Thermal Analysis and Optimization of Single Point Cutting Tool by FEA & Experimental Analysis

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Abstract- *Temperature at tool-chip interface of a single point cutting tool is determined, generated in different speed machining operations. Specifically, 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 machining process at three different cutting speeds, in order to compare to experimental results produced as part of this study.*

An investigation of heat generation in cutting tool is performed by varying cutting parameters at the suitable cutting tool geometry. The experimental results reveal that the main factors responsible for increasing cutting temperature are cutting speed (v) and depth of cut (d) respectively. Various researches have been undertaken in measuring the temperatures generated during cutting operations. Investigators made attempt to measure these cutting temperatures with various techniques during machining.

"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 various parameters the effect of those on temperature are compared with the experimental results and FEA results.

Keywords- Single Point Cutting Tool, HSS tool and Carbide tip tool, Centre lathe, Fluke IR Thermal Imager, Finite Element Analysis, Solid Modeling.

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. LITERATURE SURVEY

Shijun Zhang, Zhanqiang Liu [1] developed an analytical model with constant temperature at tool and chip interface of one-dimensional heat transfer in monolayer coated tools has been to investigate temperature distribution in metal cutting. The explicit form of temperature formulae were obtained by using the Laplace Transform technique and a Taylor series expansion. Calculations conducted for tools of three coatings (TiN, Tic and Al2O3) and two substrates (K10 and P10).

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.

J. E. Jam, V. N. Fard [3] determined the thermal contact conductance of the tool chip interface in the metal cutting process using an inverse procedure. An orthogonal cutting of the AISI 1045 steel is simulated by LS-DYNA finite element code. Tool chip interface average temperature is determined using thermo-mechanical coupled analysis of a two dimensional finite element model of the orthogonal cutting process under plane strain condition and compared with experimental measured data from literature during the inverse procedure. In thermo-mechanical coupled analysis friction condition in tool-chip interface is modelled using Coulomb’s friction law together with the shear stress limits to describe the sliding and sticking condition on the tool rake face.

The work piece material behavior has been modelled using the Johnson Cook constitutive material model. Numerical simulation results of the orthogonal cutting process consisting of temperature in the tool-chip interface and cutting forces are shown and compared with experimental data reported in literature. Also, in this paper three dimensional thermal analysis of the cutting tool is performed.

Temperature distribution in three dimensional cutting tool model and thermal contact conductance of the tool-chip interface are also presented.

Yash R. Bhoyar, P. D. Kamble [4] studied the approaches for modeling 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.

Deepak Lathwal, Deepak Bhardwaj [5] studied three different rake angles in order to find out the variation in values of Vonmisses stress for the specified applied forces. In present study mesh is created in ANSYS and the boundary conditions are applied and the analysis is carried out for the applied constraints. The results calculated on software can be verified with experiments carried out with tool dynamometers for lathe tool. For future study the applied model can be used for multipoint cutting tools such as milling cutters, broaching tools etc.

III. OBJECTIVES OF THE STUDY

Heat is a parameter which strongly influences the tool performance during the operation. So the machining can be improved by the knowledge of temperature distribution on the tool. Thus the main objectives of this project are as follows:

1. Study and comparison of temperature distribution on a single point cutting tool of different materials at various machining parameters.
2. Modeling and finite element analysis of single point cutting tool.
3. Comparison of experimental data with finite element analysis data for the tool.

There are different materials used for cutting tool such as HSS, cemented carbides, diamond etc. and the various machining parameters associated with the tool are cutting speed, feed and depth of cut. So in order to study the temperature distribution on the single point cutting tool we select different cutting tool materials and various machining parameters.

For carrying out the finite element analysis on the single point cutting tool Firstly we modelled the single point cutting tool using suitable modeling software. There are different modeling software are available such as AutoCAD, CATIA, SolidWorks, Pro/E etc. After modeling is done, this modelled single point cutting tool is imported into suitable finite analysis software such as ANSYS. So by providing suitable boundary conditions the finite element analysis of single point cutting tool is done. After finite element analysis, we compare the results obtained with experiment and finite element analysis data for the tool.

IV. METHODOLOGY

1. DESIGN OF EXPERIMENT

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.

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 in work. A hole was drilled on the face of work piece to allow it to be supported at the tailstock.

