THERMAL ANALYSIS OF SINGLE POINT CUTTING TOOL

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF

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SUBMITTED BY

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STUDENT'S DECLARATION

I **Virwal Vikas Roshanlal,** hereby certify that the work which is being presented in this thesis entitled **"Thermal analysis of single point cutting tool"** is submitted in the partial fulfillment of the requirements for degree of **Master of Technology (Computational Design)** in Department of Mechanical Engineering at **Delhi Technological University** is an authentic record of my own work carried out under the supervision of **Mrs. Navriti Gupta.** The matter presented in this thesis has not been submitted in any other University/Institute for the award of Master of Technology Degree. Also, it has not been directly copied from any source without giving its proper reference.

Signature of Student

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Signature of Supervisor

The Master of Technology Viva-Voce examination of Mr. Virwal Vikas Roshanlal has been held on ………………. and accepted.

Signature of Supervisor **Signature of HOD**

Signature of External Examiner

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CERTIFICATE

This is to certify that this thesis report entitled, **"Thermal analysis of single point cutting tool"** being submitted by **Virwal Vikas Roshanlal (Roll No. 2K14/CDN/18)** at Delhi Technological University, Delhi for the award of the Degree of Master of Technology as per academic curriculum. It is a record of bonafide research work carried out by the student under my supervision and guidance, towards partial fulfillment of the requirement for the award of Master of Technology degree in Computational Design. The work is original as it has not been submitted earlier in part or full for any purpose before.

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ABSTRACT

At various operational cutting speed of lathe, temperature of the tool-chip interface is determined experimentally and modelled. Specifically, analysis is carried out at three different speeds- low, medium and high. Analyses are done of a High Speed Steel and of a Carbide Tip Tool machining process at three different cutting speeds, in order to compare to experimental results produced as part of this study. Heat generation in cutting tool is investigated by varying cutting parameters at the suitable cutting tool geometry. The experimental results show that the factors which are responsible for increasing cutting temperature are cutting speed, depth of cut and feed respectively. Various techniques can be used to measure these cutting temperatures generated during machining.

"Infrared Thermometer" is used for measuring temperature at tool-chip interface. Single point cutting tool has been modelled and analyzed using ANSYS.

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CHAPTER 1: INTRODUCTION

1.1 General

A great amount of heat is generated during machining process and also in different process where deformation of material occurs. The temperature generated at the surface of cutting tool when cutting tool comes in contact with the work piece is cutting tool temperature. Heat is a factor which greatly influences the tool performance of the tool during the operation. The power consumed in metal cutting is mostly converted into heat. Temperature that generated during cutting process is mainly dependent on the contact between the tool and chip, cutting force and friction between the tool and chip. Largely all of the heat produced is transferred to the cutting tool and work piece material and a portion is dissipated through the chip. During machining the temperatures generated in the deformation zone affect both the work piece and tool. The largest source of error in the machining process occurs at high temperatures and contributes to the thermal deformation of the cutting tool and highly influences tool wear, tool life, work piece surface integrity, chip formation mechanism.

Many research works are devoted to develop analytical and numeric models to simulate metal cutting processes and the effects of machining variable such as cutting speed, feed and depth of cut. Numerical models are highly essential in predicting forces, chip formation, strain distributions, strain rate, temperatures and stresses on the cutting edge. To study the influence on the tool edge geometry and cutting conditions on the surface integrity especially on the machining induced stresses advanced simulation techniques are used.

1.2 Objective

Heat is a factor which highly influences the tool performance during the operation. So the knowledge of temperature distribution on the tool is required for improving machining operation. Thus the main objectives of project are as follows:

1. To study and compare the temperature distribution on a single point machining tool made of different materials at different parameters.
2. To model the single point machining tool.
3. To Compare of experimental data.

Different materials are used for cutting tool such as HSS, cemented carbides, diamond etc. and different parameters associated with these tools are cutting speed, feed and depth of cut. So we can select various materials and parameters to study the temperature distribution on the single point machining tool. Also thermal analysis can be carried out by modeling the single point machining tool and analysis in ANSYS and then comparing the results with the experimental data.

CHAPTER 2: LITERATURE

2.1 Thermal facets of metal machining process

The effect of the cutting temperature is mostly detrimental to both the tool and the job. The major portion of the heat is taken away by the chips. But it does not matter because chips are thrown out. So attempts should be made such that the chips take away more and more amount of heat leaving small amount of heat to harm the tool and the job. Due to friction three heat zones are generated.

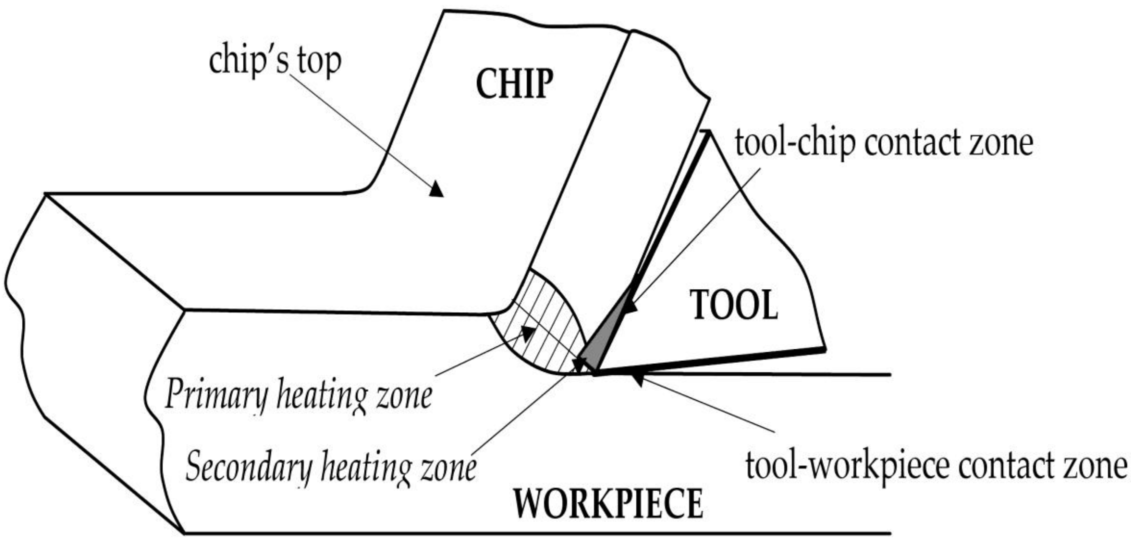


Figure 2.1 Evolution of heat at three zones

In shear zone, maximum heat is produced because of the plastic deformation of metal, and all of this heat is carried away by the chip. A very small amount of this heat (5-10%) is conducted to work piece. In friction zone, the heat is produced due to friction between moving chip and tool face and sightly due to secondary deformation of the built up edge. In work-tool contact zone, the heat is produced due to friction between tool and workpiece. It should be noted that the maximum temperature occurs slightly away from the cutting edge, and not at the cutting edge.

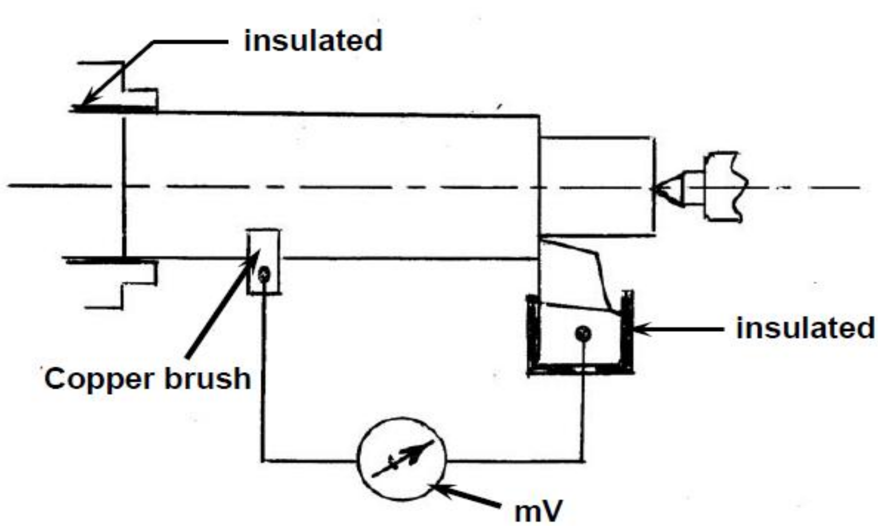
2.2 Tool-Chip interface temperature

It is necessary to measure the temperature of the interface as it decides the tool wear and tool life. There are several techniques from which cutting temperature at tool-chip interface can be measured:

- Thermocouple
- Infrared thermometer
- Infrared photography
- Thermal paints etc

2.2.1 Thermocouple

It constitutes of two dissimilar but electrically conductive metals. It is formed between tool and work piece. Whenever one of the junctions are heated, the difference in temperature at the hot and cold junctions produce a proportional current which is detected and measured by a milli-voltmeter. The hot end of tool and work piece and there Cold ends acts as thermocouple and emf accordingly proportional to temperature difference is produced. The work piece is insulated from the chuck and tailstock centre. The end of work piece is connected to a copper wire which is dipped in mercury bath which enables further connection as cold end. This point and connection from tool provide output for connection to a milli-voltmeter. Calibration curve between tool temperature and emf by laboratory methods can be obtained.



