machining, the determination of cutting temperature is also one of the important factors. A review is also done on various measurement techniques of cutting temperature. For the betterment of the machining, the perspective of heat generation in metal cutting is a prominent factor.**

***Keywords*: Metal tool, Workpiece, Flank surface**

I. INTRODUCTION

From the manufacturing aspects, metals can be shaped into different forms through various processes. Non-cutting process involves shaping the metal without removing the material, which includes the operation like rolling, spinning, extruding, drawing etc. Another process involves the shaping the metal by removing excess or unwanted material form the parent metal in the form of chips and the process termed as machining process, a few of them are turning, milling, planning, drilling etc. The study of metal cutting is one of the most fascination experiences in the manufacturing field. Machining is an important aspect of the manufacturing processes to achieve desired shape of component, good dimensional tolerances and high surface finish. Due to the demand for the higher productivity and good quality for machining parts and to increase the efficiency of the machining processes, researchers and engineers has made an eagle view on various factors that influence the machining among which heat generation is one aspect. The focus on the temperature generation in the cutting zone is an important factor taken into consideration which has critical influence on the performance of cutting tool and the quality of work piece. While machining, large amount of heat is generated from the cutting point at three distinct points of sources as shown in the figure 1. In cutting, almost all the energy dissipated in plastic deformation is converted into heat which causes raise in the temperature in the cutting zone. To some extent, it can enhance the tool wear and then decrease the tool life. This temperature generation in the cutting zone is closely related to the plastic deformation and the friction exerted between the chip and the tool, tool and workpiece and various cutting forces. As a large amount of plastic strain is involved in metal cutting, almost 99% of heat is transferred to chip, cutting tool and the workpiece, while more than 1% of work is stored as an elastic energy. The three sources of heat generation are
1. Shear-plane(AB), where the actual plastic deformation occurs
2. Tool-chip interface(BC), due to the friction between tool and chip
3. Tool-workpiece interface(BD), which occurs at flank surface

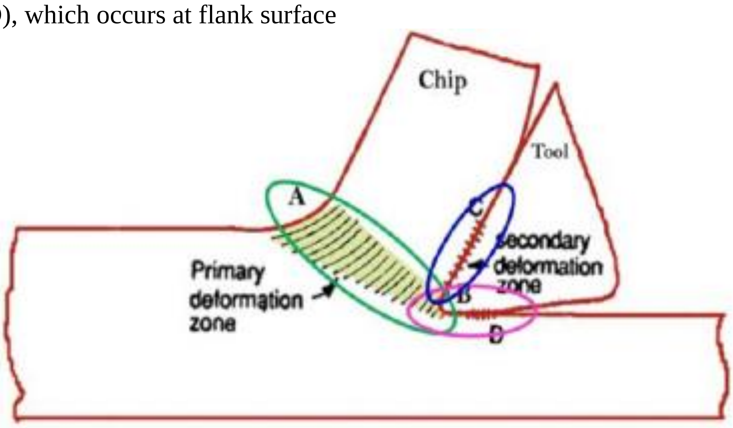

Figure 1: Sources of heat generation in metal cutting

II. LITERATURE REVIEW

L.B.Abhangand M. Hameedullahin their work developed the first-order and second -order empirical models of the chip-tool interface temperatures for turning of EN-31 steel alloy. They also investigated that the established equation in their work clearly revealed that the cutting speed is main influencing factor on chip-tool interface temperature as compared to others. It has been observed that increasing cutting speed, feed rate and depth of cut gives rise to the increase in cutting temperature. But increasing the tool nose radius may predominantly decrease the cutting temperature. The appropriate aggregation among the cutting speed, feed rate, depth of cut and tool nose radius can generate minimum cutting temperature during steel turning. They pointed out that the surface methodology coupled with factorial design of experiments actually save a lot of time and cost of experiments. Finally they suggested that 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. [1]

