AIJREAS VOLUME 1, ISSUE 11 (2016, NOV) (ISSN-2455-6300) ONLINE
ANVESHANA'S INTERNATIONAL JOURNAL OF RESEARCH IN ENGINEERING AND APPLIED SCIENCES

THERMAL MODELING AND ANALYSIS OF CARBIDE TOOLS USING FINITE ELEMENTS

SHAIK ABEED
M.Tech, CAD/CAM, A1 Global Institute of Engineering & Technology Arimadugu (Village), Markapur(M), Prakasam(Dist) -523316, A.P.
Email: abeedshaik301@gmail.com

SK. MUNEER BASHA
M.Tech, Associate Professor (HOD), A1 Global Institute of Engineering & Technology Darimadugu (Village), Markapur (M), Prakasam (Dist)-523316. A.P.
Email: muni324@gmail.com

DR.CH.SREEDHAR Ph.D
Principal**,** A1 Global Institute of Engineering & Technology Darimadugu (Village), Markapur (M), Prakasam (Dist)-523316. A.P.

ABSTRACT

The problem of tool wear monitoring in machining operations, has been an active area of research for quite a long time. The accurate prediction of tool wear is important to have a better product quality and dimensional accuracy. In cutting tools the area close to the tool tip is the most important region and conditions at the tool tip must be carefully examined, if improvements in tool performance are to be achieved

The present work involves the study of tool wear caused by the change in hardness of single point cutting tool for a turning operation to predict the tool life in orthogonal cutting based on the heat transfer analysis using Finite Element Method (FEM). The Experiments were performed with EN-24 steel as work piece and Carbide uncoated tool bit as a tool material and the flank wear has been measured experimentally. An empirical relation is used to determine temperature at tool-tip and further Finite Element Method is used to determine the distribution of temperature over the surface of tool and its impact on hardness which is related by an empirical relations.

The study shows the effect of Modified temperature due to strain rate on carbide tool to describe the thermal softening of tool material and becomes prone to wear. The results reveal that by increasing process variables in machining the wear and temperature increases causing thermal softening of tool causing it to wear.

The results obtained have been verified with the available results from literature for the variation of wear with the temperature and thermal softening of carbide tool. The results prescribed demonstrate the significance of cutting parameters (speed, feed and depth of cut) in thermal analysis for study of the cutting tool wear.

INTRODUCTION

Tool wear monitoring/sensing should be one of the primary objectives in order to produce the required end products in an automated industry so that a new tool may be introduced at the instant at which the existing tool has worn out, thus preventing any hazards occurring to the machine or deterioration of the surface finish. Cutting tools may fail due to the plastic deformation, mechanical breakage, cutting edge blunting, and tool brittle fracture or due to the rise in the interface temperatures.

Throughout the world today, there is a continuous struggle for cheaper production with better quality. This can be achieved only through optimal utilization of both material and human resources. Machining operations comprise a substantial portion of the world's manufacturing infrastructure. They create about 15% of the value of all mechanical components manufactured worldwide. Because of its great economic and technical importance, a large amount of research has been carried out in order to optimize cutting process in terms of improving quality, increasing productivity and lowering cost.

Tool wear influences cutting power, machining quality, tool life and machining cost. When tool wear reaches a certain value, increasing cutting force, vibration and cutting temperature cause surface integrity deteriorated and dimension error greater than tolerance. The life of the cutting tool comes to an end. Then the cutting tool must be replaced or ground and the cutting process is interrupted. The cost and time for tool replacement and adjusting machine tool increases cost and decreases the productivity. Hence tool wear relates to the economic of machining and prediction of tool wear is of great significance for the optimization of cutting process.

At present, the prediction of tool wear is performed by calculating tool life according to experiment and empirical tool life equations such as Taylor's equation or its extension versions. Although Taylor's equation gives the simple relationship between tool life and a certain cutting parameters, e.g. cutting speed, and is very easy to use, it gives only the information about tool life. For the researcher and tool manufacturer tool wear progress and tool wear profile are also concerned. Tool life equation gives no information about the wear mechanism. But capability of predicting the contributions of various wear mechanism is very helpful for the design of cutting tool material and geometry. In addition, such tool life equations are valid under very limited cutting conditions. For example, when tool geometry is changed, new equation must be established by making experiment.