2.2.2 Infrared Thermometer

It is a thermometer which is used to measure the temperature of a point or small region using highly focused infrared laser light. They are called non-contact thermometers or temperature guns, to describe its ability to measure temperature from a distance. By knowing the amount of infrared energy emitted by the object and its emissivity, the object's temperature can often be determined.

Sometimes, at ambient temperatures, readings may subjected to error due to the reflection of radiation from a hotter body i.e the person holding the instrument rather than radiated by the object being measured, and to an incorrect emissivity.

It consists of a lens to focus the infrared thermal radiation on to a detector, which converts the radiant power to an electrical signal that can be displayed in units of temperature after being compensated for ambient temperature. This allows measuring the temperature from a distance without contact with the object.

Figure 2.2 Infrared Thermometer

2.2.3 Infrared Photography

In this technique photographs of the side face of tool-chip while cutting are taken and they are compared with strips of known temperatures.

Figure 2.3 Infrared Photographer

2.3 Factors affecting cutting temperature

The size of shear zone and chip tool contact length and thereby, the area over which heat is distributed are affected due to various factors which leads to maximum temperature generation. Short length of contact of chip with tool results in temperature rise and vica versa. Various factors influencing cutting temperature are:

2.3.1 Tool geometry

The Rake angle of the tool has only a slight influence on the temperature generated. Temperature difference of just 20 °C has been noted for rake angle changes from -10° to +30°. It increases with increase in approach angle and radius of tool.

2.3.2 Cutting fluid

The cutting fluid would not be able to reach the tool- chip interface if the cutting speed is very high and such cutting fluid does not affect the tool-chip interface temperature which ultimately raises the temperature of interface. The outward flowing chip more rapidly would carry away the fluid rather than forcing it in between the tool and the chip.

2.3.3 Cutting conditions

The cutting speed has significant effect on the cutting temperature generated. Depth of cut has little effect and feed the least. The higher the cutting speed, the more heat will be generated by friction. Higher feed rate as well as depth of cut also results in more friction and more temperature generation.

2.3.4 Tool and workpiece materials

The cutting temperature is significantly influenced by the tensile strength and hardness of the workpiece. High tensile strength and hardness require more energy for chip formation and more heat is generated. Materials having higher thermal conductivity produce lower temperature than tools having lower thermal conductivity.

2.4 Literature Review

The purpose of this chapter is to provide a review some of past research efforts related to single-point cutting tool and finite element analysis. A review of other relevant research studies is also provided. The review is done to offer insight to how past research efforts have laid the groundwork for subsequent studies, including the present research effort. The review is detailed so that the present effort can be properly tailored to add to the present body of literature as well as to justify the scope and direction of the present effort.

Rogério Fernandes Brito, Solidônio Rodrigues de Carvalho, Sandro Metrevelle Marcondes de Lima e Silva, João Roberto Ferreira [1] studies the heat influence in cutting tools considering the variation of the coating thickness and the heat flux. K10 and diamond tools substrate with TiN and Al2O3 coatings were used. The numerical methodology utilizes the ANSYS CFX software. Boundary conditions and constant thermo physical properties of the solids involved in the numerical analysis are known. To validate the proposed methodology an experiment is used.

L.B.Abhang and M. Hameedullah [2] developed first and second order mathematical models in terms of machining parameters by using the response surface methodology on the basis of the experimental results. The experiment was turning of EN-31 steel alloy with tungsten carbide inserts using a tool-work thermocouple technique. The results are analysed statistically and graphically. The metal cutting parameters considered are cutting speed, feed rate, depth of cut and tool nose radius.

Yash R. Bhoyar, P. D. Kamble [3] studied the approaches for modelling the turning process for EN-24 type of steel. In this study, a Finite Element Analysis software Deform 3D is used to study the effects of cutting speed, feed rate, and type of alloy steel in temperature behavior. The work-piece is modelled as Elastic-plastic material to take thermal, elastic, plastic effect. Work-piece is represented by a liner model with different length for each condition. Optical Infrared Pyrometer is used for the temperature measurement. This thermal device detect temperature of an object by reckoning the emitted, reflected and transmitted energy by means of optical sensors & detectors and show temperature reading on display panel.

Maheshwari N Patil, Shreepad Sarange [4] presented a methodology in order to determine tool forces and temperatures for use in finite element simulations of metal cutting processes. From the experimental set up, it is clearly observed that as depth of cut increases, the temperature generated in the tool at the tool tip also increases. It is also observed that, as the depth of cut increases, tool forces are also increases. It is main reason of tool failure. It is also observed that tool start vibrating at the depth of cut 2.5 mm. At this condition more heat is dissipated at the tool, due to which tool blunt. Experimental set up is made for force measurement during cutting using dynamometer and analyse the effect on the tool.

S. H. Rathod, Mohd. Razik [5] conducted three analyses using a High Speed Steel and of a Carbide Tip Tool at three different cutting speeds, in order to compare the experimental results produced. The experimental results reveal that the main factors responsible for increasing cutting temperature are cutting speed (v), feed rate (f), and depth of cut (d), respectively. **"**Fluke 62 max IR thermometer**"** is used for measuring temperature at tool-tip interface. Single point cutting tool has been solid modelled by using CAD Modeller Pro/E and FEA carried out by using ANSYS Workbench 14.5.By varying various parameters the effect of those on temperature are compared with the experimental results and FEA results. After comparison nearly 4% variation is found in between the results.

CHAPTER 3: METHODOLOGY

3.1 Experimental Setup

The experiment was conducted under dry conditions on a three jaw centre lathe. Lathe removes undesired material from a rotating work piece in the form of chips with the help of tool which is traversed across the work and can be fed deep into the workpiece. A hole was drilled on the face of work piece to allow it to be supported at the tailstock.

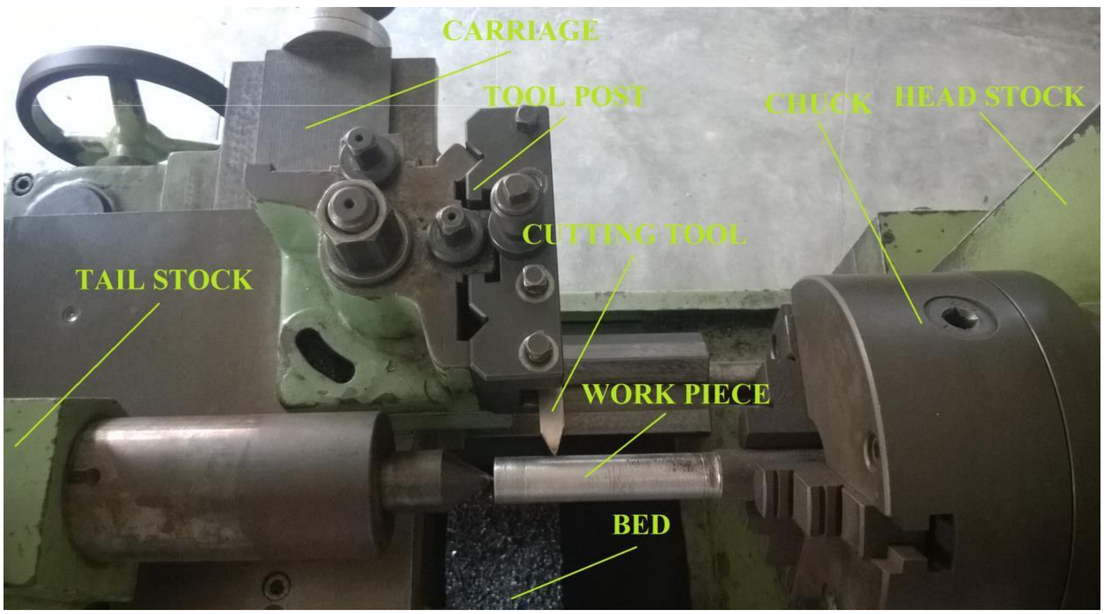


Figure 3.1 Experimental setup

The work piece used as cylindrical rod of Mild Steel (Ø23*63.7 mm). The cutting tool used as High Speed Steel and Carbide Tip Tool (13*101.98 mm). The machining is carried out at different speed and depth of cut. Feed may be kept as constant. The settings of the main machining parameters are summarized in Table

Parameters	Value
Feed (mm/rev)	0.5
Speed (rpm)	150, 420, 710
Depth of cut (mm)	0.1, 0.4, 0.7

We know that maximum temperature is on the tool chip interface during machining. So for measuring this temperature we use a infrared thermometer, a non-contact temperature measurement device. Infrared thermometer detects the infrared energy emitted, transmitted or reflected by all materials (at temperatures above absolute zero) and converts the energy factor into a temperature reading.