DESIGN OF EXPERIMENT 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 analyze the error using the temperatures obtained for HSS tool at a time 10 seconds after machining starts. The table of subjects of the design of experiment for HSS tool are summarized in table 4.1

Table 1. 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**

DESIGN OF EXPERIMENT FOR CARBIDE TOOL

Similarly here also we analyze the error using the temperatures obtained for Carbide tool at a time 10 seconds after machining starts. The table of subjects are summarized in table 4.2

Table 2. Table of subjects of the design of experiment 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**

2. MODELLING OF TOOL

The single point cutting tool has been solid modelled by using SOLIDWORKS, a solid modeling computer aided design software. Solid works is a solid modeler, 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.

MODELLING OF HSS & CARBIDE TOOL

The single point cutting tool (HSS) has been solid modelled by using SOLIDWORKS. The single point cutting tool (Tungsten Carbide) has been solid modelled by using SOLIDWORKS. The single point cutting tool (Tungsten Carbide) has been solid modelled by using SOLIDWORKS. The 3D and 2D views are shown in fig.

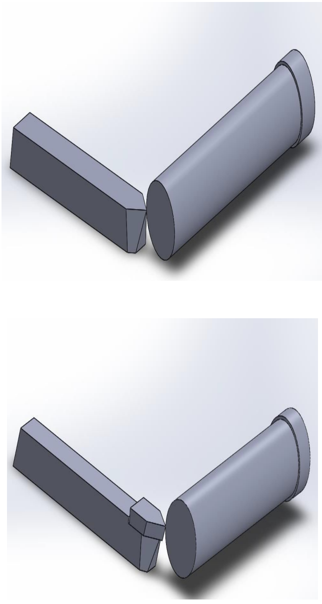


Figure 1. D view of HSS & Carbide model

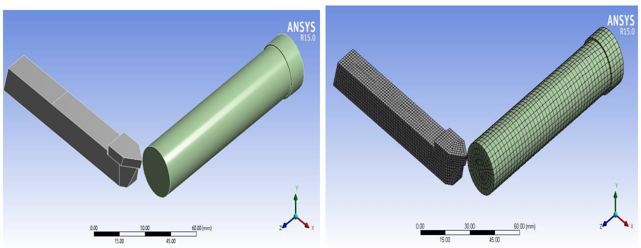
3. FINITE ELEMENT ANALYSIS OF HSS TOOL

GEOMETRY & MESHING

The geometry is modelled using „SOLIDWORKS-2013"and then it is imported into "ANSYS WORKBENCH".

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 (63.7 mm) 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)



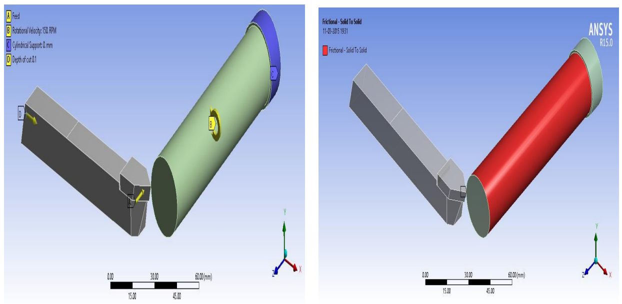


Figure 2. Geometry, Nodes and meshing, Setting Boundary Condition & Frictional Model

V. RESULTS

1. PERCENTAGE DIFFERENCE BETWEEN MAX TEMPERATURES OBTAINED THROUGH EXPERIMENT AND FEA FOR HSS TOOL

Table 3. Percentage difference between max temperatures obtained 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				0.1	67.6	69	2.03
2		150	49	0.4	104.4	108	3.33
3				0.7	152.4	155	1.68
4				0.1	78.4	77	1.79
5		420	17.5	0.4	109.6	112	2.14
6	0.52			0.7	158.6	160	0.875
7				0.1	81.6	84	2.85
8		710	10	0.4	124.6	127	1.89
9				0.7	167.6	170	1.41

2. PERCENTAGE DIFFERENCE BETWEEN MAXIMUM TEMPERATURES OBTAINED THROUGH EXPERIMENT AND FEA FOR CARBIDE TOOL

Table 4. Percentage difference between max temperatures obtained 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				0.1	75.4	77.02	2.10
2		150	49	0.4	111.8	115.03	2.81
3				0.7	159.4	162.05	1.64
4				0.1	82.8	85.025	2.62
5		420	17.5	0.4	119.2	117.04	6.36
6	0.52			0.7	167.6	169.06	0.86
7				0.1	86.8	90.027	3.58
8		710	10	0.4	127	129.04	1.58
9				0.7	175.2	174.06	0.65

VI. CONCLUSION

1. Compared 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%
2. 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.
3. 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.
4. 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.

VII. 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 modeled 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.

VIII. 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 analyze 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.

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