Mostly researchers concentrate on the study of wear mechanism and investigate the mathematical relationship between wear due to various wear mechanisms and some cutting process variables such as relative sliding velocity of workpiece material along tool face, cutting temperature of tool face and normal pressure on tool face. Some tool wear equations related to one or several wear mechanisms are also developed, such as Usui's tool wear equation [15], and [19].

In the recent decades, with the emergency of more and more powerful computer and the development of numerical technique, numerical methods such as finite element method (FEM), finite difference method (FDM) and artificial Intelligence (AI) are widely used in machining industry. Among them, FEM has become a powerful tool in the simulation of cutting process because various variables in the cutting process such as cutting force, cutting temperature, strain, strain rate, stress, etc can be predicted by performing chip formation and heat transfer analysis in metal cutting, including those very difficult to detect by experimental method. Therefore a new tool wear prediction method may be developed by integrating FEM simulation of cutting process with tool wear model.

TOOL WEAR

Cutting tools are subjected to an extremely severe rubbing process. They are in metal-to-metal contact, between the chip and work piece, under conditions of very high stress at high temperature. The situation is further aggravated due to the existence of extreme stress and temperature gradients near the surface of the tool. During cutting, cutting tools remove the material from the component to achieve the required shape, dimension and finish. However, wears are occurring during the cutting action, and it will result in the failure of the cutting tool. When the tool wear reach certain extent, the tool or edge change has to be replaced to guarantee the ordinary cutting action.

PREDICTION OF TOOL WEAR

Prediction of tool wear is complex because of the complexity of machining system [15]. Tool wear in cutting process is produced by the contact and relative sliding between the cutting tool and the work piece and between the cutting tool and the chip under the extreme conditions of cutting area; temperature at the cutting edge can exceed 530°C and pressure is greater than 13.79 N/mm^2. Any element changing contact conditions in cutting area affects tool wear. Figure 1.4 shows influencing elements of the tool wear [15]. These elements come from the whole machining system comprising workpiece, tool, interface and machine tool:

• **Workpiece**: It includes the workpiece material and its physical properties (mechanical and thermal properties, microstructure, hardness, etc), which determine cutting force and energy for the applied cutting conditions.

Figure: Influencing elements of tool wear

LITERATURE REVIEW

The problem of tool wear monitoring in machining operations has been an active area of research for quite some time. The machining processes are inherently dynamic in nature due to various factors. Some of them can be mathematically modeled, but others are too uncertain. Thus simplifications are made while modeling the extremely complex machining processes. Research in the field of machining has been primarily done on single point turning process, as it is the basic metal removal processes. Once a model has been developed for turning operation, it can be implemented for other multipoint processes like drilling, milling or grinding.

In this work tool wear along with temperature had been selected as the criterion for the process control in turning operation. In recent years, numerical calculating methods have been widely developed in most areas of engineering and have been used to determine the thermal behaviour of cutting tools. In general, the application of finite element and finite difference techniques has been successful, yet still relies heavily on the accuracy of experimentally determined boundary conditions.

Temperature measurement and prediction have been a major focus of machining research for several decades. Throughout the 20th century, much effort has been undertaken into measuring the temperature generated during cutting operations. Interfacial temperatures in machining play a major role in tool wear and can also result in modification to the mechanical properties of the workpiece and cutting tool.

Leshock et al [4] presented the results the tool chip interface temperature measurement by the tool work thermocouple technique. Tool chip interface temperature is analyzed under a wide range of cutting condition during turning of 4140 steel alloys and Inconel 718 nickel based alloys with tungsten carbide tools. The obtained experimental results are compared with the predictions based on the Loewen and Shaw's model. In addition an empirical model for the tool face temperature terms of cutting parameters is established. Finally, the tool chip interface temperature is analyzed with both flank and crater wear during machining of 4140 steel alloys.

Sullivan et al [12] presented different methods used for the measurement of temperature of a single cutting tool. Initial experiments conducted involved the simultaneous measurement of forces & temperature. Use of the tool-chip interface as a thermocouple was one of the first methods of estimating interfacial temperatures in machining process. These experiments focused on the use of embedded thermocouples and using the infrared camera to monitor the process.