Here infrared thermometer (Range -20 °C to +600 °C) is used for measuring the temperature on the cutting tool while machining. Stop watch is used for measuring the time for machining.

3.2 Design of experiments

In randomized complete block design, it is possible to reduce error variance by forming blocks such that the experimental units within the blocks are relatively more homogeneous with respect to the dependent variable of interest to the experimenter. The primary objective of creating the blocks is to eliminate from the experimental error the variation due to the differences between the blocks. The experimental units or the subjects correspond to plots and block comprises of k subjects that are fairly homogeneous with respect to a given variable. Here, each block will consist of k subjects matched on a given variable. Thus, the subjects within any block will be more homogeneous than the subjects that are selected at random. The objective of this local control is to create homogeneity within each of the r blocks and consequently heterogeneity between the blocks. The variation due to block differences is eliminated from the experimental error.

Experiments were designed using Taguchi method which uses an OA(orthogonal array) to study the entire parametric space with a limited number of experiments. In present research two parameter (factors) chosen such as speed and depth of cut. All of them were set at three different levels.

Selection of a particular OA (orthogonal array) is based on the number of levels of various factors. Here, 4 parameters each at 3 levels, therefore Degree of Freedom (DOF) can be calculated as:

(DOF)R = P (L – 1)

Where,   P = number of factors,

L = number of levels

(DOF)R = 4 (3 – 1) = 8

Total DOF of OA should be greater than or equal to the total DOF required for the experiment, here 9 > 8 hence L9 (34) OA is selected (See Table 2). Each machining parameter is assigned to a column of OA and 9 machining parameter combinations are designed. The response variables chosen for the present investigation are: surface roughness and tool tip temperature.

Table 2. L_9 (3^4) Standard orthogonal array.

Experiment no.	Factor A	Factor B	Factor C	Factor D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

3.2.1 Design of experiments for HSS tool

In our case, experimental results are the temperature formed at the cutting tool tip face when machining at different speed and depth of cut. Here we analyse the error using the temperatures obtained for HSS tool at a time 10 seconds after machining starts. The analysis carried out for a significance level of 0.01.The table of subjects of the design of experiment for HSS tool.

Speed (rpm)	Depth of Cut (mm)			Total Sum
	0.1	0.4	0.7	
150	34	70	115	937
	33	72	116	
	32	70	114	
	35	70	115	
	34	72	116	
420	73	96	148	1451
	72	94	146	
	73	95	145	
	71	94	146	
	72	95	145	
710	81	123	165	2144
	82	125	169	
	83	125	168	
	80	124	169	
	82	126	167	
Total Sum	1098	1565	1869	**4532**

The computation procedures of the design of experiment for HSS tool are given below:

i. Correction Term, C = $(4532)^2/45$

= **456422.76**

ii. Total sum of squares, SS_{Total} = $(34)^2 + (33)^2 + \ldots\ldots\ldots + (167)^2 - C$

= 526056 – 456422.76

= **69633.24**

iii. DOC sum of squares, SS_{DOC} = $(1098)^2/15 + (1565)^2/15 + (1869)^2/15 - C$

= 476532.67 – 456422.76

	=	**20109.91**
iv. Speed sum of squares, SS_{Spd}	=	$(937)^2/15 + (1451)^2/15 + (2144)^2/15 - C$
	=	505340.4 – 456422.76
	=	**48917.64**
v. Speed*DOC sum of squares, $SS_{DOC*Spd}$	=	$(168)^2/5 + (361)^2/5 + \ldots\ldots + (838)^2/5 - C - SS_{DOC} - SS_{Spd}$
	=	526010 - 456422.76 - 20109.91- 48917.64
	=	**559.64**
vi. Error sum of squares, SS_{error}	=	SSTotal - (SSDOC -SSSpd- SSDOC*Spd)
	=	69633.24- (20109.91+48917.64+ 559.69)
	=	**46**

3.2.2 Design of experiments for carbide tool

Speed (rpm)	Depth of Cut (mm)			Total Sum
	0.1	0.4	0.7	
150	37	71	118	1006
	39	71	119	
	40	72	120	
	39	73	119	
	38	72	119	
420	75	102	153	1509
	76	102	153	
	77	103	154	
	75	104	153	
	76	104	155	
710	87	127	176	2239
	88	128	175	
	86	127	176	
	86	128	174	
	87	127	175	
Total Sum	1147	1662	1945	**4754**

The computation procedures of the design of experiment for Carbide tool are given below:

i. Correction Term, C	=	$(4754)^2/45$
	=	**502233.69**
ii. Total sum of squares, SS_{Total}	=	$(37)^2 + (39)^2 + \ldots\ldots\ldots + (175)^2 - C$
	=	575588N– 502233.69
	=	**73354.31**
iii. DOC sum of squares, SS_{DOC}	=	$(1147)^2/15 + (1662)^2/15 + (1945)^2/15 - C$
	=	524058.53 – 502233.69
	=	**21824.84**
iv. Speed sum of squares, SS_{Spd}	=	$(1006)^2/15 + (1509)^2/15 + (2239)^2/15 - C$
	=	553487.52 – 502233.69
	=	**51248.84**
v. Speed*DOC sum of squares, $SS_{DOC*Spd}$	=	$(193)^2/5 + (359)^2/5 + \ldots\ldots + (876)^2/5 - C - SS_{DOC} - SS_{Spd}$
	=	575560.4 – 502233.69 – 21824.84 – 51248.84
	=	**253.03**
vi. Error sum of squares, SS_{error}	=	SSTotal - (SSDOC -SSSpd-SSDOC*Spd)
	=	73354.31- (51248.84+21824.84+ 253.03)
	=	**27.6**

3.3 Finite element analysis of cutting tool

Finite element analysis of single point cutting tool is carried out by using ANSYS, a powerful general purpose finite element analysis package. Ansys is a finite element analysis package to numerically solve a wide variety of mechanical, structural and non-structural problems. These problems include static/dynamic structural analysis (both linear and non-linear), heat transfer and fluid problems as well as acoustic and electromagnetic problems.

In this project we carried out thermal analysis of a single point cutting tool using Ansys. Thermal analysis is used for determining the temperature distribution and quantities such as thermal distribution, amount of heat loss or gain, thermal gradient, thermal fluxes etc.

The problem analysing here is basically a multiphysics coupling (structural - thermal). Usually, physics coupling is ignored or simplified. Simulation engineers are usually using single-physics. Because coupled analyses are more computationally intensive. However, coupled analyses provide more realistic results. ANSYS Workbench is designed to make it easier to simulate multiphysics coupling.

Regarding coupling methodology, multiphysics coupling can be classified as two. They are sequential coupling and direct coupling. In sequential coupling,

coupling is considered in one direction only whereas in direct coupling, coupling is considered in both directions. 1-way thermal to structural coupling can be easily defined in Workbench. However, 1-way structural to thermal coupling is not possible in ANSYS. Direct coupling is available in ANSYS, but not in the Workbench interface. To represent direct coupling, APDL commands should be used. User must select coupled-field elements. 1-way structural to thermal coupling is usually represented by direct coupling as well. It's easier than export the deformed mesh and results from the structural analysis to the thermal analysis.

ANSYS includes the coupled elements such as SOLID5, PLANE13, SOLID98, PLANE223, SOLID226, SOLID227 etc.

The analysis procedure consists of three phases such as pre-processing, solution and post processing. The Pre-processing phase consists of defining geometry, material, mesh, load and boundary conditions. The solution phase consists of defining analysis settings and convergence. The post processing phase consists of obtaining results.

