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Simulation Of Tool Chip Interface Temperature During Machining Of En31 Alloy Steel

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Abstract: Finite element methods (FEM) based modeling and simulation of machining processes continues to captivate researchers, offering a pathway to enhance understanding of chip formation mechanisms, heat generation in the cutting zone, tool-chip interfacial frictional characteristics, and surface integrity of machined components. To delve deeper into these aspects, a chromel K-type thermocouple was employed to measure cutting temperature at the tool-chip interface during the turning of En31 steel. In this research endeavor, a temperature measuring setup was meticulously designed and fabricated. Utilizing this setup, the generated temperature was accurately measured during the turning process of En31 steel, and the findings are comprehensively reported in this article. Subsequently, leveraging the insights gleaned from the experimental results, a two-dimensional simulation model for orthogonal metal cutting operations was developed using the software ANSYS. This simulation model facilitates the visualization of various temperature distribution plots, elucidating the effects of different cutting parameters on the generated temperature through distinct graphical representations. By offering a detailed understanding of temperature distribution at the tool-chip interface, the developed model serves as a valuable tool for predicting cutting temperature dynamics during turning operations, thereby contributing to advancements in machining process optimization and efficiency.

Key words: En31 steel, ANSYS, Chromel K type thermocouple, Simulation model.

1. Introduction

The metal cutting processes are widely used to remove unwanted material, to achieve dimensional accuracy and desired surface finish of engineering components. In metal cutting processes, the unwanted material is removed by the cutting tool in the form of chips when passed away on the blank or stock. In case of conventional machining, the cutting tool is significantly harder than the work piece. However, cutting tool fail by plastic deformation, wear out or mechanical breakage. The machining is inherently characterized by generation of heat and high cutting temperature. At high elevated temperature cutting tool loses their stiffness, hardness and increase the tendency of plastic deformation. If the cutting tool is not enough hot hard, it may lose their ‘Form Stability’. It an important cause of plastic deformation of the cutting tool while in service. At such cutting tool is plastically deformed or worn out during service resulting in increase of cutting forces, dimensional inaccuracy of the product and reduced tool life. Again, magnitude of the cutting tool temperature increases with increase of cutting speed, feed and depth of cut during turning. This problem also occurs while machining of high strength and hardness work-piece. Therefore, it is important to study on the temperature generated in the tool-chip interface and especially on the rake face of the cutting tool during machining.

Arrazola P. J. et al. [1] studied on 3D-FEM based numerical modeling of precision hard turning to investigate the effects of chamfered edge geometry on tool forces, temperatures and stresses during machining of AISI 52100 steel using low-grade PCBN inserts. In this study, authors focused on cutting forces, temperatures and tool stresses developed during machining with feed rate and cutting speed were constant.Bil Halil et al. [2] studied on various simulation models of orthogonal cutting process. Authors measured the cutting and thrust forces, chip thickness and determined the shear plane angle from the measured chip thickness.Calamaz Madalina et al. [3] developed a model for 2D numerical simulation of serrated chip formation during machining of Ti-6Al-4V titanium alloy.Casto S. Lo. et al. [4] studied on the ceramic cutting tool materials wear mechanisms during cutting nickel based alloys. In this work, the performance of some commercial ceramic inserts during cutting AISI 310 steels are investigated and compared to those of the carbide based tool.EITobgy M. S. et al.[5] studied the finite element modelling of erosive wear. Author state that the material damage caused by the attack of particles entrained in a fluid system impacting a surface at high speed is called ‘erosion’. In this research work, an elasto plastic finite element (FE) model is presented to simulate the erosion process in 3D configuration. Grzesik W. et al. [6] compared two variants of the FEM simulation model of orthogonal cutting process of AISI 1045 carbon steel with uncoated and multilayer-coated carbide tools.Husnu Dirikolu M. et al. [7] studied on various available machining models and found some shortfall in modelling and reasons for these shortfall in machining.Jurkovic J. et al. [8] suggested a reliable direct measuring procedure for measuring different tool wear parameters.Kadirgama K. et al. [9] conducted experiments to determine the temperature distribution on cutting tool when machining HASTELLOY C-22HS with carbide coated cutting tool. Response Surface Method (RSM) used to minimize the number of experiments and to develop first order temperature model.Lee B. Y. et al. [10] reported the use of computer vision techniques to inspect the machined surface roughness during turning operations.Mohamed N. A. et al.[11] used commercially available finite element ABAQUS software for analyzing and predicting the induced residual stresses during machining. Author claimed that this approach reduced the analyzed time. Piotr Nieslony et. al. [12] compared between two variants of the FEM simulation model of orthogonal cutting process for C45 carbon steel with multilayer-coated tools. He found that Temperature distribution patterns have some visible physical analogies to the reduced von Mises stresses and tool-chip contact behaviour.Shet Chandrakanth et al.[13] conducted the experiment in which frictional interaction along the tool-chip interface is modeled with a modified coulomb friction law and chip separation is based on a critical stress criterion.Troy D. Maruscih et al. [14] studied the simulation and analysis of chip breakage in turning processes. Many approaches such as empirical, mechanistic analytical and numerical have been proposed by the author.Vijay Sekar K. S. et al.[15] evaluated the effect of three different flow stress models on the finite element simulation of the orthogonal cutting process on AISI 1045 steel. The predicted finite element (FE) results for cutting force and shear strain were compared against the experimental values.Xie J. Q. et al. [16] studied for developing the FEA modeling and simulation of shear localized chip formation in metal cutting. Authors also compared the materials behaviors and chip formations during machining of different work piece materials.Yen Yung-Chang et al. [17] developed a methodology to predict the tool wear evolution and tool life in orthogonal cutting using FEM simulations. They concluded that location of the maximum wear rate is on the tool rake face and is nearly coincident with that of the maximum cutting temperature.