Komanduri et al [13] addresses two fundamental thermal issues of tribology in orthogonal machining with a sharp tool, namely, the nature of the apparent heat partition in the shear plane and the variable heat partition at the chip-tool interface. The distribution of temperature in the chip, the tool, and the work material was determined analytically considering the combined effect of these two heat sources in orthogonal machining. The new analytical model was verified for a wide range of Peclet numbers, using the available experimental data from the literature.

Huda et al [14] developed a technique for measuring temperature at the interface between a cutting tool and a chip. A two-color pyrometer with fused fiber coupler was applied to the temperature measurement of the tool-chip interface in dry and wet turning. By using this pyrometer, it is possible to measure the temperature of a very small object without emissivity affecting the results. The temperature distributions on the cutting tool and the work material were analyzed using the finite element method. Good agreement was obtained between the analytical results and experimental ones.

Miller et al [21] developed Experimental techniques using modern, digital infrared imaging and successfully applied them during this study to gather cutting tool temperature distributions from orthogonal machining operations. This new process has seemingly overcome many problems associated with past experimental techniques.

Ranc et al [23] developed a high-speed broad band visible pyrometer using an intensified CCD camera (spectral range: 0.4 mm–0.9 mm) for the measurement of the machining temperature. The maximum temperature in the chip can reach 730°C and minimal temperature which can be detected is around 550°C. The advantage of the visible pyrometry technique is to limit the temperature error due to the uncertainties on the emissivity value and to have a good spatial resolution (3.6 mm) and a large observation area.

Zhao et al [18] developed a methodology to investigate the effects of the internal cooling on the flank wear of the cutting tools in orthogonal cutting. A flank wear model for a cutting tool in orthogonal cutting is presented which is based on previous wear models and includes the normal stress and the effect of temperature on the flank wear. According to the prediction of this model, the wear performance of carbide cutting tools and HSS cutting tools are different due to their different thermal softening behavior, and they have formulated the following methodologies:

INSTRUMENTATION AND EXPERIMENTATION

The objective of the present work is to develop methodology to relate tool wear with mechanical properties of a material such as Hardness. Here hardness is related with the modified temperature, including the effect of strain rate, of cutting tool. Finite Element Analysis is used to depict the temperature at various points of cutting tool by changing various machining parameters such as cutting speed (V), depth of cut (d), feed rate (f).

A force measurement actually involves the measurement of a deflection, caused by that force, with a suitable calibration between the force and the deflection it produces. For measuring small deflections, various devices have been used. Some of them are listed below:

1. The dial indicator.
2. Pneumatic devices.
3. Optical devices.
4. Piezoelectric crystals.
5. Strain Gauges.

Out of these, most widely used dynamometer is of strain gauge type. In this category, bounded- wire strain gauges have commonly been used. Usually these bonded wire gauges have been specified by the resistance and the gauge factor (F). The gauge factor is a measure of sensitivity of gauge and is defined as:

$$F = \frac{\Delta R/R}{\Delta l/l} = \frac{\Delta R}{\in R}$$

Where, ∈ is the normal strain and can be calculated as

$$\in = \frac{\Delta l}{l}$$

In our case, bonded wire strain gauge of resistance 120+ and gauge factor 2, have been used. In order to measure the strains of the order of 1+, the changes of the resistance of the same order of magnitude need to be measured. This can be made by means of Wheatstone bridge as shown in figure 3.1[24]. No current will flow through the galvanometer (G) if the four resistances satisfy the equation

$$\frac{R_1}{R_4} = \frac{R_2}{R_3}$$

For the sake of simplicity, the lathe operation is frequently taken as a orthogonal cutting process. In this case, the resultant force will act in a known plane and only two force components are required to analyze the cutting process. A schematic diagram of the dynamometer used in the present work is shown in the figure 3.2[24]. In the present case, the axial cutting force, Fc, and the tangential cutting force, Ff, have been used.

