FINITE ELEMENT ANALYSIS OF SINGLE POINT CUTTING TOOL

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Abstract – *This paper is associated with the effect of temperature and cutting forces on the tip of Single Point Cutting Tool. Temperature at tool-tip is measured, generated in high speed machining operations. Temperature at cutting point of the tool is crucial parameter in the control of the machining process. Specifically, three different analyses are compared to an experimental measurement of temperature in a machining process at slow, medium and high speed. Tool-work Thermocouple technique is used for measuring temperature on tip of tool at various cutting parameters (depth of cut, speed and feed rate) and it found that with increase of speed and depth of cut temperature at tip of cutting tool increases. Cutting forces are analytically determined and stresses are found out at tip of cutting tool. Single Point Cutting Tool is modeled in CATIA software and model is then imported in ANSYS software for analysis. By applying temperature readings, temperature distribution on cutting tool is found out. Also from stress analysis of cutting tool it is observed that the effect of cutting force is more as compared to thrust force.*

Key Words: *Single Point Cutting Tool, Cutting Forces, Temperature, ANSYS, CATIA, Stresses.*

1. INTRODUCTION

Metal cutting or machining is the process of producing workpiece by removing unwanted material from a block of metal, in the form of chips. This process is most important since almost all the products get their final shape and size by metal removal, either directly or indirectly. The major drawback of this process is loss of material in the form of chips.

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 workpiece is termed as cutting tool temperature. Heat is 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 tool and chip. Almost all heat generated is transferred into cutting tool and workpiece material while some portion 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 workpiece 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 largest source of error in the machining process.

During the metal cutting process heat is produced due to shearing action and it raises the temperature of the tool. Due to this temperature the tool gets soften at the tip and various stresses and deformation is take place in the tool. It is essential to measure this temperature experimentally at various depth of cut and also to find out the effect of forces acting on the tip of the tool. The effect of feed and depth of cut is more on cutting forces than spindle speed. The mechanism of cutting and turning process generates cutting forces the material in cutting tool is pushed and material slides on shear plane.

2. LITERATURE REVIEW

The purpose of this chapter is to provide a review 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 provide 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.

[L. B. Abhang], [M. Hameedullah] worked to measure the tool-chip interface temperature experimentally during turning of EN-31 steel alloy with tungsten carbide inserts using a tool-work thermocouple technique. Average chip-tool interface temperatures have been experimentally studied using the tool work thermocouple technique. Based on the parametric study they developed empirical relation agrees well in velocity with the Shaw's non-dimensional model. It has been observed that increasing cutting speed, feed rate and depth of cut lead to an increase in cutting temperature.

Tool-work thermocouple has become a popular tool to be used in temperature measurements during metal cutting. This method is very useful to indicate the effects of the cutting speed, feed rate, depth of cut and the tool parameters on the temperature. In tool-work thermocouple the chip-tool interface forms the hot junction, while the tool end forms the cold junction. The tool and work piece need to be electrically insulated from the machine tool. This cutting temperature measurement technique is easy to apply for the measurement of chip-tool interface temperature during metal cutting over the entire contact area.

[Sushil D. Ghodam] did work on Temperature measurement of a cutting tool in turning process by using tool work thermocouple. Temperature at the cutting point of the tool is a crucial parameter in the control of the machining process. Due to advancement in the machining processes, a special attention has been given on the life of a tool. The importance of knowledge of temperature measurement at the cutting point of the turning tool occurred due to the changes in the cutting condition is well known due to severe effects on the tool and work piece materials properties. During machining heat is generated at the cutting point from three sources i.e. primary, secondary and tertiary zones. A standard K-type thermocouple embedded in the work piece was used to convert measured emf to the interfacial temperatures.

The objective of this experiment was to compare the temperature generated during machining at uncoated and CVD coated tungsten carbide cutting tool. As feed rate increases from the temperature at the uncoated tool is increases at high amount as compared to the coated tool.

