“MODELLING OF TEMPERATURE PROFILE IN TURNING WITH UNCOATED AND COATED CEMENTED CARBIDE INSERT”

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By

RAM CHANDRA KISKU

Roll No. 107ME023

Under the Guidance of

Dr. S.GANGOPADHYAY

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA 769008, INDIA

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA 769008, INDIA

Certificate of Approval

This is to certify that the thesis entitled "***Modelling of temperature profile in turning with uncoated and coated cemented carbide insert***" submitted by Sri Ram Chandra Kisku has been carried out under my supervision in partial fulfilment of the requirements for the Degree of Bachelor of Technology(B. Tech.) in Mechanical Engineering at National Institute of Technology, NIT Rourkela, and this work has not been submitted elsewhere before for any other academic degree/diploma.

Dr.S.Gangopaday
Department of Mechanical Engineering
National Institute of Technology, Rourkela
Rourkela-769008

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RAM CHANDRA KISKU

Roll No - 107me023

Department of Mechanical Engineering

National Institute of Technology

Rourkela – 769008

ABSTRACT

Determination of themaximum temperature during machining process and its distribution along the rake surface is of much importance as it influences the tool life as well as the quality of machined part. The power consumed in metal cutting during turning operation was largely converted into heat.Continuous or steady state machining operations like orthogonal cutting are studied by modelling the heat transfer between the tool and chip at the tool rake surface contact zone. The shear energy is created in the primary zone, where the main plastic deformation takes place, second at the chip tool interface zone where secondary plastic deformation takes place due to the friction between the heated chip and the tool takes place and the third zone where heat is generated at the work tool interface i.e., at the flanks where frictional rubbing takes place.The friction energy produced at the rake face chip contact zone and the heat balance between the chip and stationary tool are considered

Numerous methods have been generated to approach the problem such asexperimental, analytical and numerical analysis. In addition temperature measurement techniques used in metal cutting have been briefly reviewed. This work includes the study oh heat influencing the cutting tool in both uncoated and coated insert. The numerical methodology used here is ANSYS.Finite element method was used to model the effect of coated and uncoated cemented carbide cutting tool.

After solving the solution obtained showed that the temperature at the tip(tool-work piece contact area) was maximum and it goes on decreasing towards the surface and it was also observed that the temperature generated for coated tool is little less in comparison to uncoated cemented carbide insert this shows that the tool life can be increased by placing a coating layer of TiN.

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LIST OF DIAGRAMS

CHAPTER 1

INTRODUCTION

A large amount of heat is generated during machining process as well as in different process where deformation of material occurs. The temperature that is generated at the surface of cutting tool (insert) when cutting tool comes in contact with the work piece is termed as cutting tool temperature. Heat is a parameter which strongly influences the tool performance during the operation. We know the power consumed in metal cutting is largely converted into heat. Several experimental attempts have been made to predict and measure the temperatures involved in the process .Though it was found that there was no précised experimental method to check the analytical parameters. Temperature being developed during cutting it is of much concern as a result heat are mainly dependent on the contact between the tool and chip, the amount of cutting force and the friction between the tool and chip. Almost all the heat energy produced is transferred into the cutting tool and work piece material while a potion is dissipated through the chip. During machining the deformation process is highly concentrated in a very small zone and the temperatures generated in the deformation zone affect both the work piece and tool. Tool wear ,tool life, work piece surface integrity ,chip formation mechanism are strongly influenced at high cutting temperatures and contribute to the thermal deformation of the cutting tool ,which is considered as the largest source of error in the machining process.

There are three distinct zones where heat is generated the shear or primary deformation zone, where the main plastic deformation takes place, second at the chip tool interface zone where secondary plastic deformation takes place due to the friction between the heated chip and the tool takes place and the third zone where heat is generated is at the work tool interface i.e., at the flanks where frictional rubbing takes place. The increase in the temperature of the work piece material in the primary deformation zone softens the material, thereby decreasing cutting forces and the energy required to cause further shear. Temperature at the tool –chip interface affects the contact phenomena by changing the friction conditions, which in turn affects the shape and location of both of the primary and secondary deformations zones. Secondly, heat generated in the secondary deformation zone due to work done in deforming the chip and in overcoming the sliding friction at the tool-chip interface zone. Finally, the heat generate d at tertiary deformation zone is due to the work done to overcome friction, which occurs at the rubbing contact between the tool flank face and the newly machined surface of the work piece. Heat generation in the primary and secondary zones is highly dependent on the cutting conditions while heat generated in tertiary is strongly influenced by tool flank wear. It is seen that the power consumption and the heat generation in metal cutting process are dependent on a combination of the physical and chemical properties of the work piece material and cutting tool material, cutting conditions and the cutting tool geometry. Heat was removed from the primary, secondary and tertiary zones by the chip, the tool and the work piece. The temperature rise in cutting tool is mainly due to the secondary heat sources, but the primary heat sources also contributes towards the temperature rise of the cutting tool and indirectly affects the temperature distribution on the tool rake surface. During the process part of the heat generated at the shear plane flows by convection into the chip and then through the interface zone into the cutting tool . Therefore, the heat generated at the shear zone affects the temperature distribution of both the tool and the chip sides of the tool-chip interface, and the temperature rise on the tool rake face is due to the combined effect of the heat generated in the primary and secondary zones.

Orthogonal cutting geometry was considered .IT was found that the chip was sliding along the rake surface(secondary deformation zone) with constant average friction coefficient. The amount of heat generated in metal cutting can be measured using two methods one by calorimetric method and other by measuring the cutting forces.

According to cutting forces value, the rate of energy (Wc) consumed in metal cutting was found to be

$$Wc = F_v*V,$$

Where,Fv –cutting force(N)

V-cutting speed (m/s)

Considering, all the mechanical work done in machining process at primary deformation zone was converted into Heat. Then the amount of heat generated (Qs) was given to be,

$$Qs=W_c = F_c*V$$

The amount of heat generated in the secondary deformation zone along rake surface, calculated using friction energy is given by,

$$Qs = \frac{Fs \times V}{\lambda h}$$

Total shear force (F_t) = $F_v.\sin\alpha + F_s\cos\alpha$

(F_s -feed force, α - Rake angle)

Chip plays a major role in removing heat from primary, secondary and tertiary zones. Rise in temperature is mainly due to secondary heat source, the temperature distribution in the rake surface is indirectly initiated by primary heat source. A part of heat generated at shear plane flows by convection. Hence the temperature distribution of both the tool and the chip sides of the tool – chip interface gets affected by the heat generated at the shear zone, and the temperature rise in the rake surface is due to the combined effect of the heat generated in the primary and secondary zones.

According to first law of thermodynamics, the energy balance in a 2-D differential control zone can be written in Cartesian coordinates as:-

$(Q_x + Q_y) \quad + \quad Q.dx.dy \quad - \quad (Q_{(x+dx)} + Q_{(y+dy)}) = \rho C_p(\frac{\partial T}{\partial t}.)dx.dy$

[Heat input] [Heat Generated] [Heat Output] [Heat Stored]

Where dx.dy=area of the infinitesimal element zone.

Q,(Qx,Qy),(Q(x+dx),Q(y+dy)) are the energy generation rate per unit area.