3.3.1 Modelling of cutting tool

The single point cutting tool has been solid modelled by using SOLIDWORKS, a solid modelling computer aided design software. Solidworks is a solid modeller, and utilizes parametric feature-based approach to create models and assemblies. Parameters refer to constraints whose values determine the shape of or geometry of the model or assembly. Parameters can be either numeric parameter, such as tangent, parallel, concentric, horizontal or vertical etc. numeric parameters can be associated with each other through the use of relations.

The main dimensions of the tool and work piece is summarized below in Table:

	Cutting Tool	Work piece
Material	High Speed Steel Tungsten carbide	Mild Steel
Cross-section	13*101.98 mm Side and end cutting edge angles: 30° End relief angle: 20°	Ø23*63.7 mm

3.3.1.1 Modelling of HSS tool

The single point cutting tool (HSS) has been solid modelled by using SOLIDWORKS.

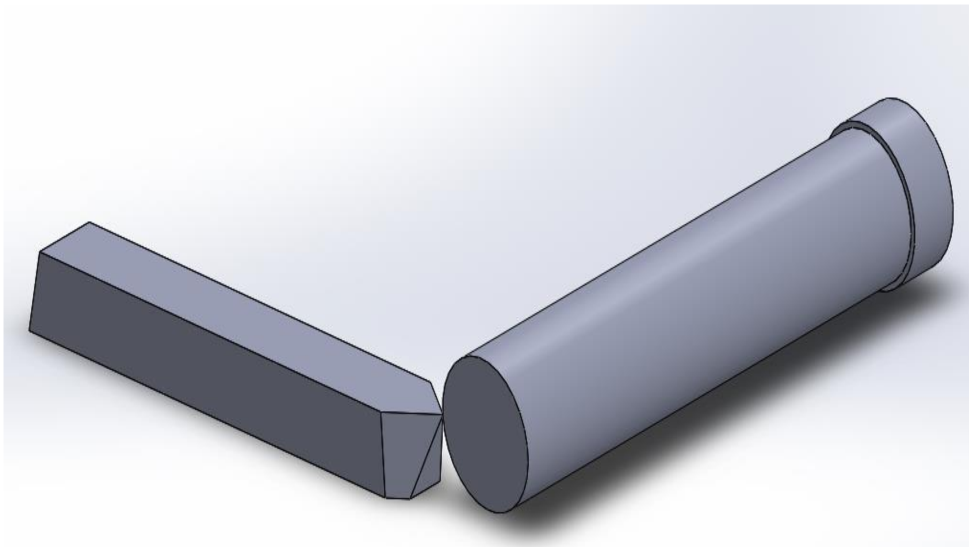


Figure 3.2 3D Model of HSS tool

3.3.1.2 Modelling of carbide tool

The single point cutting tool (Carbide) has been solid modelled by using SOLIDWORKS.

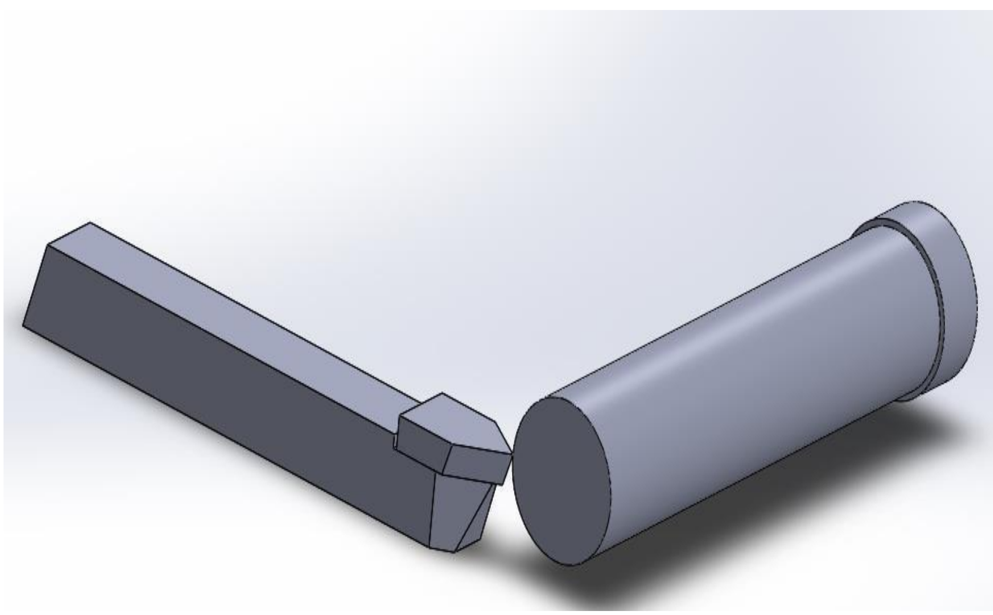


Figure 3.3 3D Model of Carbide tool

3.3.2 Finite element analysis of HSS tool

3.3.2.1 Geometry

The geometry is modelled using SOLIDWORKS and then it is imported into ANSYS WORKBENCH

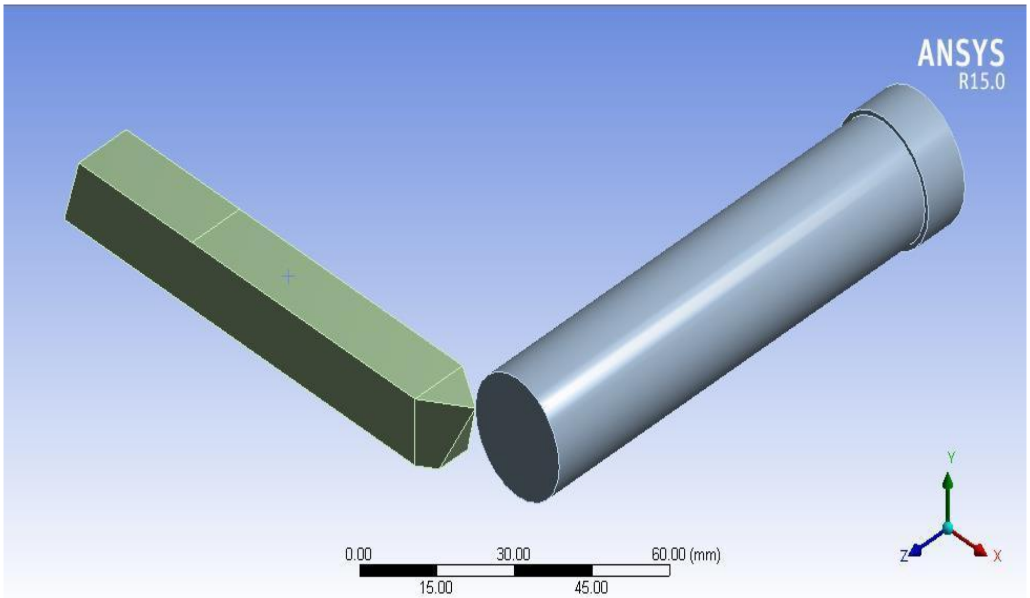


Figure 3.4 Geometry of HSS tool

3.3.2.2 Material

The cutting material used is T15 super high speed steel. The temperature dependent properties of tool are summarised below in Table and the other properties are also given below.

Sl No	Temperature (°C)	Density (kg/m^3)	Thermal Conductivity(w/mK)	Specific Heat(J/kgK)
1	0	8190	19	418.68
2	50	8186	20	420
3	75	8183	22	425.36
4	100	8179	23	430.45
5	120	8177	25	436.25
6	175	8172	26	442.57
7	200	8168	28	445.68
8	220	8162	30	448.35

- Coefficient of thermal expansion: $1.01*10^{-5}$ °C^{-1} (Ref temp: 22 °C)
- Young"s modulus: $2.07*10^{5}$ Mpa
- Poisson"s ratio: 0.25

The work piece material used is mild steel. The various properties of mild steel are given below,

- Density: 7850 kg/m^{3}
- Coefficient of thermal expansion: $1.2*10^{-5}$ °C^{-1} (Ref temp:20 °C)
- Young"s modulus: $2*10^{11}$ Pa
- Poisson"s ratio: 0.3
- Thermal conductivity: 60.5 w/mK
- Specific heat: 434 J/kgK

Next step is, An APDL command is used to change element type. Element must be chosen accordingly to mesh geometry. Here "Brick 20 node SOLID 226" is used as work piece element and "Tetra 10 node SOLID227" is used as cutting tool element.