Keeping in view, a temperature measuring setup has been designed and fabricated, utilized the fabricated setup the generated temperature was measured during turning of En31 steel and reported the results in this article. Utilizing the investigated results two dimensional simulation model is developed for orthogonal metal cutting operations. The software ANSYSis used for the purpose. Thevarious temperature distribution plots have been drawn, effect of various cutting parameters on the generated temperature have been explained via different graphs. Thereafter comparisons of the experimental and simulated results are presented in this research. The developed tool chip interface temperature distribution model will help to predict the cutting temperature occurring during turning in an advance.

2. Planning for Experimentation

The different sets of experiments have been performed by turning operation on a HMT-LB20 Center Lathe with and without use of cutting fluid. Table 2.1 represents the details of cutting tool used for the experimentation.

Table 1 Details of cutting tool used and environment for turning experiments

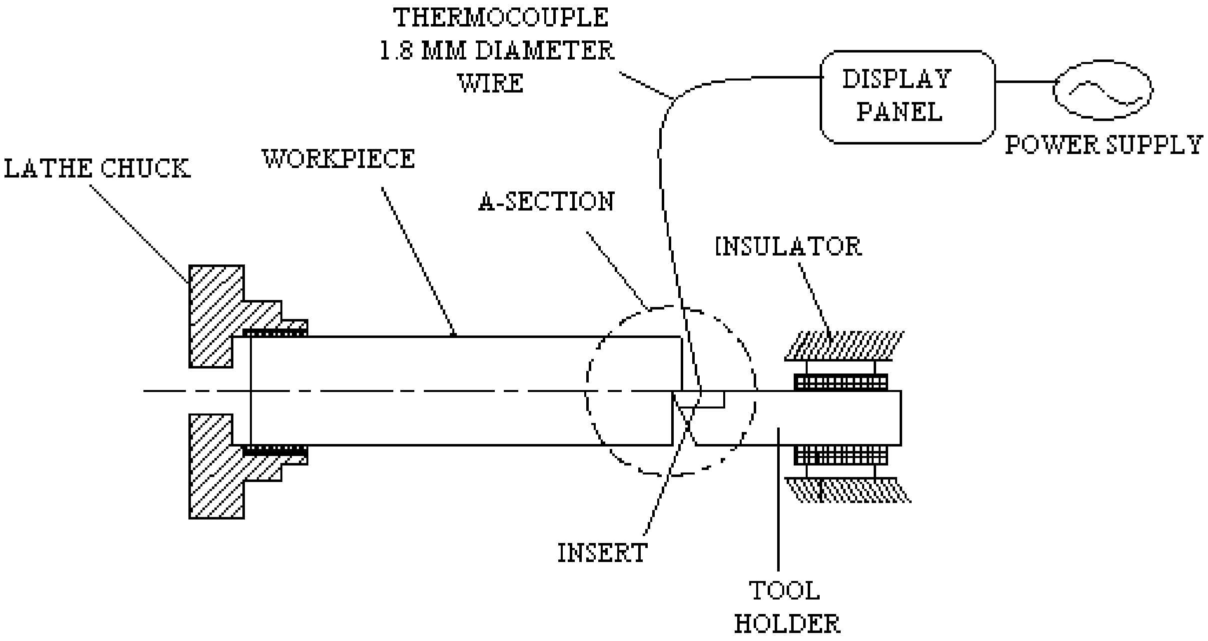
Cutting tool used	Cutting tool specification	Rake angle	Clear-ance angle	Nose radius	Cutt- ing edge ngle	Environment
T-Max-PNégative insert	DNMX150608 WM1525	- 6^0	0^0	0.8 mm	55^0	Wet and dry

Table 2 Chemical composition of En 31 steel

Specification	%C	%Mn	%P	%S	%Ni	%Cr	%V	%Mo	%Cu	%Ti	%W
En31 steel	1.07	0.53	0.08	0.07	0.04	1.12	0.02	0.04	0.08	0.01	0.16

Experimental Set up

To measure the generated temperature during turning a temperature measuring setup has been designed and fabricated. Figure 1 shows a schematic diagram of the setup used for recording the generated temperature at the tool-chip interface during turning of En31 steel.



