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Temperature Analysis with depth of cut of Single Point Cutting Tool

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Abstract: **Single point cutting tool is standard tool used for various machining operations. Work is done to find temperature at tool chip interface at various speeds and depth of cut with thermal analysis. The different analyses are done on High Speed Steel tool machining process at three different cutting speeds with varying depth of cut as part of this study. Heat generation analysis is done by varying the geometrical parameters of tool. Investigators made attempt to measure these cutting temperatures with various techniques during machining. 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 the depth of cut during the machining the temperature analysis is made with FEA which can be further useful to compare with experimental result.**

Keywords: **Single Point Cutting Tool, HSS tool tool, Centre lathe, Fluke IR Thermal Imager, Finite Element Analysis, Solid Modelling.**

I. 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 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. 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 has been a considerable amount of research devoted to develop analytical and numeric models in order to simulate metal cutting processes to predict the effects of machining variable such as speed, feed, depth of cut and also tool geometry on deformations of tool. Especially, numerical models are highly essential in predicting chip formation, computing forces, distributions of strain, strain rate, temperatures and stresses on the cutting edge and the machined work surface. Advanced process simulation techniques are necessary in order to study the influence of the tool edge geometry and cutting conditions on the surface integrity especially on the machining induced stresses. The objective is to analyze the temperature distribution on a tool of different materials at various machining parameters using analysis software ANSYS.

II. CONCEPT OF HEAT GENERATION IN SINGLE POINT CUTTING TOOL

In machining of metal with single point cutting tool, the heat is generated due to the friction between chip produced and the tool. At the same time, at the zone of metal separation and cutting edge also the heat is generated. Hence, the heat is generated in three zones as shown in Figure 1.

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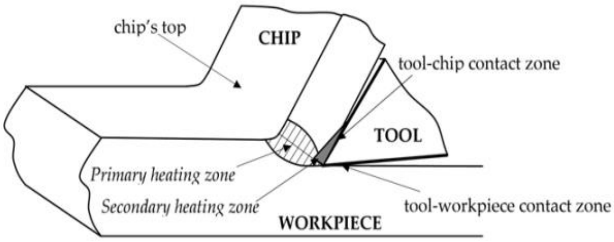

Fig. 1

In shear zone, maximum heat is generated because of the plastic deformation of metal, and practically all of this heat is carried away by the chip as machining is rapid and continuous process. Avery minor portion of this heat (5-10%) is conducted to work piece. In friction zone, the heat is generated mainly due to friction between moving chip and tool face and partly due to secondary deformation of the built up edge. In work-tool contact zone, the heat is generated due to burnishing friction and the heat in this zone goes on increasing with time as the wear land on the tool develops and goes on increasing. It will be noted that each of these three zones leads to rise of temperature at the tool chip interface and it is found that the maximum temperature occurs slightly away from the cutting edge, and not at the cutting edge.

III. MODELLING OF SINGLE POINT 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 1.

Table 1: Main dimensions of the tool and work piece

	Cutting Tool	Work piece
Material	High Speed Steel Tungsten carbide	Mild Steel
Cross-section	12*100.9 mm Side and end cutting edge angles: 30° End relief angle: 20°	Ø22.5*62.8 mm

Solidworks is used for 3D modelling of single point cutting tool. 3D views are given below for reference. Various commands are used like sketch, line, extrude, cut extrude etc.

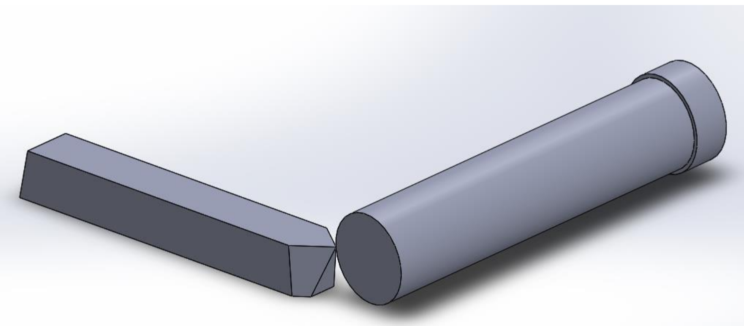

Fig. 2

The end part of the main body is made with the help of commands like sketch, pad. The sketching is on a defined plane as line diagram and it is solid extruded with the help of pad command. With the help of fillet and pad command in CATIA, the final Rocker arm is made.

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IV. FINITE ELEMENT ANALYSIS OF SINGLE POINT CUTTING TOOL

The 3D modelled cutting tool is inserted into the ANSYS WORKBENCH. The following figure shows the inserted 3D modelled tool into the ANSYS WORKBENCH. The cutting material is used as T15 High Speed Steel. The Temperature dependent properties are summarised in a table which is followed by the below figure.

Coefficient of thermal expansion: 1.01*10-5 °C-1 (Ref temp: 22 °C) Young"s modulus: 2.07*105 Mpa

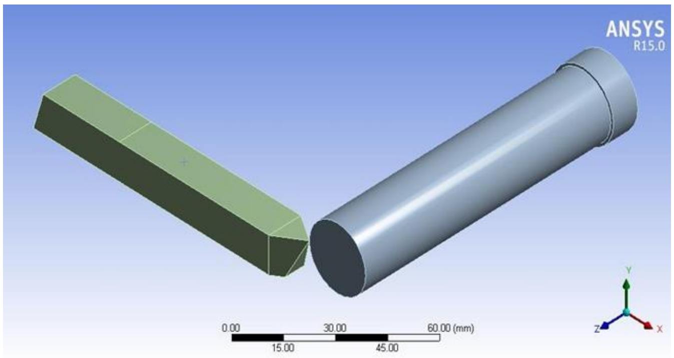

Fig. 3

Table 2: Properties of T15 super high speed steel

Sl No	Temperature (°C)	Density (kg/m3)	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

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/m3

Coefficient of thermal expansion: 1.2*10-5 °C-1 (Ref temp:20 °C) Young"s modulus: 2*1011 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.