EXPERIMENT METHODOLOGY

A HMT make lathe was used for turning experiment whose specifications have been given in appendix -A. Figure3.4 shows the schematic diagram of the machine and equipment setup. Then the actual experiments have been carried out with the different input cutting conditions for different experiments for constant volume of material removal in each case. The experiments carried out can be classified:

1. Carry out experiment on lathe machine using EN 24 as work piece and commercial available Carbide Tool of triangular shape.
2. Machining is done with different sets of Cutting speed, depth of cut, & feed rates.
3. Measuring the cutting forces with dynamometer.
4. Measuring the deformed chip thickness using venire calliper.
5. Measuring the flank wear of the carbide insert with microscope.
6. Correlating these wear trend with thermal softening of tool due to rise in temperature in insert.

The output flank wear is measured with the help of a metallurgical microscope having graduation marked on the eyepiece. These input cutting conditions are fed to program and value of temperature and Hardness at every nodes of the tool is thus calculated.

RESULTS AND DISCUSSIONS

In the present chapter the results for the present problem, that is for the solution of the thermal softening of the tool material in order to predict the tool wear have been developed in accordance with the previously developed models for tool wear [4], [20] and [22]. The number of experiments has been conducted to find out the cutting forces and flank wear of the tool, made of tungsten carbide, at varying machining parameters, which are cutting speed (V), cutting feed (f) and depth of cut (d). Using the experimental data, the strain rate and average interface temperature for the various cutting conditions have been obtained, which have been ultimately used to determine the modified temperature at the tool and the workpiece contact area. The measured experimental values are than fed into the FEM program to predict the temperature at all the nodes of a cutting tool. For simplicity the tool is assumed to be a single point with zero nose radius. This temperature of contact area have been used to determine the overall temperatures at the various parts of the cutting tool using the heat transfer equation developed and using the FEM methods for the solution of these equations for the present problem with the appropriate boundary condition as has been explained in chapter 4. This predicted temperature is than related with the hardness of the cutting tool (Thermal softening)

MACHINING PARAMETERS USED FOR EXPERIMENTATION

Table: Cutting parameters

Cutting speed v (rpm) (Range)	Feed f (mm/rev) (Range)	Depth of cut d (mm) (Range)
420	0.08	0.5
710	0.16	0.75

The table shows the numerical values of the various machining parameters (cutting speed, feed and the depth of cut), that have been selected for experimentation, for the measurement of the temperature, strain rate and flank wear. The EN24 steel workpiece material has been used for experimentation, and its specifications have been shown in appendix B. The cutting material used is Tungsten Carbide, and its specification has been mentioned in appendix C.

The table shows the experimental values of wear, strain-rate and resultant cutting forces for different speed, feed and depth of cuts for the different set of experiments conducted on the carbide cutting tool. The levels of the process variables, which have been used for the experiments of the validation set, are in between the [-1, 1] range. Here, -1 stands for the minimum, and +1 stands for the maximum level of parameters.

To eliminate the effect of wear on the experiments, the tools have been replaced after every cut of constant volume of workpiece material. In total eight carbide bits have been used for all the different set of experiments to be conducted. Tool edge has been made straight or parallel to the chuck to have an orthogonal cut. Constant volume signifies that equal amount of material was removed in all the different sets of experiment conducted.

The relationship between machining parameters and temperature generated at tool workpiece interface has been calculated using the empirical relations as mentioned in the references [4], [24], and [26]. The temperature at tool tip was calculated by changing different depth of cut, feed rate and cutting velocity. Strain rate has also been measured using the empirical relations and than both the measured temperature and the strain rate are put into the equation to find the modified temperature which considers the effect of both.

This temperature has been applied to analyze the temperature distribution on the tool at different edge, nodes and elements through finite element analysis, considering heat loss because of conduction in the tool material and convection with air at ambient temperature. Tool material hardness has been calculated with the help of the temperature distribution obtained as a result of FEM analysis [18]. The results have been obtained for tool wear with the change in machining parameters by relating the heat generated at the tool-workpiece interface and taking hardness of tool material as a function of temperature [18].