ρ - mass density

C_P - specific heat capacity

t - time

T - temperature

The heat conduction rates (Q_x,Q_y) can be evaluated from Fourier's Law,

$$-Qx = -k(dx)\frac{\partial T}{\partial y}$$

$$-Qy = -k(dx)\frac{\partial T}{\partial y}$$, k= thermal conductivity

Using Taylor series expansion and ignoring the higher order terms, heat flows in two orthogonal directions which can be written in first order approximations:

$$Q_{x+dx} = Q_x + \frac{\partial Qx}{\partial x} dx,$$

$$Q_{y+dy} = Q_y + \frac{\partial Qy}{\partial x} dy$$

Considering there is no change in thermal conductivity in the medium, the heat balance can be rewritten as:

$$\frac{\partial 2T}{\partial x2} + \frac{\partial 2T}{\partial y2} + \frac{Q}{k} = \left(\frac{1}{\zeta}\right) \frac{\partial T}{\partial t}$$

ζ=thermal diffusivity defined as $\frac{k}{\rho . Cp}$

1.1 Temperature measurement during machining operation

In the past 70 years several techniques have been developed to measure the temperature generated at cutting zones. Most techniques deal with the measurement of cutting tool.

Tool-work thermocouple is the most extensively used method as it also shows the effect of cutting conditions such as cutting speed and feed rate. In this method emf developed between tool and work piece is measured. Here cutting zone forms hot junction and work piece forms cold junction. The tool and work piece need to be electrically insulated from the machine tool .The most difficult part of this method lies in concerned with the necessity for an accurate calibration of the tool and work piece materials as a thermocouple pair. A temperature gradient exists along the contact of the tool with the chip and it is uncertain whether the thermocouple is measuring the lowest temperature at the interface or a mean value. The quantity measured in the tool work piece thermocouple method is the average thermo-electric emf at the interface between the tool and the work piece. In general the emf does not correspond to the average interfacial temperature, this being the case if the temperature is uniform or if the thermo-electric emf of the tool –work material combination varies linearly with temperature.

Another method used to measure the temperature and gradients in the tool is that of inserted thermocouples sing thermocouples of small diameter; it is possible to obtain good results in relation to the temperature gradients [13]. In the tool by means of small holes in differentpositions. Disadvantages of using this method are that it is impossible to put thermocouples very near the cutting edge where there are high temperature gradients. With ceramics used as tool material in high-speed cutting, the brittleness and electrical resistance are significant and make it difficult to implement a contact type sensor.

A very interesting method was developed to measure the temperature in the flank face of the tool using wire of a different from that of the work piece and the tool [14]. The wire is inserted into the work piece into a hole of a small diameter and is insulated. When the material is being cut, the wire will also be machined, and when this happens a thermocouple is formed between the wire and the tool. With regard to the results obtained, the temperature of the tool flank face is affected little by the cutting speed, feed rate and depth of cut. Major disadvantage of this method is that the duration of contact is very short.

A method was developed by Kato et al.[15],Cutting temperature: prediction and measurement methods-a review, MarcioBacci de Silva*,James Wallbank, to measure tool temperature distribution within the tool by means of fine powders that have a constant melting point. The tool was divided into two symmetrical parts parallel to the chip flow direction and fine powders were scattered on the side of the divided surfaces. The tools were then put together and used to cut. The temperature distribution is obtained using different powders and observations were made of the melted areas. Some results showed that using this method temperature tends to be absorbed gradually at a point away from the cutting edge, but very rapidly at the cutting edge ,the time required being about 1-2 min. The temperature gradient obtained was little different from that obtained using other methods.

The technique of measuring temperature by the method of radiation [16-21] is sometimes very useful in obtaining the temperature of the surface of work piece. This method gives information only about the temperature on exposed surfaces, although some experimental techniques attempted to measure the temperature distribution on the flank or the rake face of the tool through small holes in the work piece. The radiation methods are very complicated and are suitable for laboratory studies. Extreme care is required assembling and using radiation pyrometer and the minimum temperature detectable is a limiting factor for the use of these set-ups.

CHAPTER 2

LITERATURE REVIEW

2.1 Determination of temperature distribution in the cutting zones using hybrid analytical- FEM Technique

For the past 5 decades, metal cutting researchers have developed many modelling techniques including analytical techniques, slip-line solutions, empirical approaches and finite element techniques. In recent years, the finite element method has gained importance for simulating metal cutting processes [1-3]. Finite element models are widely used for calculating the stress, strain, strain-rate and temperature distributions in the primary, secondary and tertiary zones. In consequence, temperatures in the tool, chip and work piece, as well as cutting forces, plastic deformation (shear angle and chip thickness), chip formation can be determined faster than by using other costly and time consuming experiments. Typical approaches for numerical modelling of metal cutting processes are Lagrangian and Eulerian techniques, as well as a combination of both called an arbitrary Lagrangian– Eulerian formulation (denoted in the literature by ALE acronym) [3,6]. It should be noticed that all these methods are mathematically equivalent. The major feature of Lagrangian formulation used in this study is that the mesh is attached to the work piece. Earlier finite element analyses were performed by Usui and Shirakashi [3], Iwata et al. [4] and Strenkowskiand Carroll [5], who were the first to use Eulerian formulations for steady-state metal cutting simulations.

On the other hand, Marusich and Ortiz [6] have developed a Lagrangian formulation in which the material model contains deformation hardening, thermal softening and strain-rate sensitivity tightly coupled with a transient heat conduction analysis appropriate for finite deformations. Most of the early investigations on the FEM modelling of orthogonal cutting were limited by the the fundamental 2D cutting model proposed by Ernst and Merchant. In recent years, a few trials were undertaken [7] to extend the FEM modelling technique to real non-sharp cutting tool geometries including round/hone and T-land/ chamfer edges. In particular, the Lagrangian thermoviscoplastic cutting simulation of 0.2% carbon steel performed by Yen et al. [7] have observed that plastic deformation and interface temperature changes by increasing the nose radius of the cutting tools. FEM analysis can help to investigate thermodynamically effects occurring in the cutting zone which, cannot be measured directly [2]. An example for such effects is the influence of cutting temperature distribution in the chip and the tool

In this paper, a Lagrangian finite element code advantage was also applied to construct a coupled thermo-mechanical finite element model of plane-strain orthogonal metal cutting with continuous chip formation produced by plane-faced uncoated and differently coated carbide tools.

The entire cutting process is simulated, i.e. from the initial to the steady-state phase.

Several experiments have been conducted to determine the amount of heat generated and cutting temperature during machining. Analytical as well as Numerical methods were applied with an objective of calculating the peak and average temperature at shear zone where first, second and tertiary deformation takes place. The above mentioned method involved analysis of heat conduction for both moving and stationary heat sources. The inverse heat conduction effect too was analysed where the unknown boundary values of heat flux were obtained from interior heat distribution.

2.1.a Analytical Models

A steady state 2-D analytical model was developed by Trigger and Chao .It was developed to determine the average temperature in metal cutting. They calculated the average temperature rise in chip based on the existence of two heat sources, shear plane and tool-chip interface.

They made following assumptions:-

(i) plane heat sources at the shear plane and tool-chip interface,

(ii) frictional energy was uniformly distributed,

(iii) no redistribution of the thermal shear energy.

(iv) work surface and machined surface as adiabatic boundaries

Loewen and Shaw [10] used same assumptions to calculate the average temperature. They applied Blok's heat partition principle for their analysis. Two temperature solutions were obtained. Solution for finding average temperature was found out but this method had something wrong with the assumptions as it was impossible to match the temperatures on the two sides of the heat sources and to do so heat flux distribution must be non – uniform.