The SOLID226 element has twenty nodes with up to five degrees of freedom per node. Structural capabilities include elasticity, plasticity, viscoelasticity, viscoplasticity, creep, large strain, large deflection, stress stiffening effects, and prestress effects. Thermoelectric capabilities include Seebeck, Peltier, and Thomson effects, as well as Joule heating. In addition to thermal expansion, structural-thermal capabilities include the piezocaloric effect in dynamic analyses. The Coriolis Effect is available for analyses with structural degrees of freedom. The thermoplastic effect is available for analyses with structural and thermal degrees of freedom. The diffusion expansion effect is available for analyses with structural and diffusion degrees of freedom.

The SOLID227 element has twenty nodes with up to five degrees of freedom per node. Structural capabilities include elasticity, plasticity, viscoelasticity, viscoplasticity, creep, large strain, large deflection, stress stiffening effects, and prestress effects. Thermoelectric capabilities include Seebeck, Peltier, and Thomson effects, as well as Joule heating. In addition to thermal expansion, structural-thermal capabilities include the piezocaloric effect in dynamic analyses. The Coriolis Effect is available for analyses with structural degrees of freedom. The thermoplastic effect is available for analyses with structural and thermal degrees of freedom. The diffusion expansion effect is available for analyses with structural and diffusion degrees of freedom.

The APDL command used for changing the element type is given below.

ET, matid, SOLID 226: This changes element type to SOLID226.
KEYOPT, mat id, 1, 11: This defines Thermal-Structural behaviour.
ET, matid, SOLID227: This changes element type to SOLID227.
KEYOPT, mat id, 1, 11: This defines Thermal-Structural behaviour.

3.3.2.3 Meshing

The method used for meshing the cutting tool is "Hex dominant method" giving a body sizing of 1.5 mm and for work piece is "Multi zone method" giving a body sizing of 2.5 mm. The meshed geometry is given in Figure

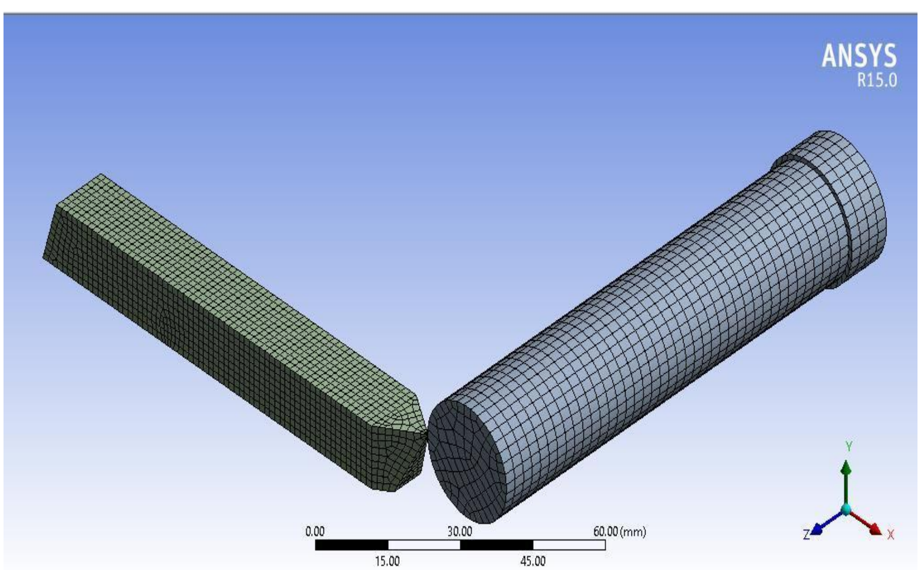


Figure 3.5 Meshed Geometry of HSS tool

For mesh convergence study, different mesh element sizes are provided for cutting tool as well work piece. The objective of this study is to reduce the error as well as the computational time. The summarized study is given below in Table

Work piece element size [mm]	Cutting Tool element size [mm]	Number of nodes	Number of Elements	Max FEA Temp [°C]	Max Expt Temp [°C]	%error	Computational Time [Hrs]
4	3	13231	2971	80.2	**67.6**	15.71	74.6
3.5	2.5	18678	3975	78.9		14.32	102.2
3	2	25345	5340	72.1		6.241	105.65
2.5	**1.5**	**49197**	**11059**	**69**		**2.03**	**115.94**
2	1	144399	36793	68.8		1.744	140.45
1.5	0.5	725465	183714	68.7		1.601	163.2

3.3.2.4 Load and Boundary conditions

Structural loads and boundary conditions are applied as usual. Here we have four conditions.

- Cylindrical support for work piece
- Longitudinal displacement of tool (63.7 mm)
- Tangential displacement of tool (0.1 mm, 0.4 mm, 0.7 mm)
- Speed of rotation of work piece (150 rpm, 420 rpm, 710 rpm)

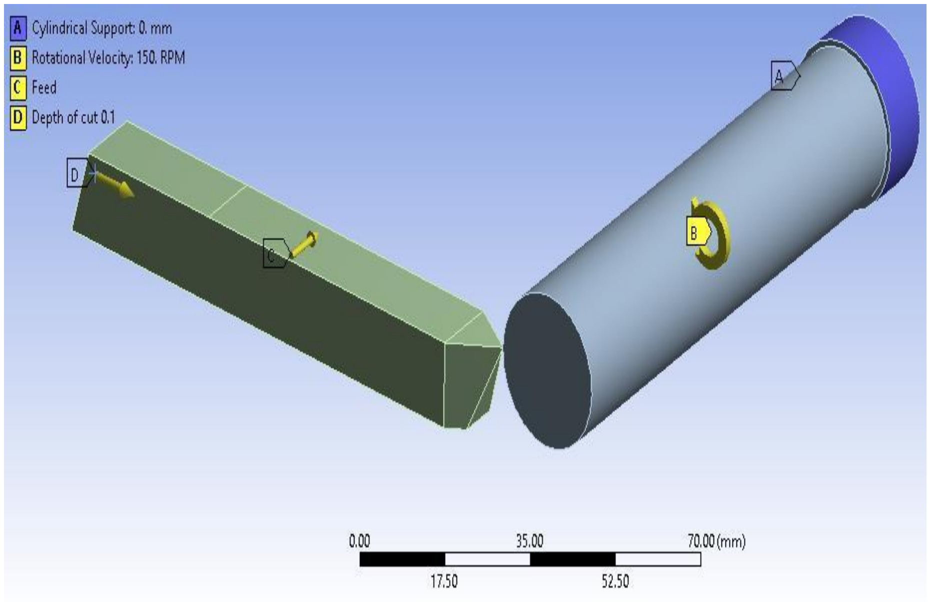


Figure 3.6 Load and boundary conditions for HSS tool

Here the model is defined as frictional model. That is heat is generated due to contacting friction when machining. So we define a contact element and target element. In this case, cutting tool is contact element (CONTA175) and work piece is the target element (TARGE170) and a node to surface contact is obtained. The coefficient of friction is given as 0.5 and contact behaviour is asymmetric.

CONTA175 may be used to represent contact and sliding between two surfaces (or between a node and a surface, or between a line and a surface) in 2-D or 3-D. The element is applicable to 2-D or 3-D structural and coupled field contact analyses. This element is located on the surfaces of solid, beam, and shell elements. 3D solid and shell elements with midside nodes are supported for bonded and no separation contact. For other contact types, lower order solid and shell elements are recommended.

Contact occurs when the element surface penetrates one of the target segment elements (TARGE169, TARGE170) on a specified target surface. Coulomb friction, shear stress friction, user-defined friction with the USERFRIC subroutine, and user-defined contact interaction with the USERINTER subroutine are allowed. This element also allows separation of bonded contact to simulate interface delamination.

The below APDL commands are for changing the behaviours of contact elements.

KEYOPT, cid, 1, 1: This includes displacement and temperature degrees of freedom.
KEYOPT, cid, 5, 3: This close gap or reduce penetration.
KEYOPT, cid, 9, 1: Exclude both initial penetration and gap.
KEYOPT, cid, 10, 2: Contact stiffness update on each iteration based.

The below APDL commands are for modifying the real constant sets.

RMODIF, cid, 9, 500e6: This changes maximum frictional stress in N/m^2
RMODIF, cid, 14, 1e4: This changes thermal contact conductance between tool and work piece in w/m^2 °C
RMODIF, cid, 15, 1: This includes a real constant FHTG , the fraction of frictional dissipated energy converted into heat.
RMODIF, cid, 18, 0.95: This gives fraction of frictional dissipated energy converted into heat.