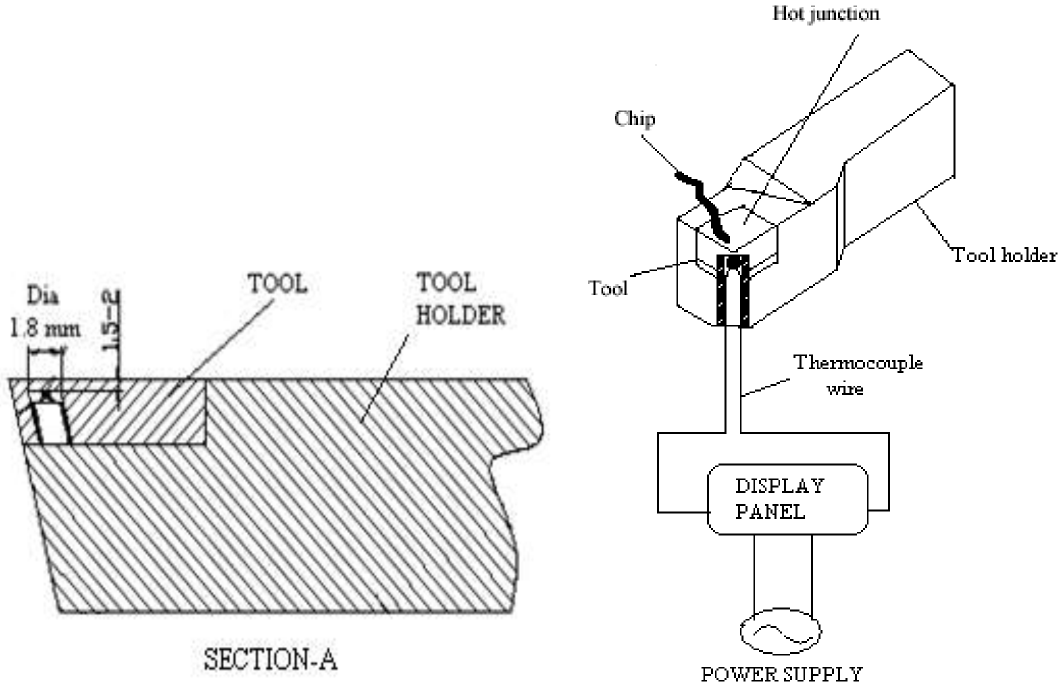


Fig. 2 Temperature measuring Set-up

The cutting temperature was measured using a Chromel K-type thermocouple (thermal conductivity: 9W/m/K and heat capacity:3.91x10^6J/m³.K). Thermocouple terminalis brazed on insert cutting edge. The output of the thermocouple consists of two terminals, which are connected to a LED display panel. The generated temperature is recoded directly from LED display.A TL-14X AD display panel is used.The temperature was measured on the rake face of the tool. Figure 2 shows the actual tool temperature measurement during turning.

Fig. 3 Actual tool temperature measurement showing thermocouple wire and holder

Scheme of Temperature Recording

The scheme of experiments has been setup to perform the experimental studies on the machining parameters, stability of the insert during turning of En31 steel. The experiments have been carried out without the use of coolant. The cutting speed range has been selected between 80 m/min to 120 m/min for machining ofEn31 steel during turning. The experimental investigation was carried out at different feed rate and combined effect of cutting velocity and feed rate on the temperature was plotted for further explanation. The nose radius of cutting tool insert has been selected as 0.8 mm.The cutting tool DNMX150608WM1525, T-Max-P Negative Insert of 55^0 cutting edge angle was used for turning of En31 steel. Further the recorded data were used to simulate by ANSYS software. Ultimately simulated temperature compared with the actual measure temperature.

3. Results and Discussion

Effect of predominate process parameters on Temperature generated during turning of En31 steel