To solve this problem Chao and Trigger used two approaches. Firstly they considered Heat flux value to be a exponential function. Through this method they were able to achieve more realistic values but they found that it required time consuming cut-and-try method to find the values of constant in their equation. Secondly they followed discrete iteration method, which involved a combination of both analytical and numerical methods.

Weiner developed another method in which the shear plane was considered as a inclined plane with the heat source moving with speed of cutting speed. to simplify the geometry he assumed the chip flow normal to the shear plane. Results however showed the chip temperature was overestimated and the maximum temperature was obtained at the end of chip tool contact length.

Young and Chou [11] too developed an analytical model to predict tool-chip interface temperature distribution during orthogonal metal cutting. They assumed that the shear plane was inclined to the chip velocity; heat conduction in the direction of motion could be neglected, heat generated along the shear plane was at uniform rate.

Komandurii and Hou[12] developed model for temperature rise distribution which considered the combined effect of the shear and the frictional heat source. The backside of the chip was considered an adiabatic boundary. The result obtained showed that the contribution of friction heat source is predominant.

2.1.b Numerical Models

Finite element Simulations has been successfully applied for modelling plain strain orthogonal metal cutting simulations based on Lagrangian techniques and thermo, mechanically coupled modelling software with adaptive remeshing. Large number of input parameters such as large deformation, high strain rate, temperature effects, tool – chip contact and friction models.

FEM uses two type of formulations; Eulerian and Lagrangian. Adaptive remeshing here means, the initial mesh becomes distorted after certain cut of length. In simulation the main advantage is that, there is no separation criterion defined and the chip is formed continuously by remeshing the work piece. However the main limitation of this method is that the inputs must be obtained from cutting test of specific combination of tool geometry and work piece. A coating layer of constant thickness of specific coating material is added to the inserts surface in original model. In graphical representation of simulation model after construction of mess, the area which is going to come in contact with the work pieces made denser to get better observation of temperature distribution. It was found that the maximum interface temperature was obtained at the midpoint of contact length.

Certain assumptions have been made to simulate the complex procedure of metal cutting with FEM.

Following are the assumptions made to define how the problem is going to be solved as well as how and where to apply the boundary conditions:-

1. The cutting speed was kept constant.

2. The width of cut taken was larger than the feed.

3. The cutting velocity vector was perpendicular to cutting edge.

4. Constant friction at tool-chip interaction and tool-work piece interaction.

5.The initial coolant temperature is selected as the room temperature.

2.2 Temperature and Cutting conditions

The main focus during metal cutting has been given to the tool temperature and on analytical models because tool wear is of much concern to researchers. Cutting speed, depth of cut, tool geometry, feed rate or unreformed chip thickness are the parameters which influence cutting zone temperature. The main reason behind increase in temperature is that more heat being generated and is concentrated in a small area where less amount of heat is dissipated which leads to the increase in temperature.

Tool-work thermocouple method obtained temperature as a function of cuttings speed for three different feed rates however good idea about values of temperature were achieved by the tool. Water was used as coolant and it effects decreased as the cutting speed increased.

The heat was generated even during the sliding of chip over rake surface, so there is contribution from seizure and sliding zones. Errors arise from the fact of its impossibility to distinguish the two regions. The method used for measuring strain is the quick-stop method, consisting of a device capable of disengaging the tool very quickly while cutting.

The distribution of temperature was explained in terms of seizure zone and crater were formed on the rake surface due the high temperature developed.

Finally it was observed that for particular combination of tool and work piece, the tool temperature will be affected by the extent of the contact length between chip and tool. It was also observed that with increase in contact length the temperature also increases.

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Significance of Meshing in ANSYS

The fluid flow and heat transfer that are governed by partial differential equation which are inadequate to give analytical solutions, except for very simple cases. Therefore to analyze the fluid flows, the flow domains are required to be split into smaller sub domains (which are hexahedra and tetrahedral in 3D and quadrilaterals and triangles in 2D) as shown in figure.,

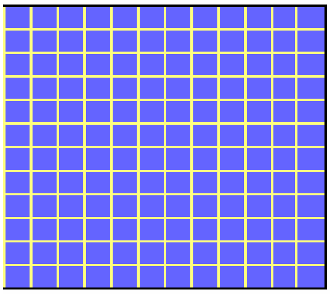


Fig 1: Meshing in 2D(Square block)

This helps the governing equations to be solved inside the sub domains.Out of three methods namely: finite volumes, finite elements, or finite differences, one is used for solving the equation. The sub domains are also called elements or cells, and mesh or grid is the name termed to the collection of all elements or cells. Mesh (or grid) was generated in CFD when most analyses were 2D in nature. Generation of mesh is one of the most complicated aspects in engineering simulation. Generation of mess should be properly balanced as generation of too many may result in long solver runs and generation of very few can result in inaccurate results. ANSYS meshing technology provides a means to balance these requirements and obtain the right mesh for each simulation in the most automated way possible.

There are various types of meshing:-

(i) Tetrahedral

(ii) Hexahedral

(iii) Prismatic inflation layer

(iv) Hexahedral inflation layer

(v) Hexahedral core

(vi) Body fitted Cartesian

(vii) Cut Cell Cartesian

3.2 Insert specification

The tool material is mainly categorized into two types:-

(i) SNMA XYZ

S → Square shape

N → 0^0Clearance

M → Medium tolerance for Manufacturing of insert

A → Flat surface without features and with central hole

X → Length of cutting edge

Y → Thickness

Z → Nose radius

(II) SNUN XYZ

S → Square shape

N → 0^0Clearance

U → Utility tolerance (not too close ,not too rough)

N → Flat type insert without any features and without central hole

X → Length of cutting edge

Y → Thickness

Z → Nose radius

The tool material used in numerical analysis was in SNUN 120408 and the coating material TiN used was of ISO K10 cemented carbide type (92% carbide and 8 % cobalt)