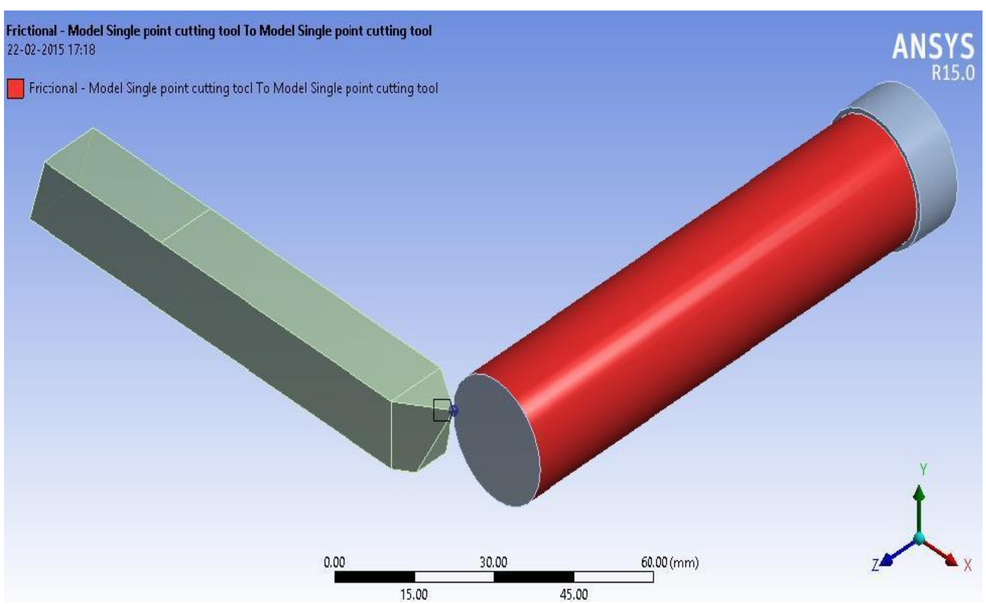


Figure 3.7 Frictional model of HSS tool

3.3.2.5 Analysis settings

For time step controls, program controlled (automatic) time step are used.

The step end times are 49 sec, 17.5 sec and 10.0 sec. The initial time step may be given as 0.49 sec, 0.175 sec and 0.10 sec. The ranges for time step are given as,

Minimum time step: $4.9*10^{-2}$ sec, $1.75*10^{-2}$ sec, $1.0*10^{-2}$ sec.

Maximum time step: 4.9 sec, 1.75 sec, 1.0 sec.

For non-linear control, Unsymmetric Newton Raphson method is used.

The below APDL commands are for setting thermal boundary conditions and analysis settings.

/SOLU: To enter into solution stage

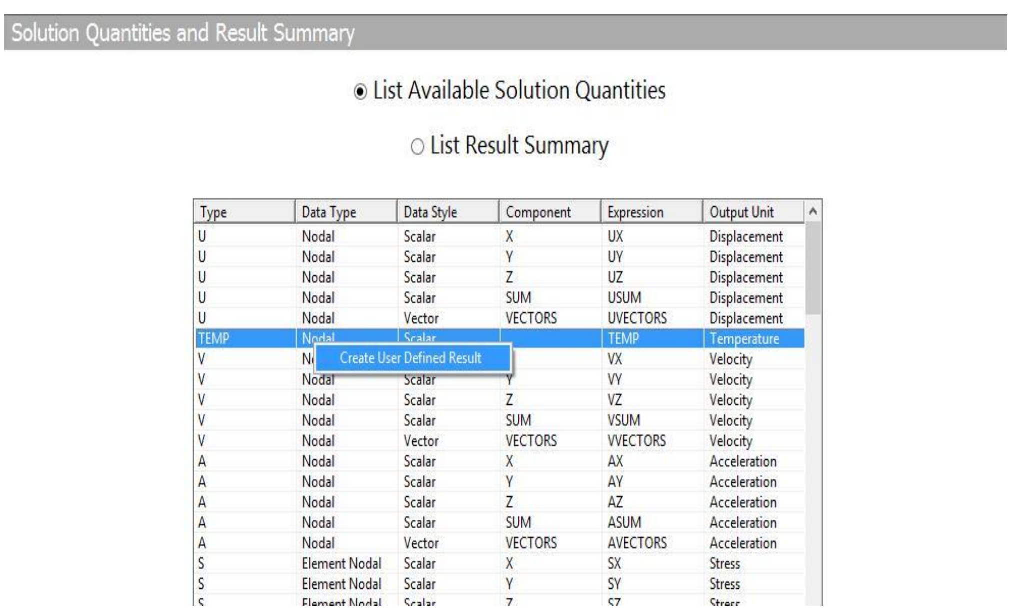
TREF, 22: Setting reference temperature to 22 °C.

SF, conv-face, CONV, 200, 22: To give convection condition with its film coefficient and bulk temperature.

ALLSEL: Select all entities.

TRNOPT, full: Switching transient analysis option to full method which is more accurate.

3.3.2.6 Solution



3.3.3 Finite element analysis of Carbide tool

3.3.3.1 Geometry

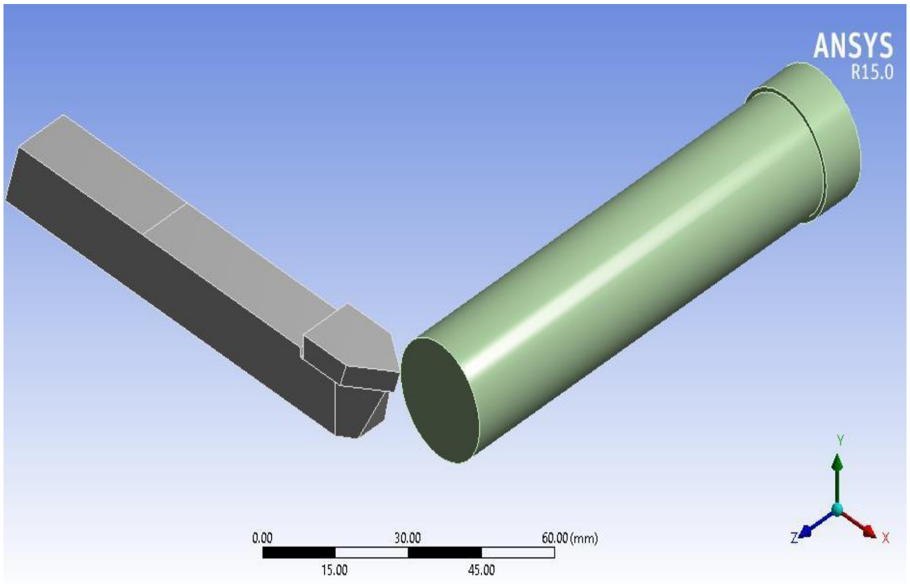


Figure 3.8 Geometry of Carbide tool

3.3.3.2 Material

The cutting tool tip material used is C20 Tungsten Carbide. The temperature dependent properties of tool are summarised below in Table 3.8 and the other properties are also given below.

Sl No	Temperature (C)	Density (g/cm^3)	Thermal Conductivity(w/mK)	Specific Heat(J/kgK)
1	0	14.90	84	210
2	50	14.70	84.5	212.3
3	75	14.67	85	213.5
4	100	14.62	85.5	214
5	150	14.58	87	215.8
6	175	14.55	87.4	216.8
7	200	14.45	87.8	217.3
8	230	14.40	88.2	218

- Coefficient of thermal expansion: $5.2*10^{-6}$ °C^{-1} (Ref temp: 25 °C)
- Young‟s modulus: $6.1*10^{5}$ Mpa
- Poisson‟s ratio: 0.25

The shank material used for the tool is medium carbon steel. The various properties of medium carbon steel are given below,

- Density: 7870 kg/m^{3}
- Coefficient of thermal expansion: $1.3*10^{-5}$ C^{-1} (Ref temp: 25 °C)
- Young‟s modulus: $2*10^{5}$ Mpa
- Poisson‟s ratio: 0.29
- Thermal conductivity: 60.5 W/mK
  Specific heat: 434 J/kg/K

The work piece material used is mild steel. The various properties of mild steel are given below,

- Density: 7850 kg/m^{3}
- Coefficient of thermal expansion: $1.2*10^{-5}$ °C^{-1} (Ref temp: 20 °C)
- Young‟s modulus: $2*10^{11}$ Pa
- Poisson‟s ratio: 0.3
- Thermal conductivity: 60.5 w/mK
  Specific heat: 434 J/kgK

Next step is, An APDL command is used to change element type. Element must be chosen accordingly to mesh geometry. Here „Brick 20 node SOLID 226‟ is used as work piece element and „Tetra 10 node SOLID227‟ is used as cutting tool element.