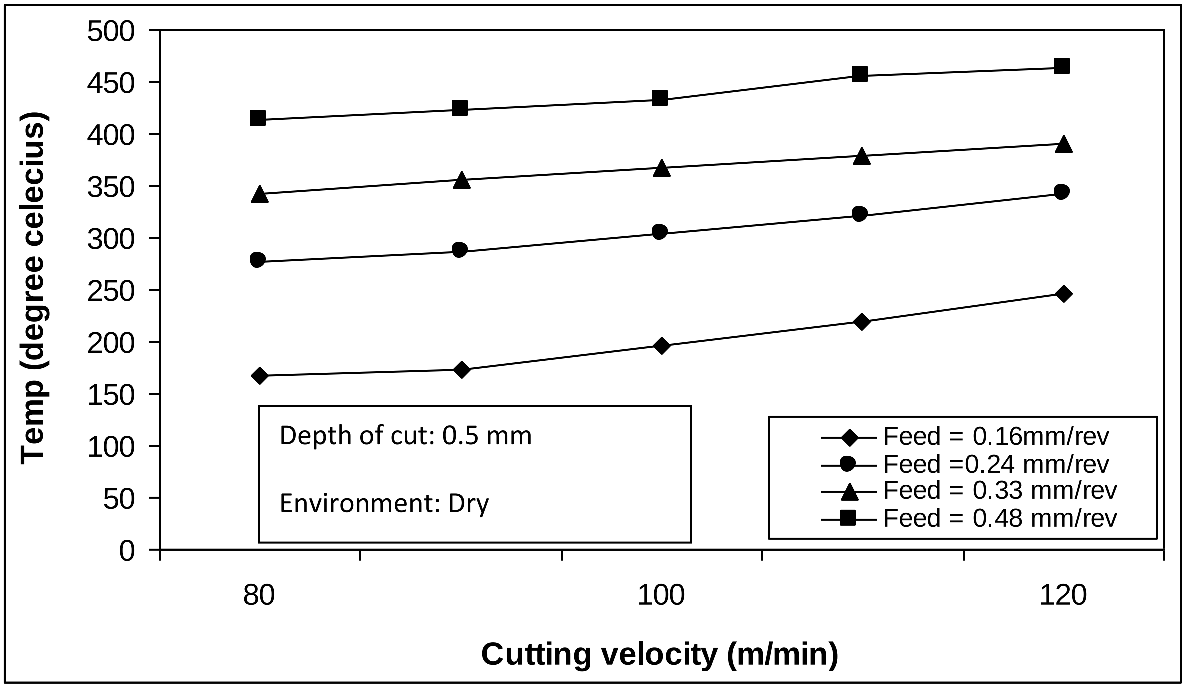


Fig. 4 Cutting velocity Vs Temperature curves at different feed rate

Figure 4shows the effect of the cutting speed at different feed rate on recoded temperature during turning of En31 steel. The temperature was recorded at 0.5 mm constant depth of cut. From the Fig. 2.44, it is clear that the temperature curve first goes up by increase of cutting speed at all feed rate. The increase in temperature is directly proportional to the increase in speed of the work piece. It is also observed that a small variation from the ideal path,which follows the cutting speed Vs temperature graphs because of variation in local conditions.From the recoded results it can be concluded that the there is approximately 62% rise in temperature for increase in feed rate from 0.16 mm/rev to 0.24 mm/rev. It indicates that the parameter cutting velocity has the most influential effect in raising the tool temperature, which is one of the important factors cutting tool fail by deformation.