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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.

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 4.

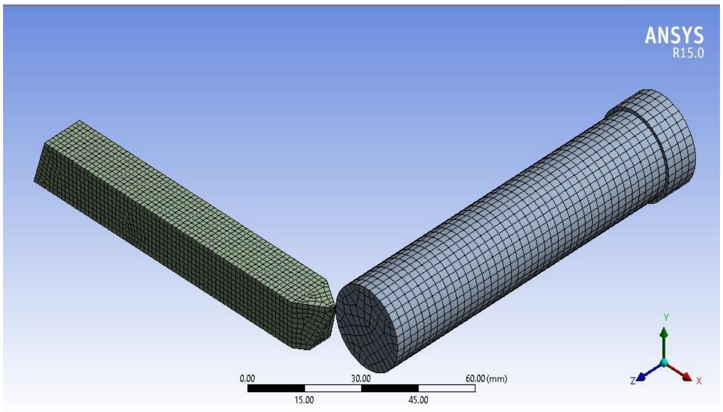

Fig. 4

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

1. Cylindrical support for work piece

2. Longitudinal displacement of tool

3. Tangential displacement of tool (0.1 mm, 0.4 mm, 0.7 mm) 4.Speed of rotation of work piece (150 rpm, 420 rpm, 710 rpm)

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 delaminating.

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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/m2 RMODIF, cid, 14, 1e4: This changes thermal contact conductance between tool and work piece in w/m2 °C

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

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

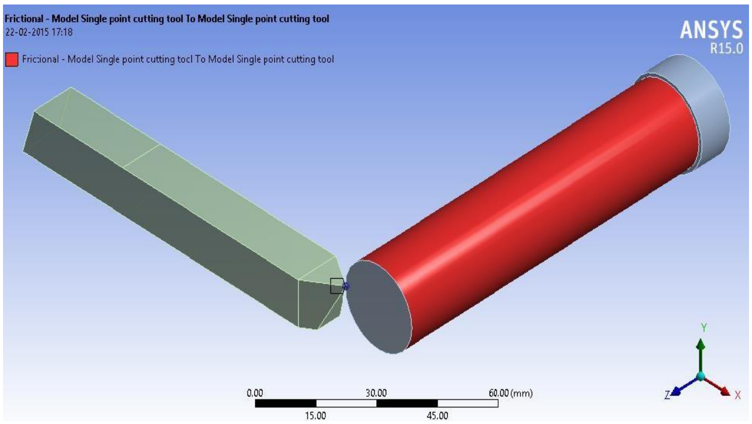

Fig. 5

We use Modal Analysis to determine the vibration characteristics (Natural frequencies and mode shapes) of a structure of a machine component while it is being designed. It also can be a starting point for another, more detailed, Dynamic Analysis, such as a transient dynamic, a harmonic response analysis, or a spectrum analysis. Uses for Modal Analysis: The Natural frequencies and mode shapes are important parameters in the design of a structure for Dynamic loading conditions. They are also required if you want to do a spectrum analysis or a mode superposition harmonic or transient analysis.

Open Ansys Workbench through Start All programs – Ansys – Workbench. Right Click on the mesh – Insert -Sizing, Select Units from Units Menu as Metric (mm, kg, N, S etc.), Put the cursor on body sizing – select all objects by using body and box selection method, select all by dragging a window –apply – Ok and keep the cursor on body sizing and enter element sizing 10mm in bottom details window. Right Click on the mesh – Generate Mesh. The mesh will be generated as shown below.

The temperatures obtained for high speed steel tool at various speed and depth of cut through FEA are summarized in Table and graph below.

TEMPERATURE OBTAINED AT SPEED: 150 rpm, DOC: 0.1 mm

Table 3: Results and analysis

Sl No	Time [sec]	Max Temp [°C]
1	0	28.7
2	10	32.4
3	20	36.4
4	30	47.3
5	40	56.7
6	**49**	**65.8**

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TEMPERATURE OBTAINED AT SPEED: 150 rpm, DOC: 0.4 mm

Table 4: Results and analysis

Sl No	Time [sec]	Max Temp [°C]
1	0	57
2	10	70.8
3	20	81.8
4	30	91
5	40	99.6
6	**49**	**104.4**

TEMPERATURE OBTAINED AT SPEED: 420 rpm, DOC: 0.1 mm

Table 5: Results and analysis

Sl No	Time [sec]	Max Temp [°C]
1	0	40.8
2	5	52.3
3	10	70.1
4	**17.5**	**76.7**

TEMPERATURE OBTAINED AT SPEED: 420 rpm, DOC: 0.4 mm

Table 6: Results and analysis

Sl No	Time [sec]	Max Temp [°C]
1	0	70.3
2	5	79.8
3	10	92.5
4	**17.5**	**107.9**

V. CONCLUSION

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

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