A. G. F. Alabi, T. K. Ajiboye and H.D. Olusegun conducted the study on finite element modelling which was utilized to simulate the temperature distribution for orthogonal cutting of medium carbon steel subjected to various form of heat treatment operations. For all the samples that they have been conducted, Very high and localized temperatures were observed at the tool-chip interface because of a detailed friction model and the shearing action within the cutting zone. The temperature profile along the shear plane was also analytically simulated. The temperature were however, expressed as a fraction of the instantaneous distance, located by the coordinate axis in the nodal grids structure for both the tool, chip and the workpiece to obtain the temperature profile. The temperature profile obtained indicated that the tool has a higher machining temperature when machining steel materials. [2]
Majumdar et al.in a paper studied the influences of the heat generation during machining operation processes and their effects on cutting forces and tool wear. In order to study this they have built a fem based computational model to determine the temperature distribution in a metal cutting process on high-speed carbon steel. Results shows that as cutting speed increases from 29.6 m/min to 155.4 m/min maximum temperature in the tool will also increase from 709.36 K to 1320 K. Their experiment model also infers that significant effect of conduction and convection losses in heat dissipation and temperature rise in the cutting tool. [3]
Sushil D. Ghodamin his paper advocates that the Tool-Work thermocouple is the best way to obtain the temperature at the tool rake face because of its easiness to install and inexpensive as compared to other methods.
His paper also states that with the increase in a cutting speed or a feed rate, the temperature at the tool rake face also increases that is found in the machining tests. He pointed that generation of high temperature at the tool rake face takes place due to the enormous frictional forces caused at tool-chip interface. 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 his 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. [4]
Uzorh Augustine .C and ,NwufoOlisaemeka .C addressed a concept to determine the problem of temperature and heat flux at tool-chip interface they used a technique called Inverse heat conduction, proved that at any cutting interface heat flux estimation can calculate temperature field from any region of tool set.They also proposed algorithms that can also be used in selecting various parameters in order to reduce excess thermal load on tool. They also used partial differential equations for chip and the tool to get the Heat balance equations. Hence that leads to decreasing accelerated wear of cutting tools and edge chipping. [5]
AbdilKus ,YahyaIsik , M. CemalCakir, SalihCoşkun and KadirÖzdemir concluded that vital effecting factor with regards to tool-chip interface is cutting speed.As the speed increases major changes can be seen in chip formation and curvature while feed rate is not so important. Cutting parameters can be optimized by heat distribution of cutting tool, work piece and interface of tool-chip. This leads to the relation between the cutting parameters and heat distribution. They used the Techniques like IR pyrometer and a K-type thermocouple to measure the temperature of the tool and contact behaviour between tool-chip in turning process of heat treated AISI 4140 alloy steel 50 HRC. By using multi sensor application they have studied the behaviour of cutting parameters during heat distribution. In order to verify the test FEM results will be playing curial role in future studies these results are obtained based on estimated heat over the tool chip interface. [6]
Vamsi Krishna Mamidi and M. Anthony Xavior from their paper it is noticed Machining process, work piece materials and cutting tool material are the three major factors affecting the cutting fluid during machining process proper selection of cutting fluids provides longer tool life, higher surface finish etc.., along with uninterrupted cutting speeds, high depth and high feed rates. Dry machining process is the new machining process produced from the concept of applying less cutting fluid during the machining process. Cutting fluid cost and disposals cost can also be reduce by using a method of regeneration of fluids which will leads to the decrease in environmental pollution to maximum extent. [7]
Mr. Lathiya Dharmeshkumar and Mr. ViswakarmaAjay stated that for increasing the tool life and to reduce production costs, Study of temperature in various fields in machining are very prominent. Quality of machined part and tool life can be influenced and predicted by the temperature produced during machining process along rake surface. MATLAB is a program written for the determination and distribution of temperature. Five different types of metal cutting, namely, conventional machining verified andresults presented in the literature manner are found in good agreements. The analytical method provides good physical bond with thermal. [8]
A.A. Sri Rama Krishna, Dr.P.RavinderReddy stated that the Maximum temperature is found at chip-tool interface with the cutting speed 50m/min is 3150C. Along radial and tangential to the direction to the tool contact temperature will be gradually decreases along with reduced temperature from the chip tool mating point to the tool flank. All the views and reports given by Sri Rama Krishna and Dr. P. Ravinder Reddy with variation of 1.25% were observed are correlated with finite element results. [9]

II. HEAR GENERATION AT SHEAR PLANE

The mechanism of shearing of metal is the reason to generate the heat around the shear plane. During machining, when the tool is passed over the workpiece, the region in the work piece which is ahead of the cutting edge of the cutting tool gets compressed and severely stressed. Where, this stress is maximum along a plane called shear plane, in which actual plastic deformation occurs. The disturbance caused in the atoms of workpiece during plastic deformation along the shear plane where the friction is involved in sliding the atoms over one another are the responsible for the heat generation in the shear plane. When a material is deformed resinously, the energy used is stored in the workpiece as strain energy and no heat is liberated. However, when the workpiece is deformed plastically almost all the energy used is converted into heat. A portion of the heat generated in the shear plane is carried away by the chip. A very minor portion of heat is retained by the workpiece. Shear plane also known as primary deformation zone