3.3 Insert profile

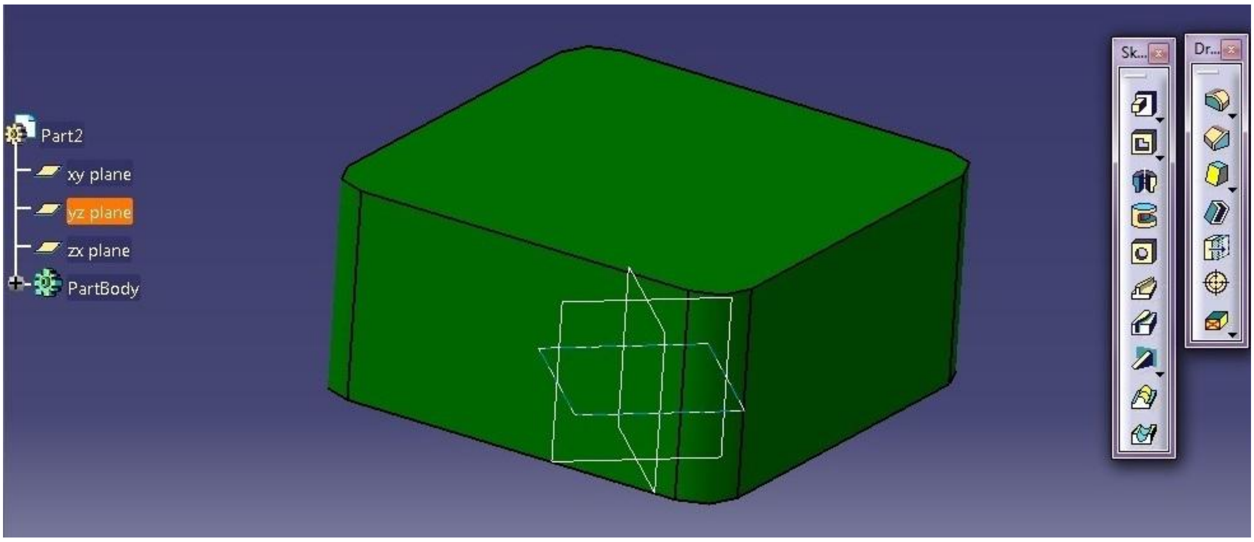


Fig 2: 3-D model of WC-Co turning insert

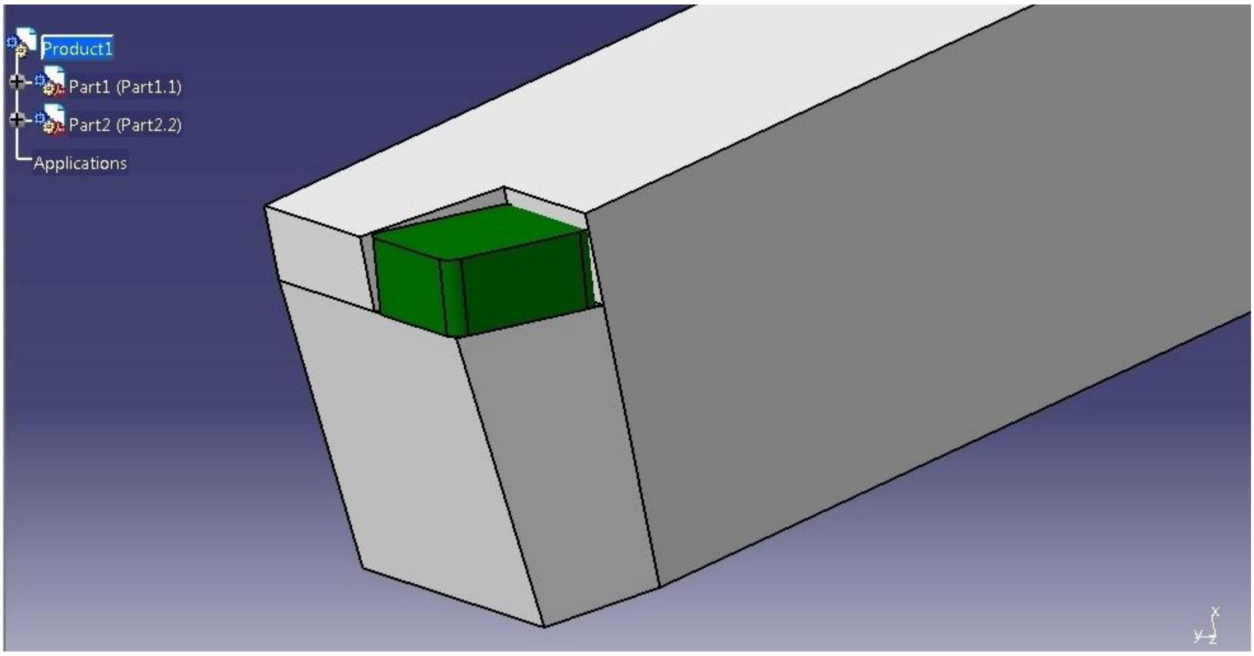


Fig 3: 3-D model of WC-Co turning insert with tool holder

3.4Thermal properties of Materials used :

Table 1 : Thermal properties of Tool

Tool Material	Thermal conductivity($Wm^{-1}K^{-1}$)	Density(kgm^{-3})	Specific heat capacity($Jkg^{-1}C^{-1}$)
WC-Co	84.02	14200	150

Table 2 : Thermal properties of coating material

Coating Material	Thermal conductivity($Wm^{-1}K^{-1}$)	Density(kgm^{-3})	Specific heat capacity($Jkg^{-1}K^{-1}$)
TiN	21	4650	645

3.5. Procedure

A insert of SNUN 120408 specification was taken 12 here indicated the length of cutting edge to be 12 mm , 04 indicates the thickness of the insert to be 4 mm and 08 represents the nose radius to be 8 mm . The main objective is to analyze the thermal influence of heat flux in both coated and uncoated tool during cutting operation using ANSYS 9.0 Software. A coating of TiN was provided with a thickness of 10µm.

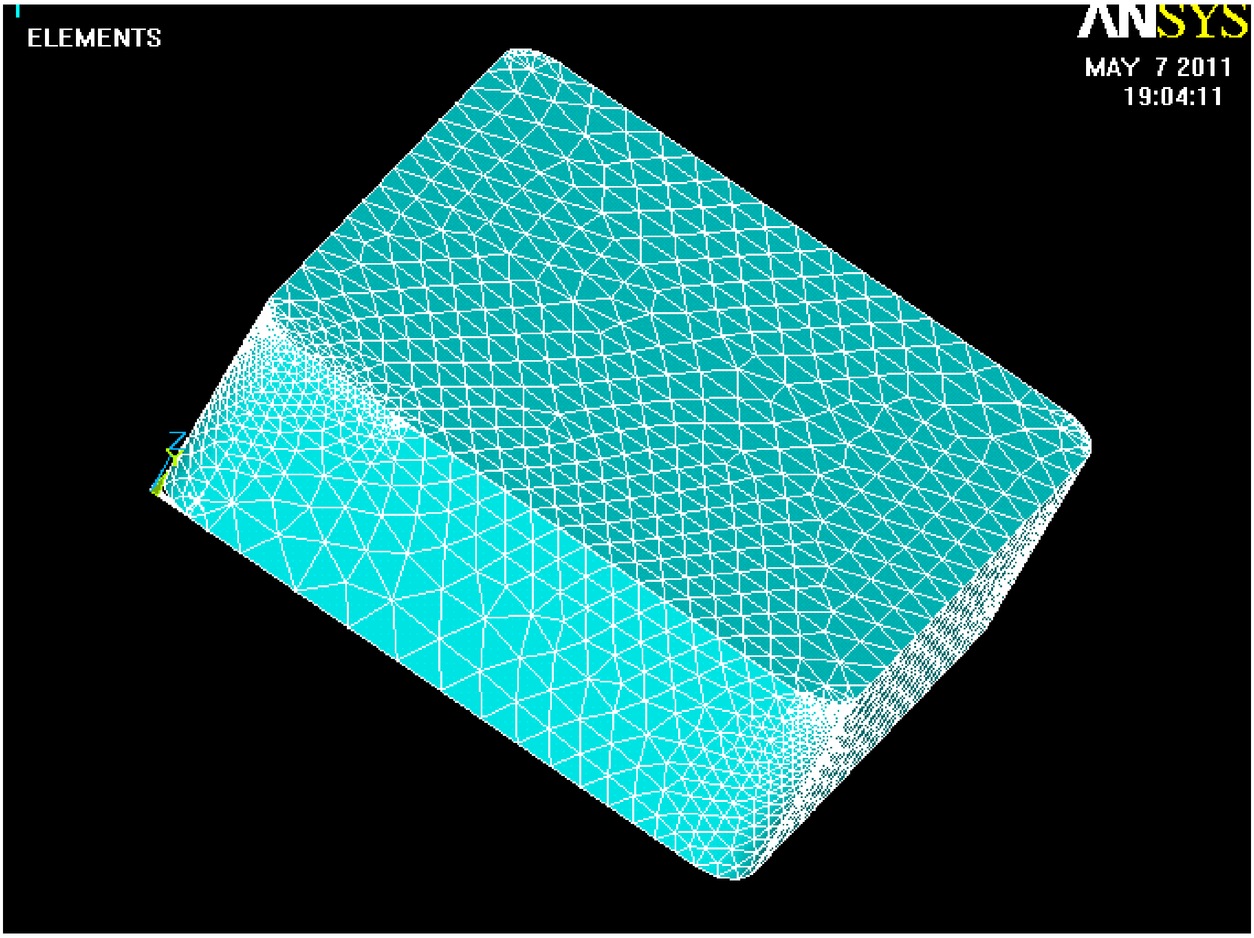
First the insert of 12×12×04 mm3 volume was made with value of Thermal conductivity (k)= 84.02 $Wm^{-1}K^{-}1$, Density (ρ)= 14200 kgm^{-3}, Specific heat capacity (c_p)=150 $Jkg^{-1}K^{-1}$ then meshing of insert was done and the area where the contact between work piece and tool is going to take place is made much denser to obtain better view of temperature profile. In this case tetrahedral meshing was done along the volume. The numerical meshing was done using ANSYS 9.0 . The software generated a three-dimensional structure mesh.