MODELLING OF SOLUTION DOMAIN USING FEM

In order to use the finite element technique, mathematical expressions have been derived and discussed in the previous chapter and have been used to predict the temperature at the various locations of the cutting tool. Computer program in VC^{++} environment based on the FEM formulation presented in the previous chapter have been developed and numerical results for temperature and its effect on the hardness of the cutting tool have been obtained and discussed in preceding topics.

The following are the details of the discritization of the solution domain carried out for the FEM Analysis and thus used in the developed computer program for the generation of the results.

VALIDATION OF RESULTS

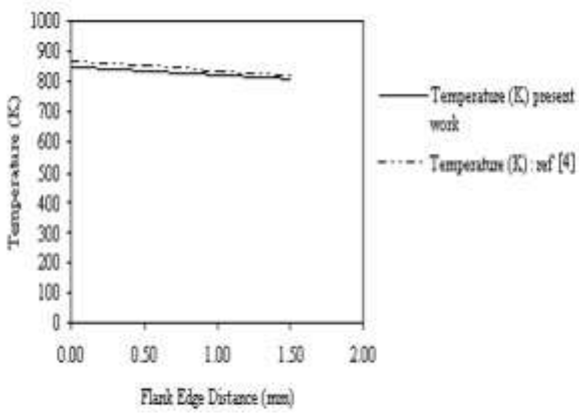


Figure: Relationship between Cutting tool temperature and flank distance

In order to check the validity of the analysis and the solution procedure discussed in chapter 4, the results for temperature field and its effect on thermal softening of cutting tool have been obtained from the developed computer program by using the experimental data of strain-rate and flank wear, and have been compared with the results of Leshock et al [4], for checking the validity of the results. The relation between flank edge distance and the final temperature variation on the cutting tool have been developed for the range of the cutting parameters as given in the table, and have been shown here in graphically form in figure. It is interpretable from the graph, that as we move away from the flank edge, the temperature keeps on decreasing and thus the tip of the carbide cutting tool is prone to more wear rather than the distances away from the tool tip. The results from the reference are well in accordance with the results of the present work, as the maximum variation in the results is only of the order of 5.8 %.

VARIATION OF HARDNESS WITH FLANK-EDGE DISTANCE

The figure shows the relation of tool hardness with the flank distance at different temperature distribution on flank edge of the carbide tool bit. As at the tool tip the temperature is maximum, therefore the hardness is less. Using the mathematical model for modified cutting temperature as discussed in section, the three different values of modified cutting temperatures 750 K, 900 K, and 1050 K, have been calculated from the corresponding strain-rate values which are 840 s^{-1}, 830 s^{-1}, and 577 s^{-1} respectively, corresponding to the different values of feed, speed and depth of cut as shown in table 5.1. At the same flank-edge distance, for these values of modified cutting temperatures, we have different hardness values along the flank face of the tool. The temperature starts decreasing because of heat loss as we move away from the tool tip along the flank surface the hardness of material increases.

Variation of flank wear with cutting velocity at constant depth of cut (d =+1)

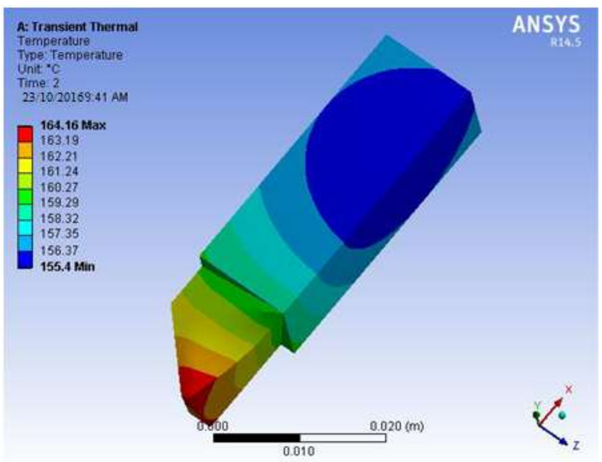
The figure 5.13 also shows similar results but at depth of cuts (d = +1). The trend is almost same depicted in other graphs as shown before, that is with increase in the cutting velocity for some constant value of depth of cut, the tool wear increases.