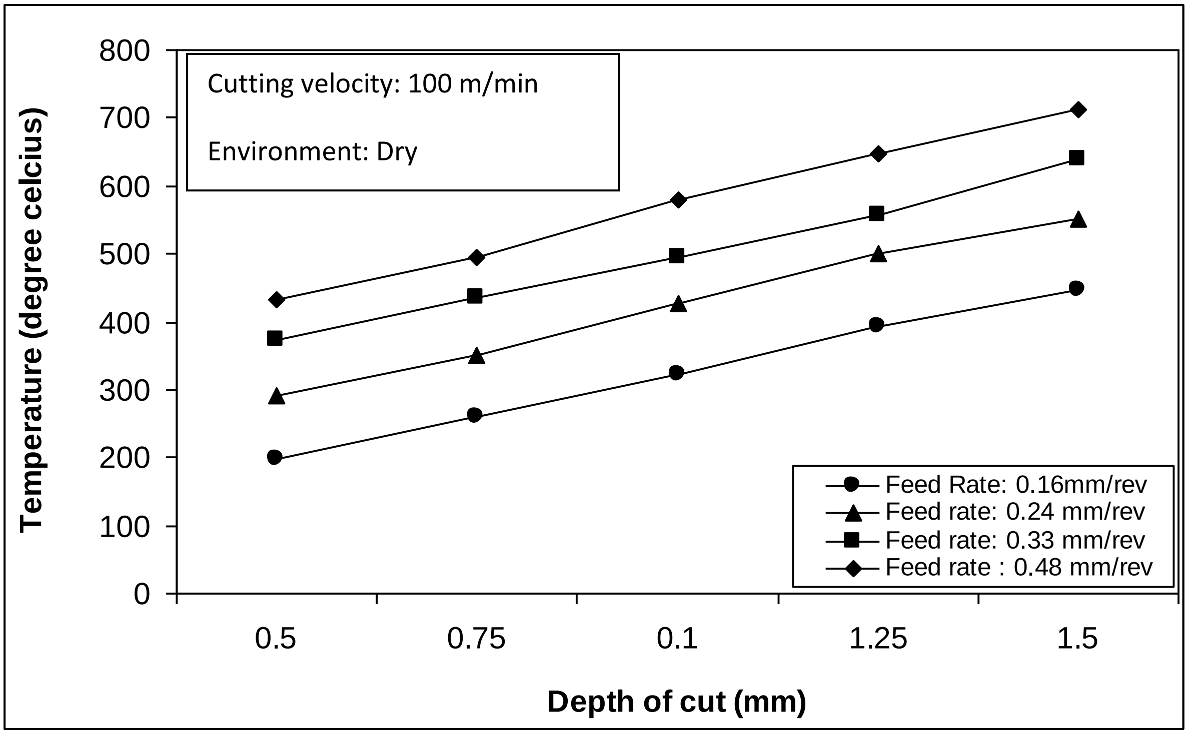


Fig. 5 Depth of cut Vs Temperature curves at different feed rate

Fig.5 shows the effect of depth of cut on the generated temperature at different feed rate during turning of En31 steel by DNMX150608WM1525 insert in dry environment. From the graphs Fig. 5 it is clear that temperatures increases with increase in depth of cut.

4. Analysis of Tool-Chip Interface Temperature Distribution by ANSYS software

As no significant deformation takes place in the tungsten carbide (WC) insert, friction and conduction are the causes of temperature rise. In order to get the correct value of steady state temperature in the insert, a lower heat capacity value has been used. When approaching the steady state the importance of heat capacity decreases to zero. The insert can be considered rigid.

Specify element type and constant e.g. considered two-dimensional thermal analysis PLANE55 element problem was simulated in ANSYS software. The element has four nodes with a single degree of freedom, temperature, at