After generation of mesh the value of heatflux (Φ) was inserted which was found to be 1.5×10^6 Wm^{-2} . During operation the time duration of machining was taken to be 110 secondswith equal time interval of 0.22 seconds was maintained for analysis i.e, after every 05 seconds it gets analysed for better result and room temperature was maintained at 20^0c, and a constant and equal heat transfer coefficient of 20 $Wm^{-2}K^{-1}$ was taken.

After obtaining the temperature profile for un coated tool, a coating of 10 µm of TiN was applied over the surface of insert .After construction of coated tool first we have to insert the thermal properties of WC-CO then the thermal properties of TiN :

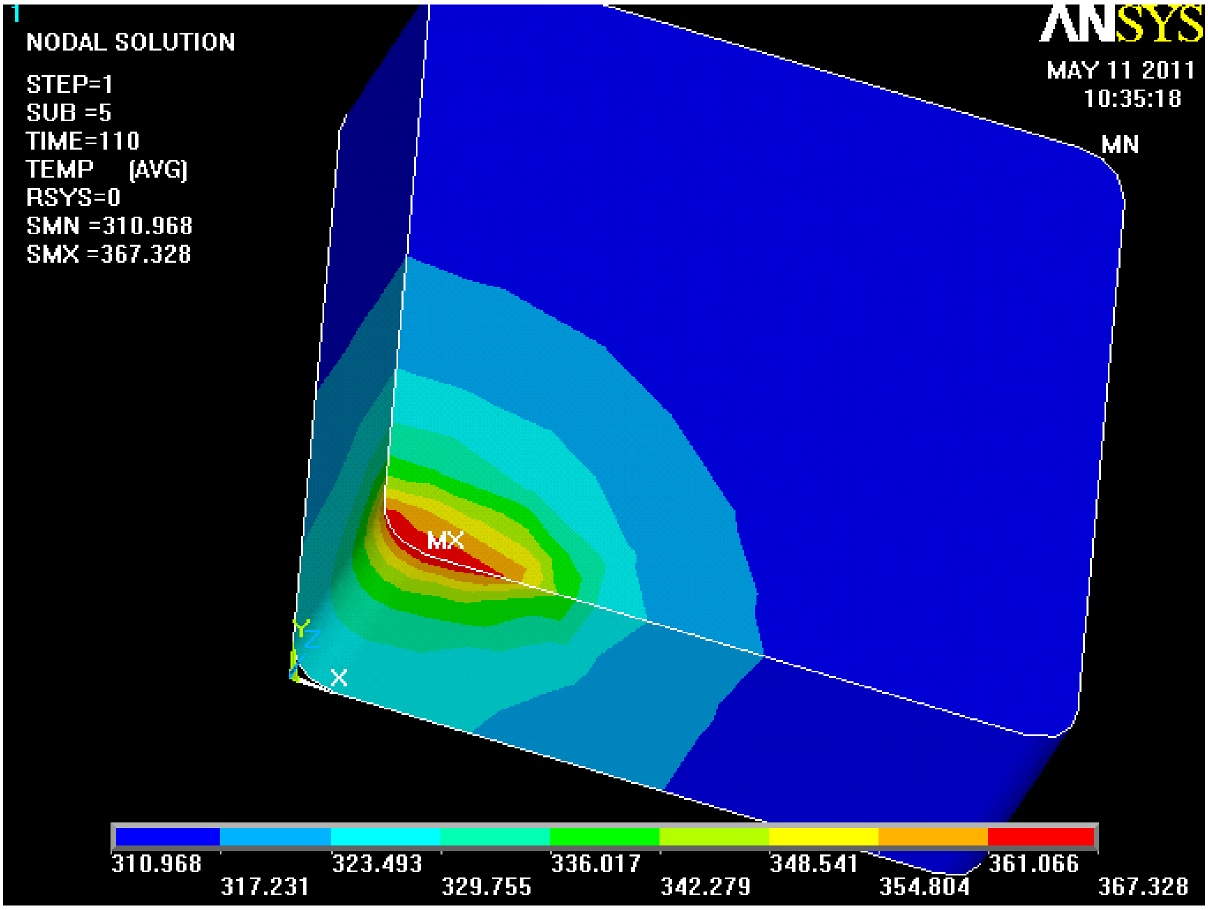
Thermal conductivity (k) =21$Wm^{-1}K^{-}1$, Density (ρ) = 4650 kgm^{-3}, Specific heat capacity (c_p) =645 $Jkg^{-1}K^{-1}$ respectively. Then the solution was obtained for same heat flux value.