Finite Element Analysis by ANSYS SOFTWARE

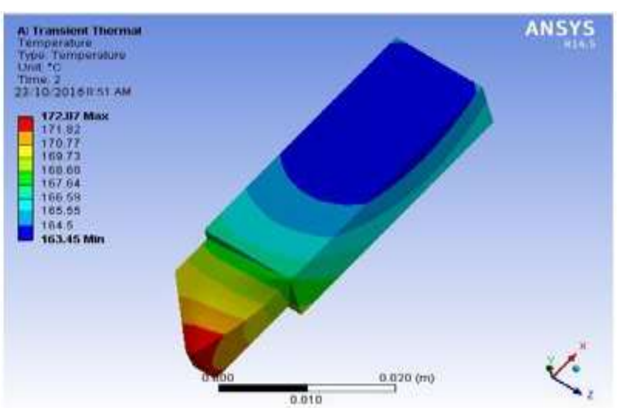
FEA analysis of the experimental results will have to be processed using the analysis (ANSYS). ANSYS is a computational technique that enables the estimation of the relative contributions of each of the control factors to the overall measured response. In the present work, only the significant parameters are used to develop relation between temperature and various parameters like speed, feed and depth of cut. These models are of great use during the optimization of the process variables.

Finite Element Analysis of Tool (Thermal)

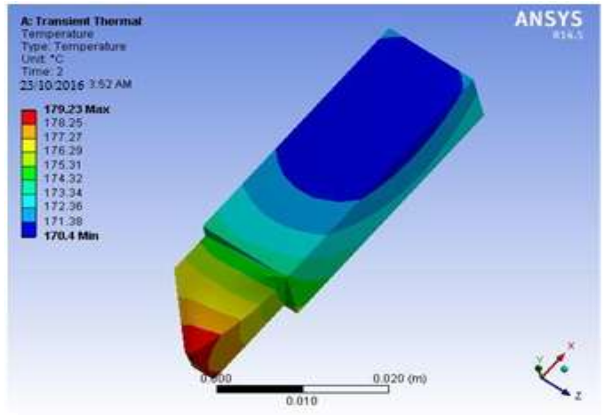
Transient Thermal analysis of tool
Finite Element Analysis of HSS tool at Medium speed (V- 750 RPM):