each node. The element is applicable to a two-dimensional, steady-state or transient thermal analysis. The element can also compensate for mass transport heat flow from a constant velocity field. The geometry, node locations, and the coordinate system for this element are defined as well.Heat generation rates considered as input to elemental body loads. Define the material properties of the work piece, **t**aking the work-piece material to be elastic and isotropic and define the values of density (ρ), thermal conductivity (k) and specific heat(c). Similarly, define the material properties of the cutting tool,consideringthe tool material to be elastic and isotropic we define the values of density (ρ1), thermal conductivity (k1) and specific heat (c1). The specify geometry and created model in ANSYS is shown in Fig.2.46. The segregated physical domain with finite elements is known as meshingand it was created is also shown in Fig. 6

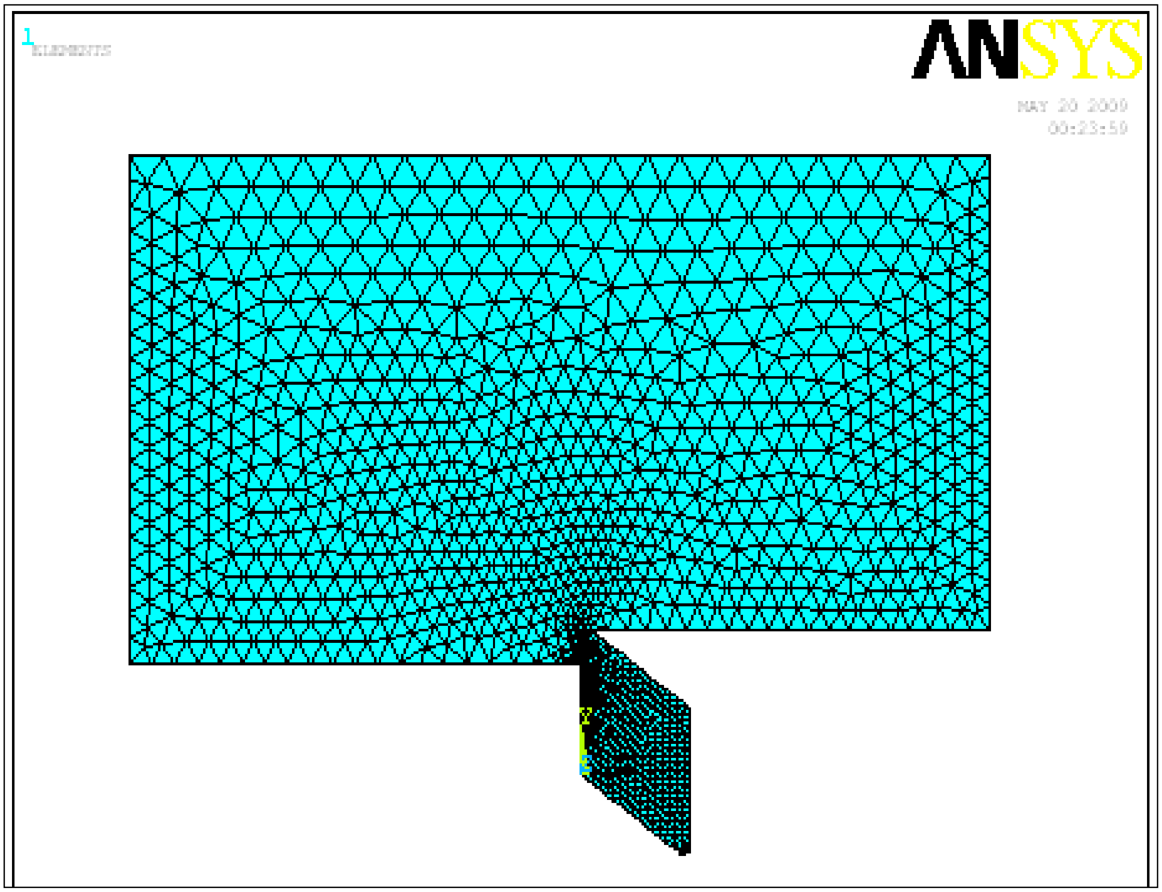
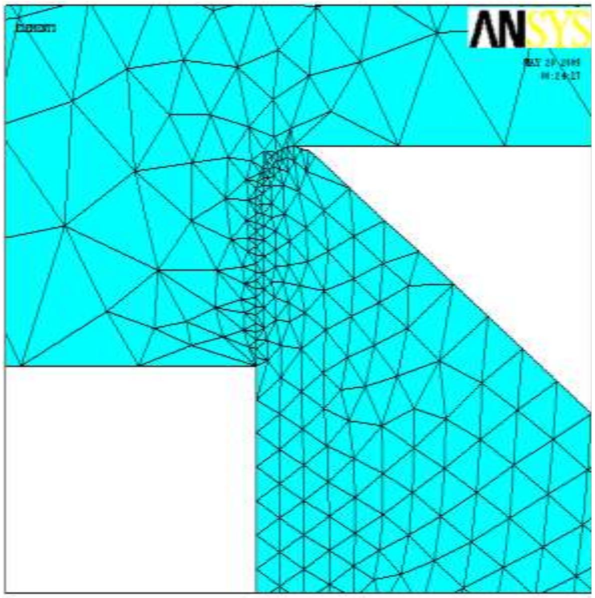