Fig 4: Meshing in cutting tool



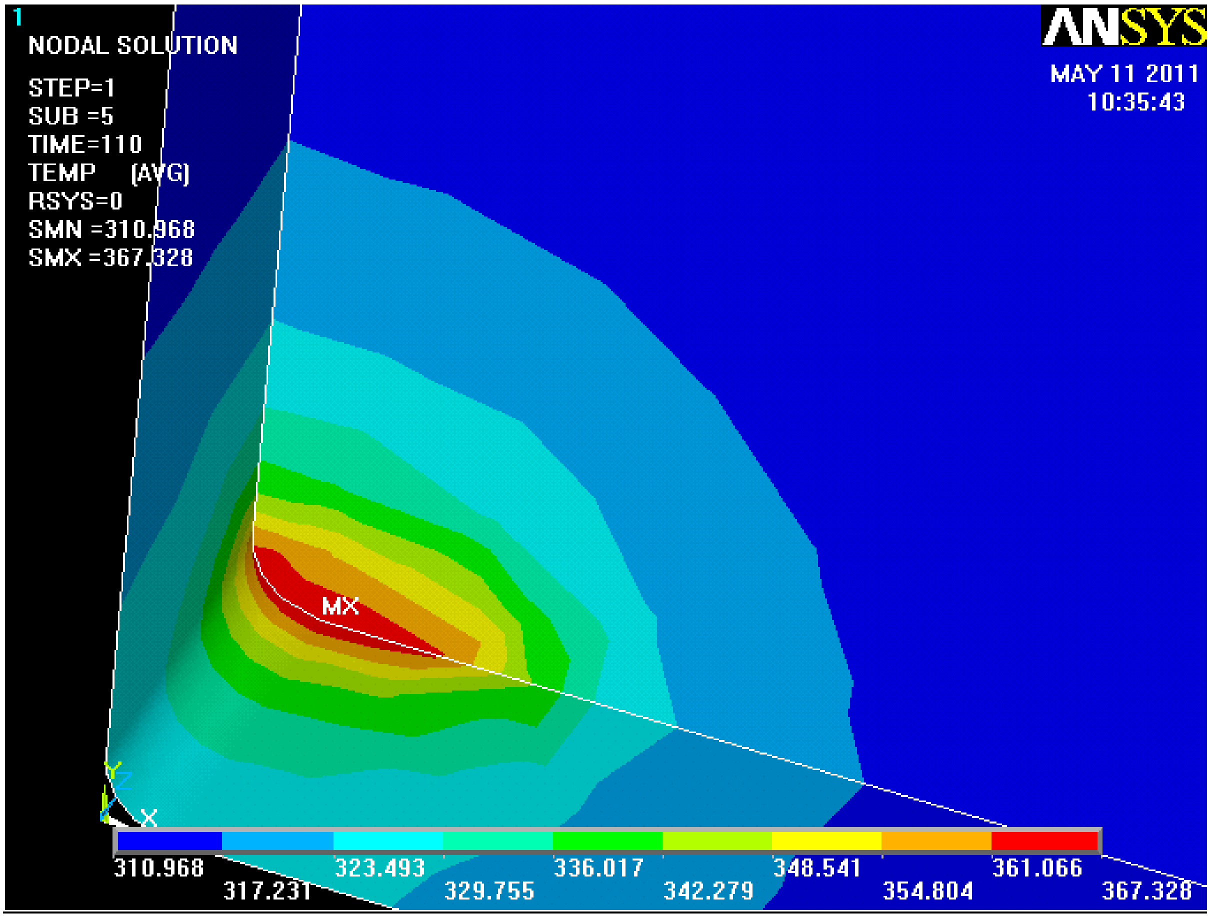
[Volume = 12×12×04 mm^3, Nose radius = 0.8 mm]

Fig 5(a): Temperature profile of uncoated insert



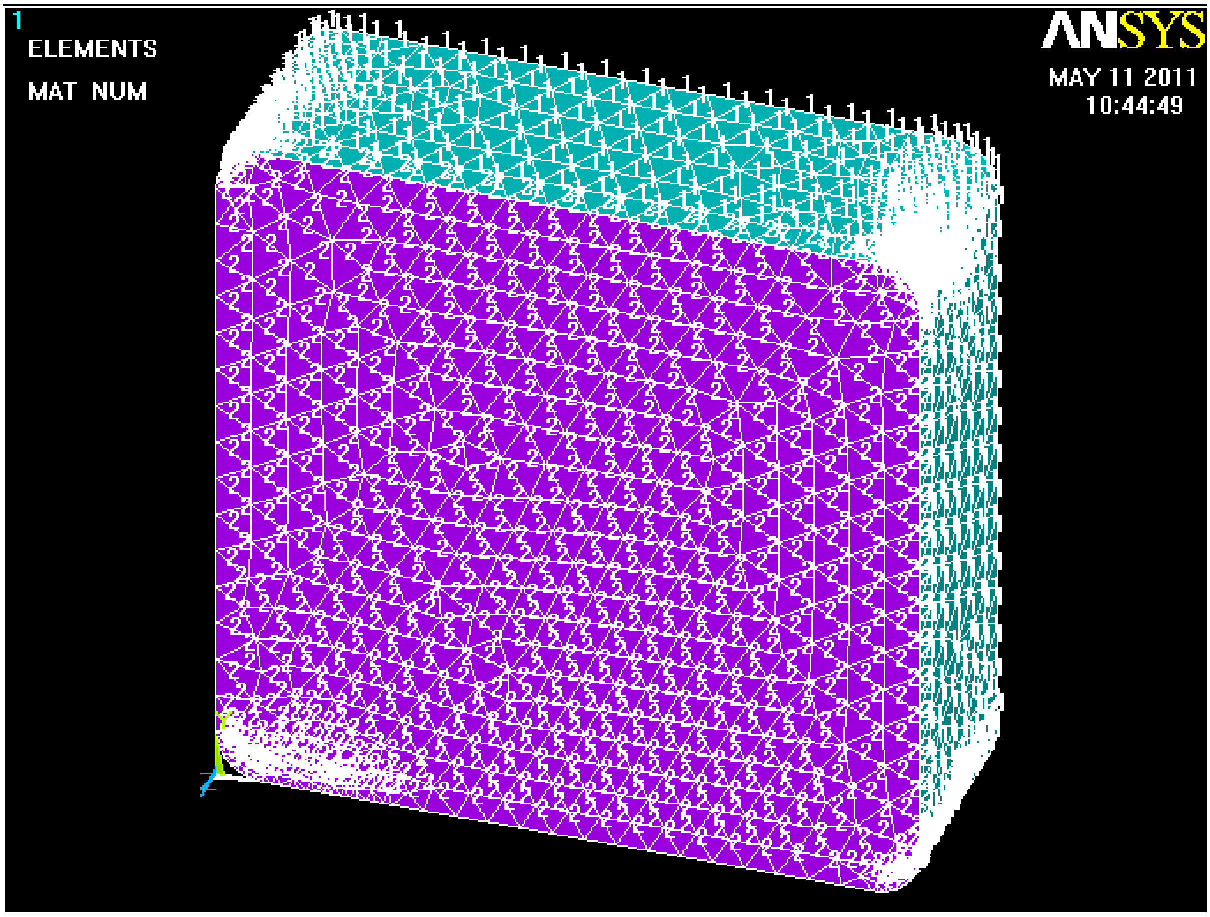
[V_c = 150 m/min, depth of cut = 1.5 mm,f = 0.1 mm/rev, ϕ = 1.5×10^6]