HSS tool at Depth of cut 1.0 mm

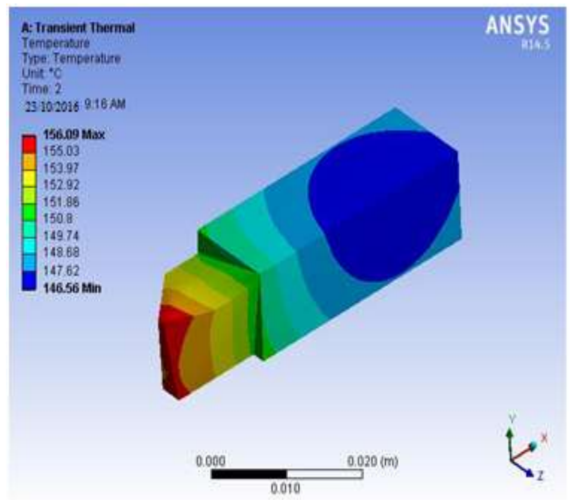


HSS tool at Depth of cut 1.3 mm

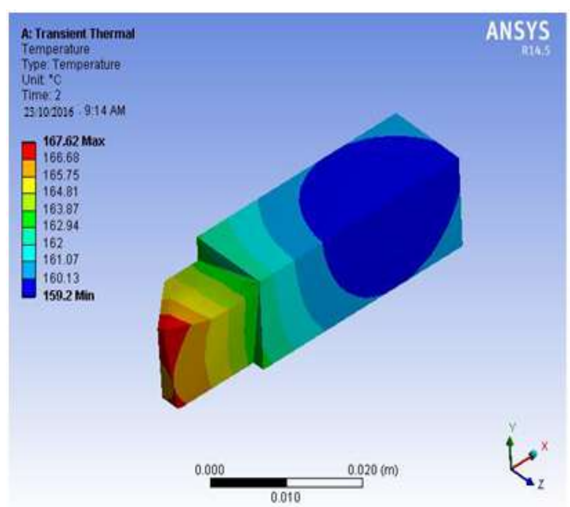


HSS tool at Depth of cut 1.5 mm

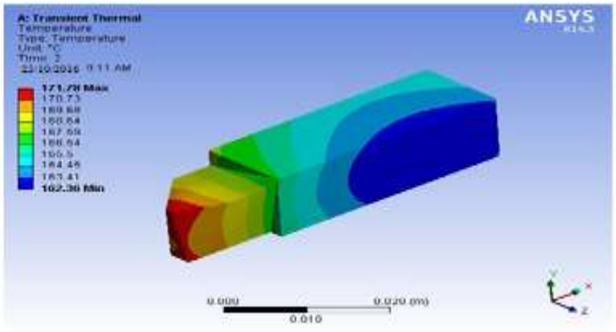
Finite Element Analysis of Carbide tool at High speed (V- 750 RPM):



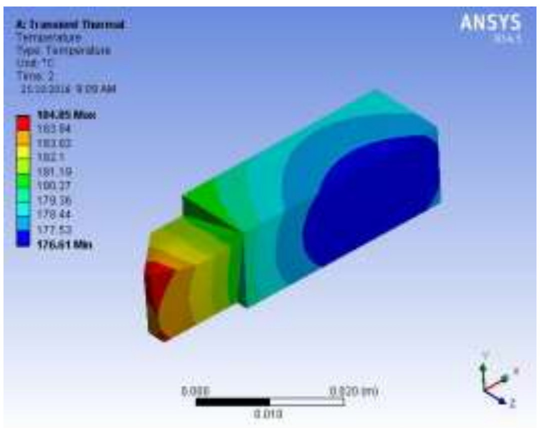
Carbide tool at Depth of cut 0.5 mm



Carbide tool at Depth of cut 0.7 mm



Carbide tool at Depth of cut 1.0 mm



Carbide tool at Depth of cut 1.3 mm

CONCLUSIONS

Based on the results presented in previous sections, the following conclusions have been observed:

1. The hardness increases with increase in distance from the flank edge and with decrease in the tool-workpiece contact temperature.
2. The change in the tool workpiece contact temperature depends upon the cutting parameters and it increases with increase in resultant cutting force, but do not follow a linear trend and thus we can find an optimum set of machining parameters to have a minimum heat generation at tool-workpiece contact.
3. The flank wear is directly proportional to the resultant cutting force and approximately follows a linear trend.
4. The flank wear increases with increase in modified cutting tool temperature (due to increase in the strain rate), but there is a nonlinear trend so we can find an optimum value of cutting parameters so as to give minimum strain rate, because heat generated increases with increase in the strain rate.
5. The contact temperature increases with the increase in the cutting velocity, but at constant cutting velocity, there is a significant increase in the contact temperature with increase in the depth of cut as compared to the increase in the contact temperature with the increase in the feed rate.
6. The flank wear increases significantly with the increase in the cutting velocity. Also at constant cutting speed it increases with increase in both feed rate and depth of cut.
7. From the results obtained experimentally and by FEA, the difference in temperature is not more than 4%.

Thus finally it can be observed that we must select the cutting parameters, which are cutting speed, feed rate, and depth of cut, in such a way so as to have the optimum temperature at the tool tip-workpiece contact because of the heat generated, so that the minimum tool wear is encountered, and thus we could have the longest tool life and better machining economy.

SCOPE FOR FURTHER WORK

With increasing competitiveness as observed in the recent times, manufacturing systems in the industry are being driven more and more aggressively. So there is always need for perpetual improvements. Thus for getting still more accurate results we can take into account few more parameters as given below:

- The transient analysis for the machining operation can be studied.
- The study can also be extended on coated carbide tools, CBN, or other harder tools.
- CNC machines can be used for the experimentation to have the better control of the process variables and also parameters can be set to the desired accuracy.
- The presently developed system can be used for other conventional as well as unconventional processes such as milling, drilling.
- The other combinations of machine, cutting tool and work material can be studied.

REFERENCES

Books

[1] J N Reddy, "An introduction to finite element Method", McGraw-Hill, 1993.

[2] B.S Raghuwanshi, "A Course in Workshop Technology", Dhanpat Rai & Co, Vol-2 (1998).