Fig. 6 Meshing and Enlarged view of the cutting tool

A refined mesh for the same domain is shown in Fig.7. Fig.8 shows the defined meshing with nodal numbers and element numbers. Here, the refined mesh includes significantly more of the physical domain in the finite element representation and the curved boundaries are more closely approximated. Total number of element created in ANSYS software for doing the analysis is equal to 2427 and the numbers for nodes are 1310. Then specify Boundary Conditions considering 40 ^{0}C is the boundary conditions, fix the degree of freedom and analyzed the temperature distribution.



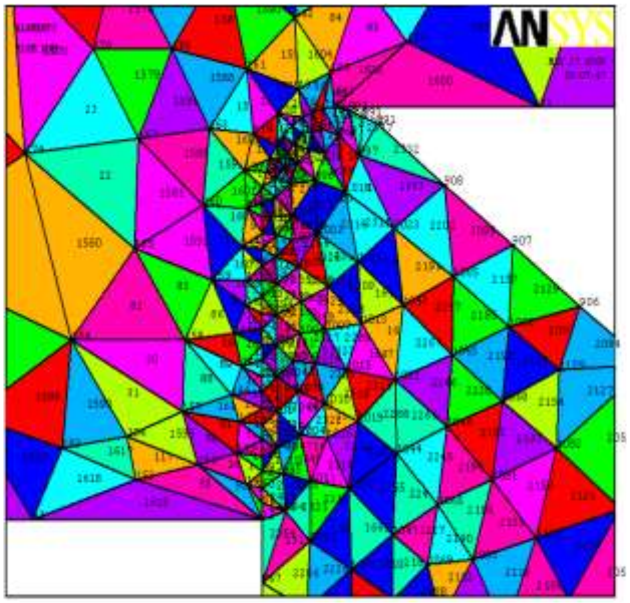


Fig. 7Chip tool interface

Fig. 8 Meshed model with node numbers and element numbers

Discretization of the tool-chip interface and meshed model with node number

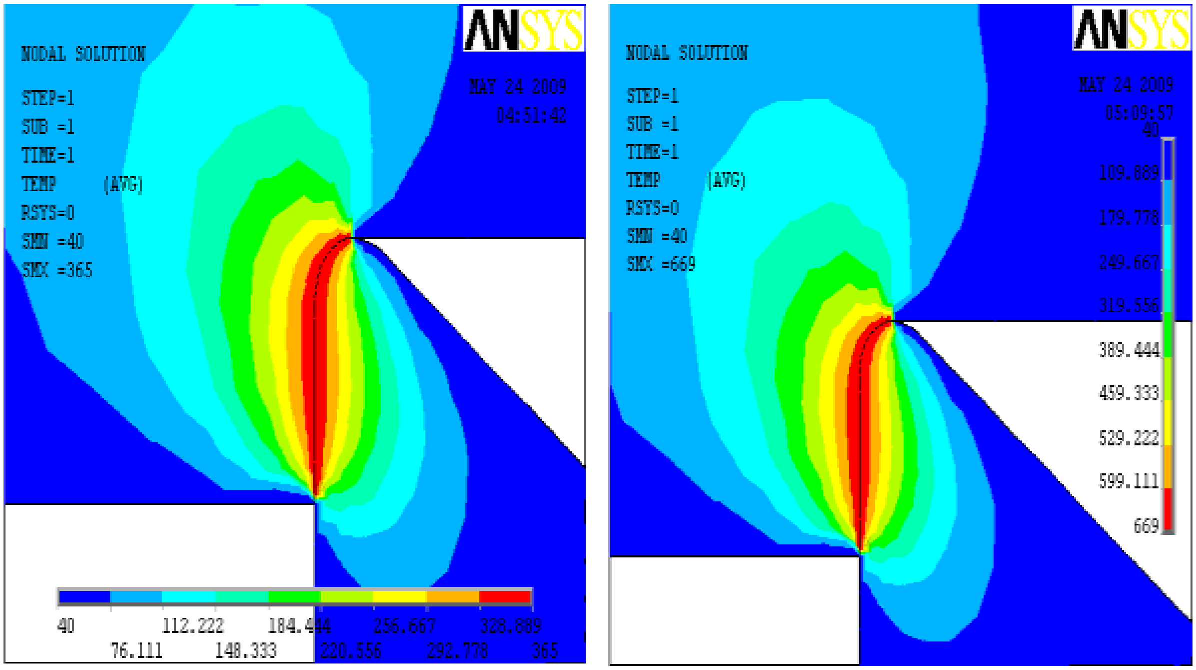


Fig.9 (a)Temperature distribution plot at 365º C

Fig.9 (b)Temperature distribution plot at 669 ºC

Fig.9 Temperature distribution plot using FEM

5. Validity Test

The simulated and experimentally obtained results are compared for confirmation of the simulation. Fig. 2.50 shows the effect of depth of cut on generated temperature both recoded and simulated.

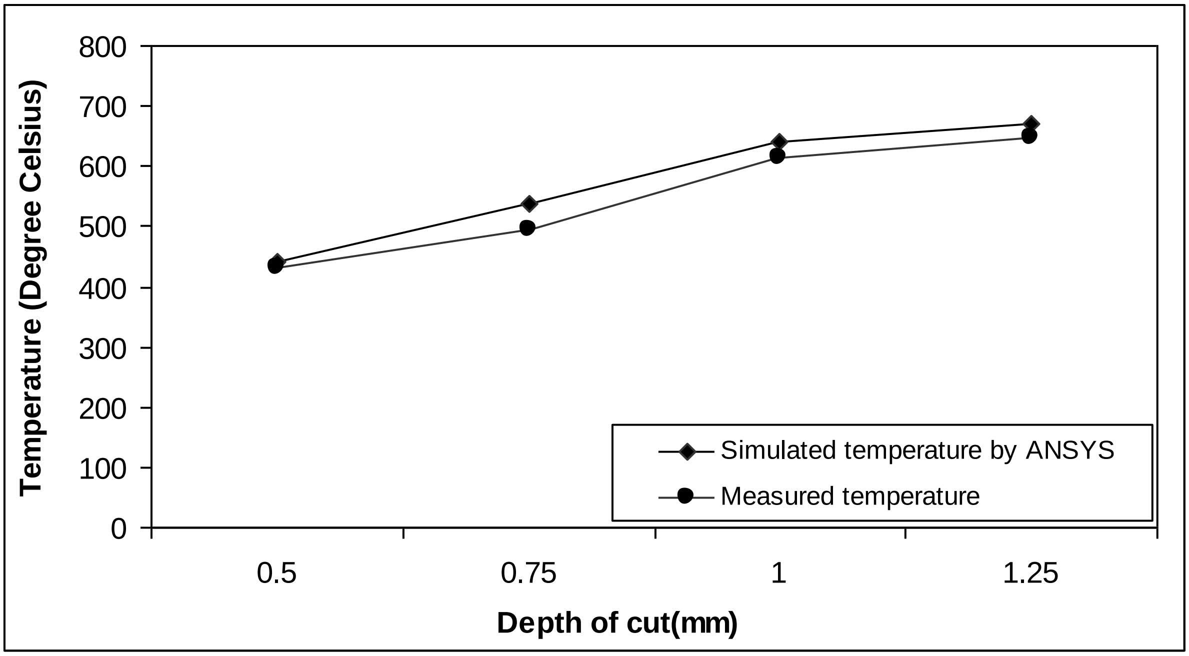


Fig. 10 Recoded and simulated temperature graphs with variation of depth of cut.

Fig. 10 variation of temperature with depth of cut at 0.48 mm/rev and 100 m/min constant feed rate and cutting velocity. The temperature curve goes up in both the cases e.g. in actual and simulated temperature.From the Fig. 10 it is clear that the simulated temperature make a good agreement with the recoded actual temperature. Fig. 11 shows the variation of the recoded and simulated temperature with feed rate. There is also observed that the trend of the generated temperature goes up with rise in feed rate. This graphs was constructed from the results obtained during turning of En31 steel with constant 100 m/min and 0.5 mm depth of cut. From the Fig.11 it is also clear that the simulated temperature is make a good agreement with the actual recorded temperature.