IV. HEAT GENERATION AT TOOL-CHIP INTERFACE

Heat generated at tool-chip interface in an important factor considered in metal cutting. This is the region where maximum heat is generated among all the three sources. Because of the high shear stress and the frictional forces dissipated during machining, the temperatures in the primary and secondary zones are very high. Experiments show that the heat generated at each of three sources leads to rise of temperature at tool-chip interface. When the cutting tool advances and passed over the workpiece, material near the cutting edge gets separated and removed in the form of chips. As the chips move upwards along the rake face of the cutting tool, friction occurs between chip and tool face which gives rise to heat. Some part of heat is carried by chip, and the rest is transferred to the cutting tool. The rate of tool wear and the crater wear on the rake face of the cutting tool are greatly influenced by the temperature at chip-tool interface.

V. HEAT GENERATION AT TOOL-WORK INTERFACE

As the cutting tool is not perfectly sharp, there exists friction between the tool and the newly machined surface. To avoid this, clearance angle is provided. The function of clearance angle is to avoid rubbing between flank surface and the machined surface. But still some portion of flank surface will be in contact with workpiece which rubs against each other, which is another source of heat generation. Heat produced is transferred to both tool and the workpiece. However, heat generated at this source is small and can be neglected. Heat generated at this region may influence on the quality of the workpiece.

VI. DISTRIBUTION OF HEAT GENERATION IN METAL CUTTING

From the basic study of heat transfer, heat can be transferred via three ways viz., conduction, convection and radiation. The study of temperature distribution can be made through these three modes. Figure 2 shows the distribution of heat during machining. Distribution of temperature depends on the heat conductivity and the specific heat capacity of the tool and the workpiece and finally the based on radiation and convection the amount of heat loss depends. The maximum temperature occurs in the contact zone between the chip and the tool. In the entire heat generated, 80% of the total heat is carried away by the chip, about 10% is transferred to the tool and the remaining 10% is retained by the workpiece. The shear angle also affects the heat generation. A larger shear angle leads to a smaller heat generation in the primary deformation zone.

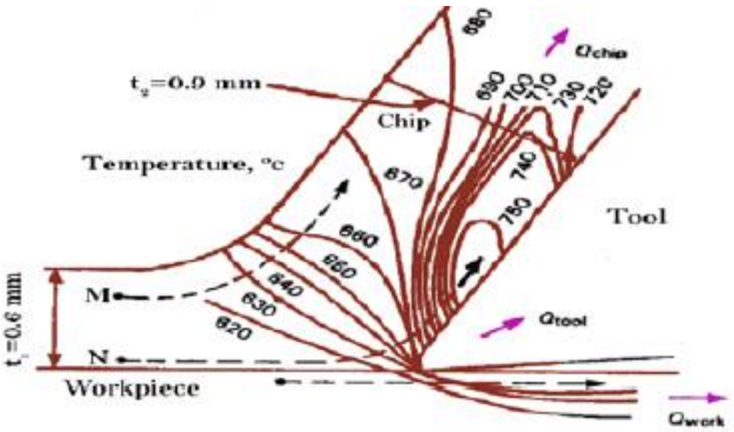

Figure 2: Distribution of Heat in chip and work during machining

VII. INFLUENCE OF MACHINING PARAMETERS ON HEAT GENERATION

Cutting temperature depends upon several machining parameters such as cutting speed, feed and depth of cut. Cutting speed has a superior effect on the temperature. From the figure 3it is observed that with an increase in the cutting speed a higher amount of heat is absorbed by the chip and lesser amount is transferred to the tool and the work piece. It is also observed that with increase in cutting speed forces decreases but temperature increases. Feed rate has a very little effect on heat generation whereas depth of cut had least affect. These machining parameters also affect the size of shear zone and tool-chip contact length.