Fig 5(b): Temperature profile of uncoated insert



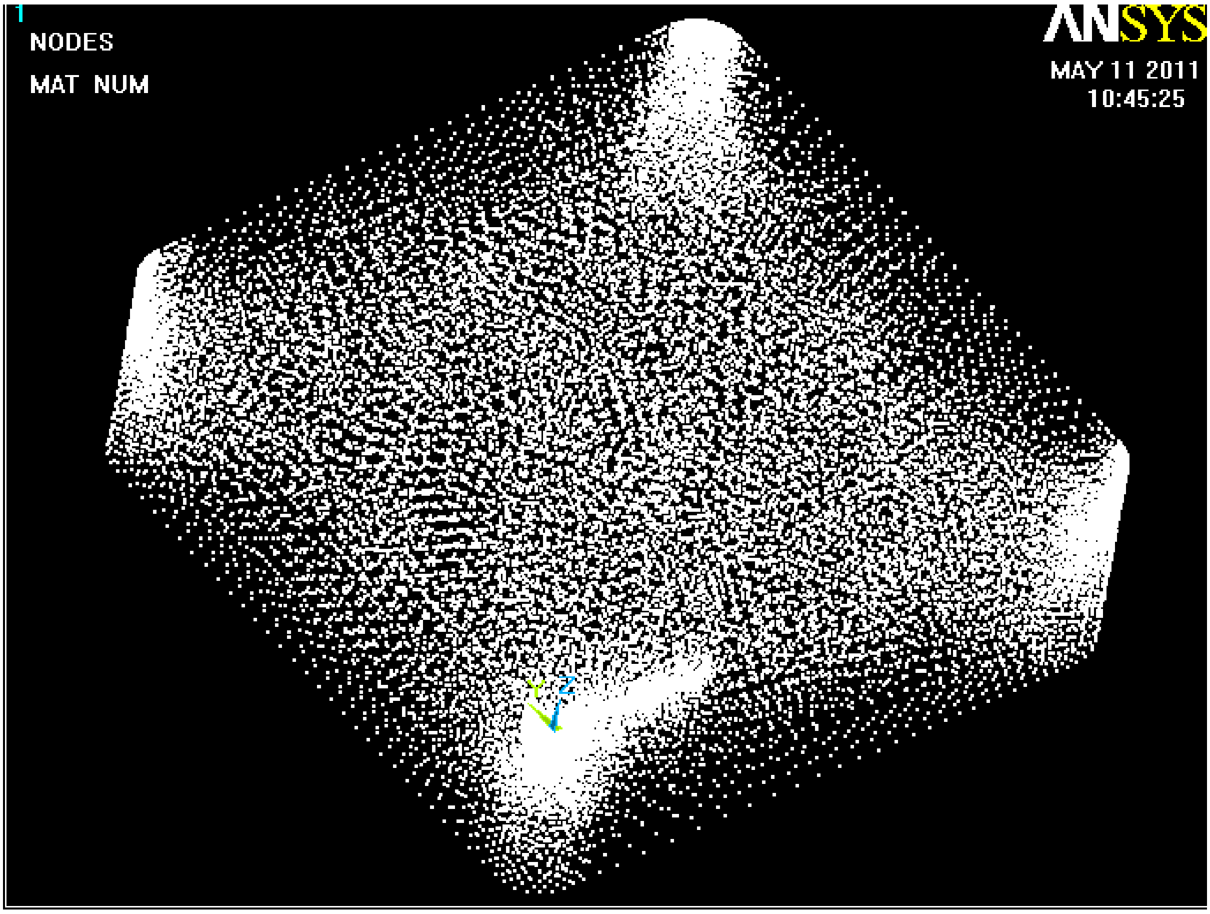
[V_c = 150 m/min, depth of cut = 1.5 mm, f = 0.1 mm/rev, $\phi = 1.5 \times 10^6$]

Fig 6:Meshing of coated tool



[Diagram indicating Area1 and Area 2 :- Area1 shows uncoated surface, Area 2 shows coating]

Fig 7:Nodal points



[Points where temperature is going to be generated]