[3] G.K.Lal, "Introduction to machining science", New Age International Publishers, 1999.

[4] R.K.Jain, "Production Technology", Khanna Publishers, 2001

[5] Tirupathi R.Chandrupatla, Ashok D. Belegundu, "Introduction to Finite Elements in Engineering", Pearson Education, 2002.

Research Papers

[1] Shih Albert J., Yang Henry T.Y., "Experimental and Finite Element Predictions of Residual Stresses due to Orthogonal Metal Cutting", International Journal for Numerical Methods in Engineering, vol. 36(1993), pp.1487-1507.

[2] Shih Albert J, "Finite Element Simulation of Orthogonal Metal Cutting", Journal of Engineering for Industry", ASME, vol. 117(1995), pp. 84-93.

[3] Gillibrand D., Bradbury S.R., Yazdanpanah, Mobayyen S.,"A Simplified approach to Evaluate the Thermal Behaviour of Surface Engineered Cutting Tools", Journal of Surface & Coatings Technology, vol. 82(1996), pp.344- 351.

[4] Leshock C.E., Shin Y.C., "Investigation on cutting Temperature in Turning by a Tool-Work thermocouple technique", Journal of Manufacturing Science and Engineering, vol. 119 (1997), pp. 502 – 508.

[5] Mills B., Hao C.S., Qi H.S., "Formation of an adherent layer on a cutting tool studied by micro machining and finite element analysis", Wear, vol. 208(1997), pp. 61-66.

[6] Tieu A.K., Fang X.D., Zhang D., "FE analysis of cutting tool temperature field with adhering layer formation", Wear, vol. 214 (1998), pp. 252-258.

[7] Chu T.H., Wallbank J., "Determination of the temperature of a machined surface", Journal of Manufacturing Science and Engineering, vol.120 (1998), pp. 259-263.

[8] Ostafiev V., Kharkevich A.,Weinert K.,Ostafiev S., "Tool Heat Transfer in Orthogonal Metal Cutting", Journal of Manufacturing Science and Engineering, vol. 121(1999),pp. 541-549.

[9] Chou Kevin Y., Evans J.Chris, "White layers and thermal modeling of hard turned surfaces", International Journal of Machine Tools & Manufacture, vol. 39 (1999), pp. 1863–1881.

[10] Choudhury S.K., Kishore K.K., "Tool Wear Measurement in Turning using Force Ratio", International Journal of Machine Tools and Manufacture, vol.40(2000), pp. 899-909.

[11] Lim C.Y.H., Lau P.P.T., Lim S.C., "The effects of work material on tool wear", Wear, vol. 250(2001),pp. 344–348.

[12] Sullivan D.O., Cotterell M., "Temperature measurement in single point turning", Journal of Material Processing Technology, vol. 118(2001), pp. 301-308.

[13] Komanduri R., Hou Z.B., et al, "Tribology in Metal Cutting-Some Thermal issues", Journal of Tribology, vol.123 (2001), pp. 799 - 815.

[14] Huda Mahfudz Al, Yamada Keiji, Hosokawa Akira, Ueda Takashi, "Investigation of Temperature at Tool-Chip Interface in Turning Using Two-Color Pyrometer", Journal of Manufacturing Science and Engineering, vol. 124(2002),pp. 200-207.

[15] Yen Y.C.,Sohner J.,Weule H.,Schmidt J.,Altan T., "Estimation of tool wear of carbide tool in orthogonal cutting using Fem simulation", Machining Science & Technology, vol. 6(2002) ,pp. 467-486.

Principal, A1 Global Institute of Engineering & Technology Arimadugu (Village), Markapur(M), Prakasam(Dist) - 523316, A.P.

Educational Qualification:

B.Tech, Koneru Lakshmaiah Engineering College

M.Tech, Industrial Engineering in Andhra University.

HOD (M.Tech) A1 Global Institute of Engineering & Technology Arimadugu (Village), Markapur(M), Prakasam(Dist) - 523316, A.P.

Educational Qualification:

B.Tech, Mekapati Rajamohan reddy Institute of Tech & Sci.

M.Tech, Sri Visvesvaraya Institute of Technology & Science.