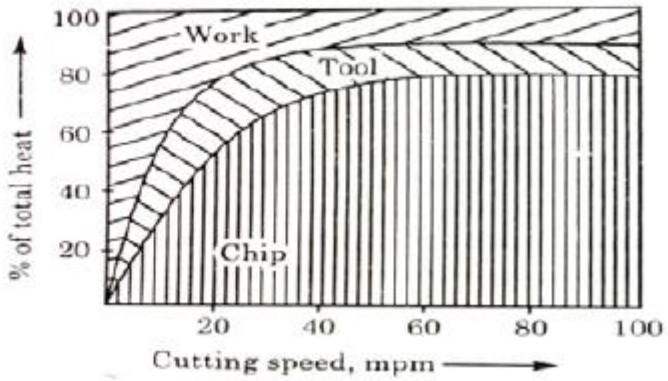

Figure 3: Cutting speed vs heat generation

VIII. INFLUENCE OF CUTTING TOOL GEOMETRY ON HEAT GENERATION

Among all the angles which favour the cutting tool, rake angle has the mixed effect. The increase in the rake angle in the positive direction leads to the less amount heat generation at tool chip interface but on the other hand it weakens the cutting tool. Thus it necessitates a balance in the value of rake angle which varies between-5° to +10°. Another important angle is clearance angle which avoids rubbing which in turn helps in lowering the amount of heat generation. These angles normally vary from 5° to 8°. There needs an optimum value for rake and clearance angle in order to balance between the strength of the tool and heat generation. While there will be a minor effect on heat generation with both the cutting edge angles. Another interesting factor is cutting tool nose radius. Some studies have shown that with increase in the cutting tool nose radius may decrease the cutting temperature. A proper combination of feed, speed, depth of cut may minimize the heat generation and may maximize the tool life

IX. EFFECT OF HEAT GENERATION ON CUTTING TOOL

As already been described, during the machining process heat is generated at various elements, among which cutting tool is the prominent element. Due to the intimate contact of the chip and workpiece with cutting tool, severe temperature gradients are developed that causes several losses to the cutting tool. The temperature rise in all the three zones has significance in the generation of heat near the tool. However, cutting tool material is hard and able to withstand at high elevated temperatures, but every material has a limited value to withstand up to a certain temperature without demolishing its hardness. When the cutting tool has crossed its limit, its ability to perform machining will be lost and is said to be failure due to softening. Cutting tool may also fail due to the mechanism called thermal cracking. This is due to the expansion and contraction which gives rise to setting up thermal stresses due to which cracks are developed. After a while of machining it is seen that there will be some reduction in weight of tool, which is due to wear at the face. As machining is concerned two types of wear are generally seen viz., crater wear and flank wear. With the excess heat on the rake face of the tool, there is a chance for the formation of the built-up-edge. All these factors results in the reduction in the tool life.

X. EFFECT OF HEAT GENERATION ON JOB

Heat generated during machining had combined effect on tool and the job. Major part of the heat is carried away by the chips and the remaining heat is retained by tool and the job. As all the machining process is done for the better surface finish and the dimensional accuracy of the workpiece, some amount of heat is also transferred to the workpiece which has some losses in its performance. Due to the thermal distortion and thermal expansion during cutting, there may chance of dimensional inaccuracy of the job Because of the oxidation, there is a chance of surface damage. In some cases microcracks at the surface, corrosion and burning of job can also be seen

XI. METHODS OF DETERMINING THE CUTTING TEMPERATURE

There are two ways to determine the temperature distribution in metal cutting; they are analytical method and experimental method. In analytical method using a set of mathematical equations (models) which already existed or a newly developed model is used to determine the temperature. Whereas the second method uses a set of experimental set up to measure the temperature. Analytical method is inexpensive and simple but less accurate and precise whereas the former one is more accurate and precise. The major concern areas in the measuring the temperature are shear zone, tool-chip interface and the work tool interface. **Experimental methods for determination of cutting temperature** The following are some of the methods used for measuring temperature experimentally.

• Photo-cell technique
Radiation pyrometers technique
• Tool work thermocouple technique
Indirect calorimetric technique

XII. CONCLUSION

In this paper a review has been done on various temperatures that are generated during machining process. A study was conducted on the various aspects of heat generation, as it is caused due to the cutting edge of the tool slides across the surface of the work. Because of this, heat is generated at three different sources (Shear-zone, tool-chip interface, tool-work interface). From this study it can be concluded that heat distribution in the chip, workpiece and tool are in the ratio 80:10:10. This shows the heat generated at tool-chip interface is more and diverts to focus on that region. The influence of machining parameters and cutting tool geometry on the temperature is also a vital aspect. Among all the parameters, cutting speed has a major influence and then rake angle. The adverse effects on the tool and job due to the heat generation have also been discussed. The reduction in the life of tool and the poor quality of the job is the cause for temperature generation. Lastly in this study various methods which are prominent in determining the temperature have also been reviewed.

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