Fig 8: Element model

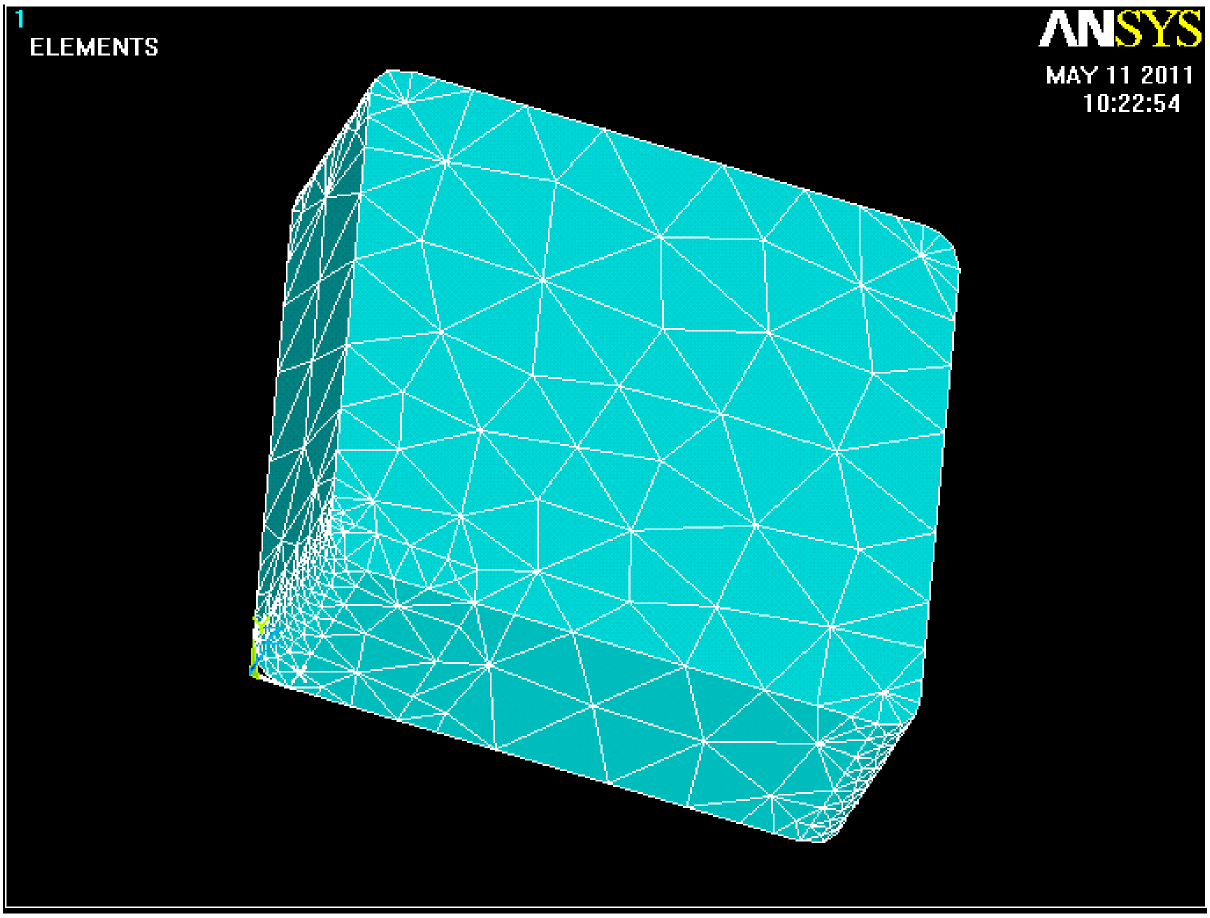
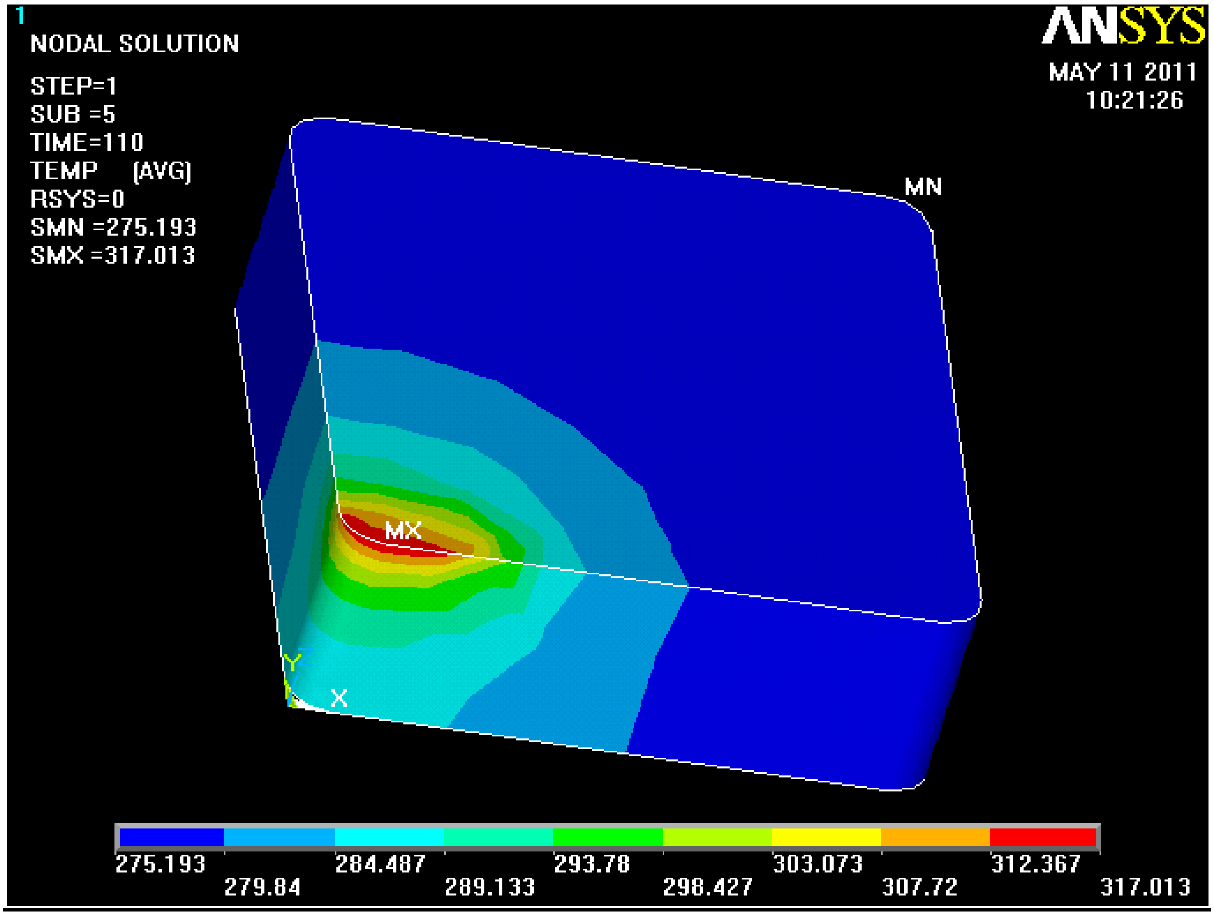
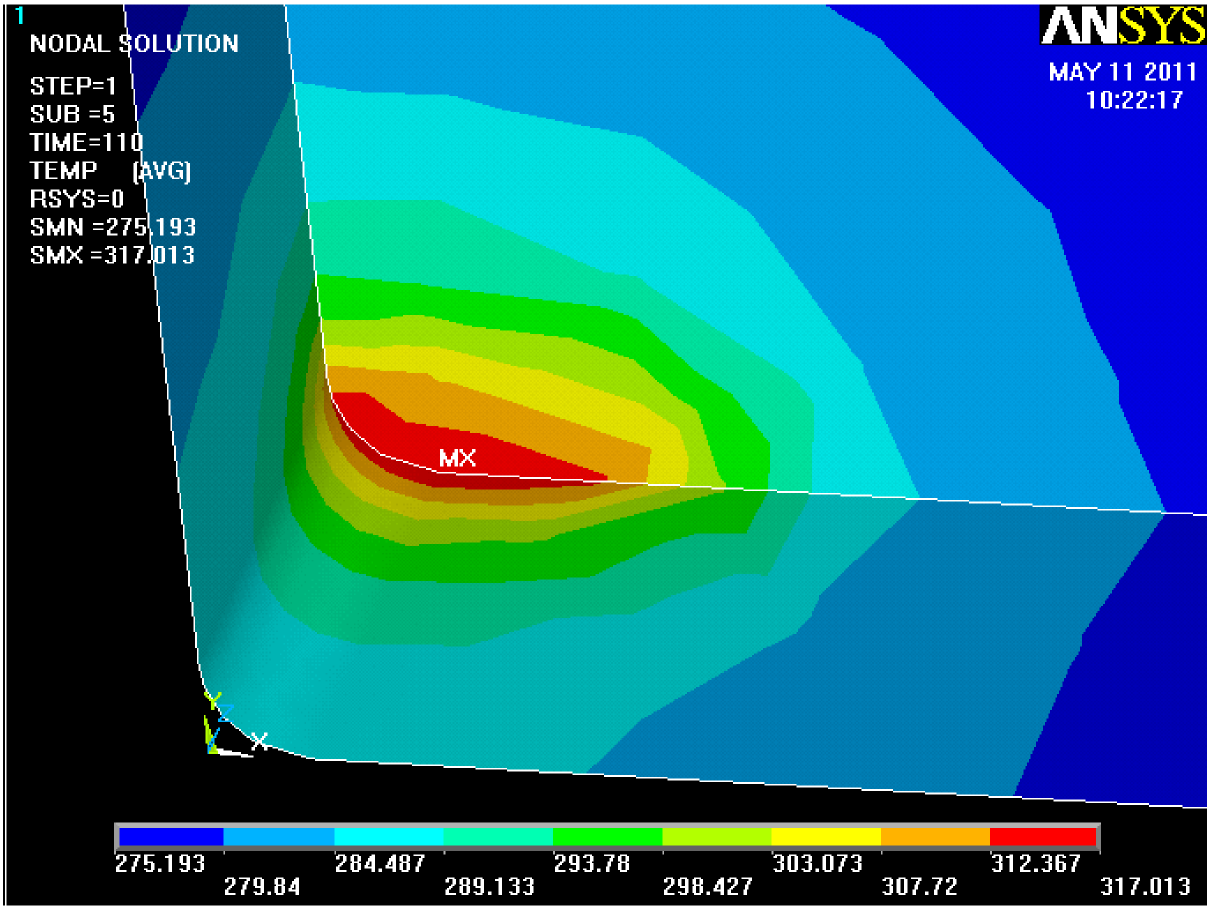


Fig 9(a):Temperature profile of coated insert



[V_c = 150 m/min, depth of cut = 1.5 mm, f = 0.1 mm/rev, $\phi = 1.2 \times 10^6$]

Fig 9(b):Temperature profile of coated insert



[V_c = 150 m/min, depth of cut = 1.5 mm, f = 0.1 mm/rev, $\phi = 1.2 \times 10^6$]

CHAPTER-4

CONLUSIONS

The studies carried out during the execution of the work showed that for a uniform heat source and uniform heat flux was varying with time, considering aconstant contact surface on the chip-tool, the temperature on the tool may be slightly influenced by the coatings when the thermalproperties of the coating are very different from those of the substrate, even for fine 10(µm) coating of TiN cemented carbide.

After solving the solution obtained showed that the temperature at the tip(tool-work piece contact area) was maximum and it goes on decreasing towards the surface and it was also observed that the temperature generated for coated tool is little less in comparison to uncoated cemented carbide insert this shows that the tool life can be increased by placing a layer of coating as the coating material has anti-friction and low thermal conductivity which does not allow heat to penetrate as a result heat is carried away by the chip.

CHAPTER - 5

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