The APDL command used for changing the element type is given below.

ET, matid, SOLID 226: This changes element type to SOLID226.
KEYOPT, mat id, 1, 11: This defines Thermal-Structural behaviour.
ET, matid, SOLID227: This changes element type to SOLID227.
KEYOPT, mat id, 1, 11: This defines Thermal-Structural behaviour.

3.3.3.3 Meshing

The method used for meshing the cutting tool is "Hex dominant method" giving a body sizing of 1.5 mm and for work piece is "Multi zone method" giving a body sizing of 2.5 mm. The meshed geometry is given in Figure

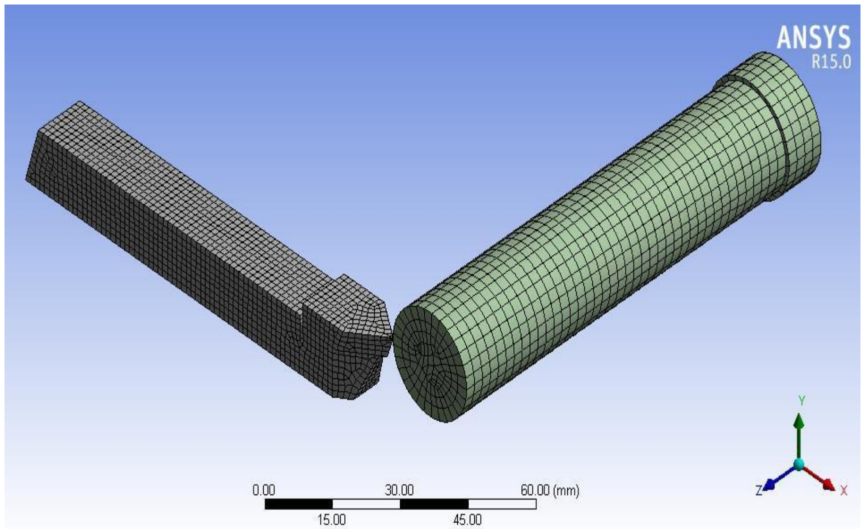


Figure 3.9 Meshed Geometry of Carbide tool

3.3.3.4 Load and Boundary conditions

Structural loads and boundary conditions are applied as usual. Here we have four conditions.

- Cylindrical support for work piece
- Longitudinal displacement of tool (63.7 mm)
- Tangential displacement of tool (0.1 mm, 0.4 mm, 0.7 mm)
- Speed of rotation of work piece (150 rpm, 420 rpm, 710 rpm)

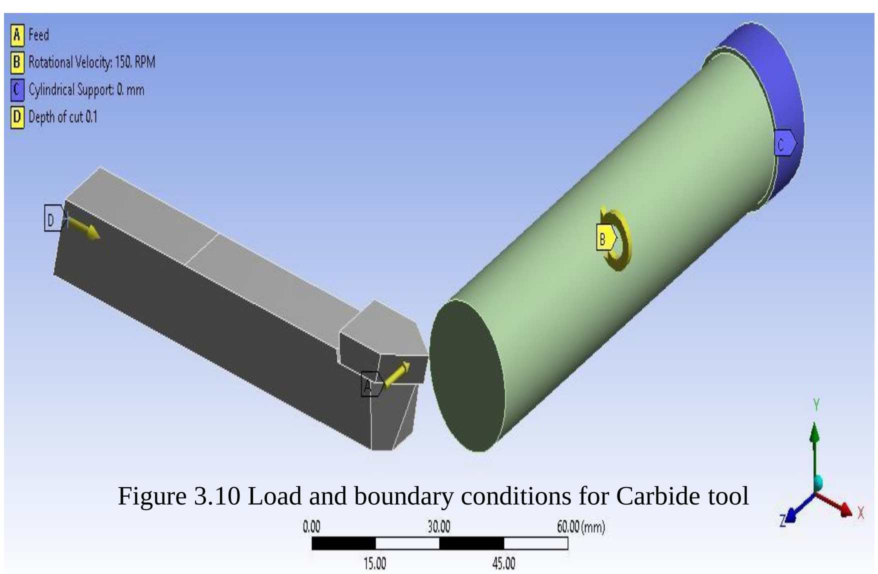


Figure 3.10 Load and boundary conditions for Carbide tool

Here the model is defined as frictional model. That is heat is generated due to contacting friction when machining. So we define a contact element and target element. In this case, cutting tool is contact element (CONTA175) and work piece is the target element (TARGE170) and a node to surface contact is obtained. The coefficient of friction is given as 0.3 and contact behaviour is asymmetric.

The below APDL commands are for changing the behaviours of contact elements.

KEYOPT, cid, 1, 1: This includes displacement and temperature degrees of freedom

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KEYOPT, cid, 9, 1: Exclude both initial penetration and gap.

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RMODIF, cid, 15, 1: This includes a real constant FHTG , the fraction of frictional dissipated energy converted into heat.

RMODIF, cid, 18, 0.95: This gives fraction of frictional dissipated energy converted into heat.

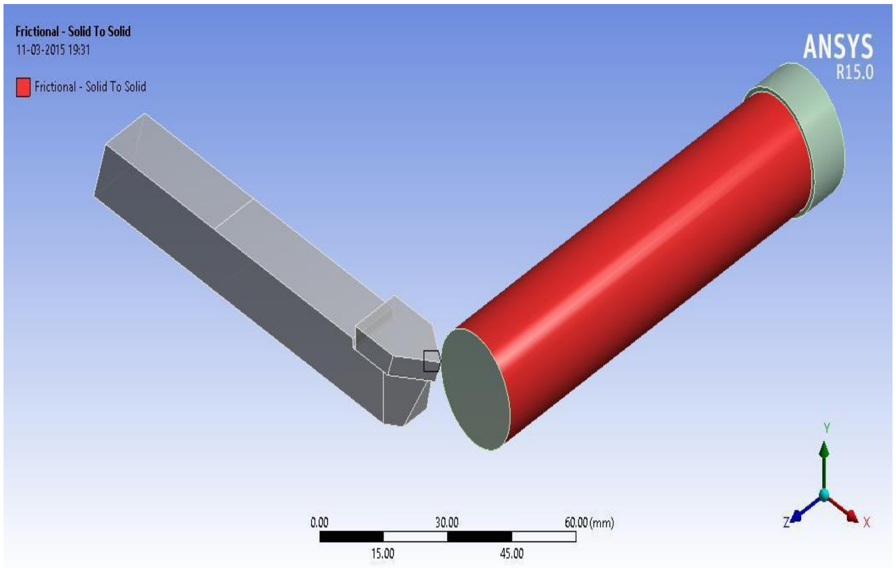

Figure 3.11 Frictional model of Carbide tool

3.3.3.5 Analysis settings

For time step controls, program controlled (automatic) time step are used.

The step end times are 49 sec, 17.5 sec and 10.0 sec.

The initial time step may be given as 0.49 sec, 0.175 sec and 0.10 sec.

The ranges for time step are given as,

Minimum time step: $4.9*10^{-2}$ sec, $1.75*10^{-2}$ sec, $1.0*10^{-2}$ sec.
Maximum time step: 4.9 sec, 1.75 sec, 1.0 sec.
For non-linear control, Unsymmetric Newton Raphson method is used.

The below APDL commands are for setting thermal boundary conditions and analysis settings.

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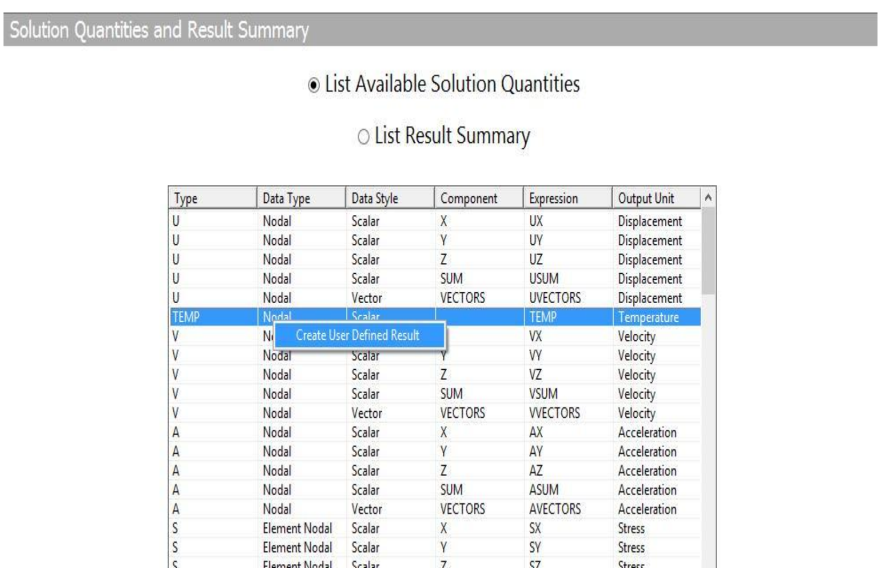
TREF, 22: Setting reference temperature to 22 °C.