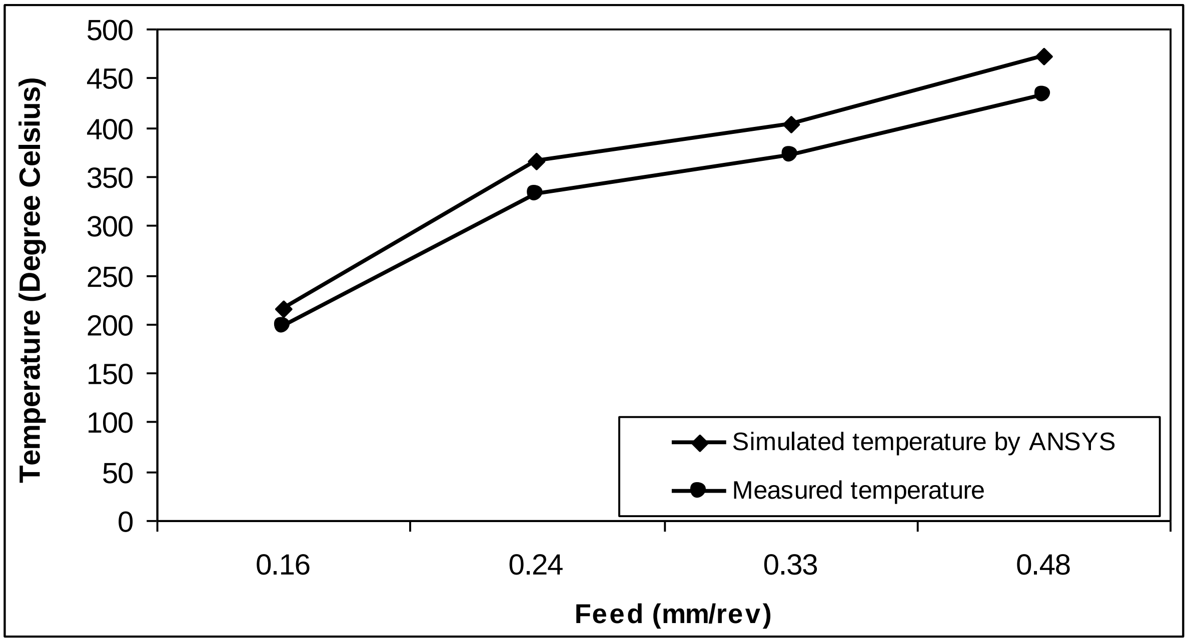


Fig. 2.51 Recoded and simulated temperature graphs with variation of feed rate.

Table No. 3 represents the recorded temperature obtained from the experiments ($T_{experiment}$) and calculated temperatures°C ($T_{simulation}$) from the simulation using ANSYS software.This table was constructed taking the recoded and simulated temperature shown in Fig. 2.50. From the table it is clear that the percentage of error is within 8.01%. Hence, it is proved that simulation results make a good agreement with the experimental results. The simulation can helps to predict the tool-chip interface temperature during turning in advance.

Table No. 3 Comparison of results

$T_{experiment}$	432	494	615	648
$T_{simulation}$	443	537	640	669
Error%	2.48	8.01	3.90	3.14

This study demonstrates that it is possible to carry out sophisticated finite element simulations of metal cutting processes using advanced general-purpose commercial codes and the results obtained are very close to the experimental results with an average error of 8.01% in the maximum temperature obtained. There is increase in temperature generated with increase in cutting speed, depth of cut and feed. From the experimental results it is clear that the cutting velocity is more sensitive temperature. As it can be seen that the temperature curve for any particular speed is not a straight line but a combination of different straight lines this happens because the tool and work materials may not be the ideal elements of a thermocouple due to which the e.m.f. tends to be low, and the shape of the emf-temperature curve is far from a straight line. However, ANSYS software can be successfully applied for two dimensional temperature analyses during turning.

6. Conclusions

Following conclusions can be drawn from this investigation

1. FEM has been successfully applied for two dimensional analysis of the machining process.
2. Tool chip interference temperature affects the performance of the tool as long as the chip remains in contact it can be seen that the temperature curve for any particular speed is not a straight line but combination of different straight line, so it can deduced that this method is not the perfect method. This happen because tool and work material are not ideal elements of a thermocouple due to which the emf-temperaturetends to be low and the shape of the emf -temperature curve is far from a straight line.
3. There is a increase in maximum temperature generated with increase in the value of cutting speed, depth of cut and feed. The maximum effect is of cutting speed and the minimum effect is of feed.
4. This study demonstrate that it is possible to carry out sophisticated finite element simulation of metal cutting process using advance journal purpose commercial code and the results obtained are very close to the experimental results with an average error of 4.38% in the maximum temperature obtained.

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