SF, conv-face, CONV, 200, 22: To give convection condition with its film coefficient and bulk temperature.

ALLSEL: Select all entities.

TRNOPT, full: Switching transient analysis option to full method which is more accurate.

3.3.3.6 Solution



CHAPTER 4: RESULTS AND DISCUSSION

4.1 Variance of the design of experiment for HSS tool

The analysis of variance of the design of experiment for HSS tool are summarized in table

Source of variation	Sum of squares	DOF	Mean of squares	F_{Static}	$F_{Critical}$	P	% C
Speed	48917.64	2	244458.82	19108.45	5.25	< 0.01	70.25
DOC	20109.91	2	10054.96	7855.44	5.25	< 0.01	28.88
Speed*DOC	559.64	4	139.92	109.31	3.89	< 0.01	0.80
Error	46	36	1.28				0.066
Total Sum	69633.24	44					100

From the ANOVA table, it is clear that speed is the most significant parameter followed by depth of cut. However the interaction of speed*depth of cut has least effect.

4.2 Variance of design of experiment for Carbide tool

The analysis of variance of the design of experiment for Carbide tool are summarized in table

Source of variation	Sum of squares	DOF	Mean of squares	F_{Static}	$F_{Critical}$	P	% C
Speed	51248.84	2	25624.42	33278.47	5.25	< 0.01	69.86
DOC	21824.84	2	10912.42	14171.97	5.25	< 0.01	29.75
Speed*DOC	253.03	4	63.26	82.16	3.89	< 0.01	0.35
Error	27.6	36	0.77				0.038
Total Sum	73354.31	44					100

From the ANOVA table, it is clear that speed is the most significant parameter followed by depth of cut. However the interaction of speed*depth of cut has least effect.

4.3 Percentage difference between maximum temperature obtained through experiment and FEA (finite element analysis) for HSS tool

Sl No	Feed (mm per rev)	Speed (rpm)	Machining Time (sec)	Depth of Cut (mm)	Max Expt Temp (°C)	Max FEA Temp (°C)	Percentage Difference (%)
1	0.52	150	49	0.1	67.6	69	2.03
2				0.4	104.4	108	3.33
3				0.7	152.4	155	1.68
4		420	17.5	0.1	78.4	77	1.79
5				0.4	109.6	112	2.14
6				0.7	158.6	160	0.875
7		710	10	0.1	81.6	84	2.85
8				0.4	124.6	127	1.89
9				0.7	167.6	170	1.41

4.4 Percentage difference between maximum temperature obtained through experiment and FEA (finite element analysis) for Carbide tool

Sl No	Feed (mm per rev)	Speed (rpm)	Machining Time (sec)	Depth of Cut (mm)	Max Expt Temp (°C)	Max FEA Temp (°C)	Percentage Difference (%)
1	0.52	150	49	0.1	75.4	77.02	2.10
2				0.4	111.8	115.03	2.81
3				0.7	159.4	162.05	1.64
4		420	17.5	0.1	82.8	85.025	2.62
5				0.4	119.2	117.04	6.36
6				0.7	167.6	169.06	0.86
7		710	10	0.1	86.8	90.027	3.58
8				0.4	127	129.04	1.58
9				0.7	175.2	174.06	0.65

CHAPTER 5: CONCLUSION

5.1 Summary

Temperature at tool-chip interface of a single point cutting tool of High Speed Steel and Carbide Tip is determined, generated in a machining process at slow speed, medium speed and at high speed. Fluke IR Thermal Imager is used for measuring temperature at tool-chip interface. Single point cutting tool has been solid modelled by using SOLIDWORKS 2013 and Finite Element Analysis carried out by using ANSYS Workbench 15.

By varying speed and depth of cut, the effect of those on temperature are compared with the experimental results and FEA results. After comparison nearly 7% variation is found in between the results. Also the results reveal that the main factors responsible for increasing cutting temperature are cutting speed (v) and depth of cut(d) respectively.

5.2 Conclusion

1. Using ANOVA table, the speed is the most significant parameter followed by depth of cut for rising the temperature during machining. The percentage contribution obtained for HSS tool and Carbide tool as,

HSS tool - Speed: 70.25%, Depth of cut: 28.88%

Carbide tool - Speed: 69.86%, Depth of cut: 29.75%

2. Comparing the results obtained from experiment and finite element analysis, the results were validated. The difference in temperature obtained for HSS tool and Carbide tool as,

HSS tool - not more than 4%

Carbide tool - not more than 7%

3. It can be observed that an increase of the cutting speed produces an increase of the cutting temperature. This result is due to the fact that an increase of the cutting speed produces an increase of the cutting forces. More energy is needed to remove the material away increasing the cutting temperature.

4. It can be observed that an increase of the depth of cut produces an increase of the cutting temperature. When a material is plastically deformed, most of the energy is turned into heat since the material is subject to extremely severe deformations; being the elastic deformation the ones that represents a small part of the total deformation. Hence, the increase of depth of cut represents a bigger compression in the tool-work piece interface this will increase the energy supplied to the system during the cut of the material.

5.In both experiment and finite element analysis, the temperature formed during machining is more in carbide tool than in HSS tool. So the chances for tool wear or tool failure is more in carbide tool than in HSS tool at same cutting conditions.

5.3 Scope for future work

In this study, three different analyses are comparing to an experimental measurement of temperature in a machining process at slow speed, medium speed and at high speed. In addition, three analyses are done of a High Speed Steel and of a Carbide Tip Tool with Mild Steel machining process at three different cutting speeds and depth of cuts. Similarly we can use this analysis procedure for Different cutting tool and work piece combinations or for different tool geometries. Also we can analyse the machining by changing cutting conditions.

In this study, the finite element analysis was carried out by using ANSYS. It takes more computation time for the analysis. So for the same analysis we can use other simulation software for less computation time and better results.

CHAPTER 6: REFERENCES

1) Rogério Fernandes Brito, Solidônio Rodrigues de Carvalho, Sandro Metrevelle Marcondes de Lima e Silva, João Roberto Ferreira, 2009.Thermal analysis in coated cutting tools.International Communications in Heat and Mass Transfer 36, 314–321.

2)L.B.ABHANG and M. HAMEEDULLAH, 2010. Chip-Tool Interface Temperature Prediction Model for Turning Process International Journal of Engineering Science and Technology Vol. 2(4), 382-393.

3) Yash R. Bhoyar, Asst. Prof. P. D. Kamble, 2013. Finite element analysis on temperature distribution in turning process using deform-3D International Journal of Research in Engineering and Technology ISSN: 2319-1163.

4) Maheshwari N Patil, Shreepad Sarange, 2014.Numerical analysis to determine the distribution of tool forces and temperatures of single point cutting tool. International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064.

5) S. H. Rathod, Mohd. Razik, 2014. Finite Element Analysis of Single Point Cutting Tool. IJMER | ISSN: 2249–6645 | Vol. 4 | Iss. 3 | 12 |.

6) Shijun Zhang, Zhanqiang Liu, 2008. An analytical model for transient temperature distributions in coated carbide cutting tools International Communications in Heat and Mass Transfer 35, 1311–1315.

7) R.K. Jain "A Text Book of Production Technology", Khanna Publishers.

8) A.Fata, M.R. Razfar, "Measurement Tool Temprature by Finite Elements Methods," 15th AnnualInternational Iranian Mechanical Engineering Conference, 2007

9) W. Grzesik, M. Bartoszuk and P. Niesłony. Finite element modeling of temperature distribution in the cutting zone in turning processes with differently coated tools., 13th international scientific conference. 2005.

10) S.R. Carvalho , S.M.M. Lima Silva , A.R. Machadoa, G. Guimar˜.Temperature determination at the chip–tool interface using an inverse thermal model considering the tool and tool holder. Journal of Materials Processing Technology 179 (2006) 97–104.