[Meenu Sahu] [Komesh Sahu] They developed an optimization method of the cutting parameters (cutting speed, depth of cut and feed) in dry turning of AISI D2 steel to achieve minimum tool wear, low work piece surface temperature and maximum material removal rate (MRR). The experimental layout was designed based on the Taguchi's L9 (34) Orthogonal array technique and analysis of variance (ANOVA) was performed to identify the effect of the cutting parameters on the response variables. The results showed that depth of cut and cutting speed are the most important parameter influencing the tool wear. The minimum tool wear was found at cutting speed of 150 m/min, depth of cut of 0.5 mm and feed of 0.25 mm/rev. Similarly low w/p surface temperature was obtained at cutting speed of 150 m/min, depth of cut of 0.5 mm and feed of 0.25 mm/rev. Whereas, at cutting speed of 250 m/min, depth of cut 1.00 mm and feed of 0.25 mm/rev, the maximum MRR was obtained. Thereafter, optimal range of tool wear, work piece surface temperature and MRR values were predicted. Finally, the relationship between factors and the performance measures were developed by using multiple regression analysis.

[Ved Prakash Singh Parihar, M. A. Saloda, B.P. Nandwana and M. S. Khidiya] Cutting forces during machining can be a serious problem influencing manufactured parts quality, precision, tool service life, lathe performance and cutting rates. This paper presents an analysis of cutting mechanics in turning process. Cutting forces have significant impact on cutting process stability, which affects the quality of manufactured parts and productivity rates. The cutting forces applied on the surface of work piece by Lathe tool is measured using experimental setup. The forces works on the work piece applies in three directions as longitudinal, axial and lateral directions. The experimental setup is used to find all these forces and optimization of result found. The cutting forces can be measured using Dynamometer. The experiment is performed by changing three parameters in the cutting process as feed, spindle speed and depth of cut and their effects on cutting forces is analyzed for changing parameters.

3. OBJECTIVE OF PROJECT WORK

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:

- Study and comparison of temperature distribution on a single point cutting tool of HSS material at various machining parameters.
- Modeling and finite element analysis of single point cutting tool.
- Comparison of experimental data with finite element analysis data for the tool.
- Determination of stresses on cutting tool using ANSYS.

4. EXPERIMENTAL METHODOLOGY

In this experiment we are setting up a temporary arrangement for measuring temperature at the tool tip during turning operation in centre lathe as shown in figure. Temperature measuring device consists of an assembly of K type thermocouple and multimeter .The tool being used in the experiment is high speed steel tool. A hole of diameter 4mm is drilled on the shank of the tool and probe of the thermocouple is inserted in the hole such that it touches the tool tip. The negative and positive end of the thermocouple is connected to the corresponding terminals of the multimeter. In this arrangement the temperature at the tip of the tool will develop an emf in the thermocouple which will be displayed in the multimeter. The tool is fixed on the tool post and the work piece is fixed on the four jaw chuck. The multimeter reading is taken for different machining conditions by varying the cutting parameters like cutting feed, depth of cut, cutting speed etc.

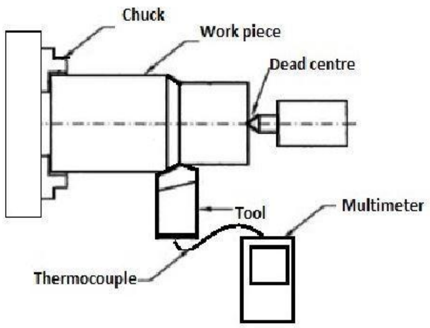

Fig. 1 Schematic Diagram of Experimental setup

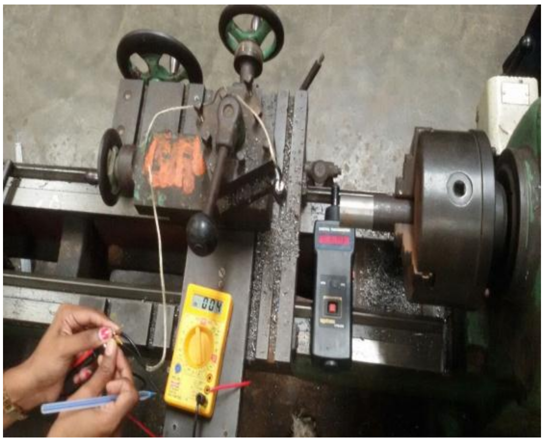

Fig-2 Experimental Set-Up of Tool-Work Thermocouple

4.1 EXPERIMENTAL RESULTS

The experiment of measuring cutting temperature during machining was completed successfully using artificial thermocouple and multimeter. The feed rate and cutting speed is made constant and the values of voltages were measured from multimeter at four different depths of cuts, the feed rate is made constant by adjusting the pitch values. The experiment is repeated at three different cutting speeds and the obtained values are tabulated below:

Table-1: Values of Parameter

	FEED RATE (cm/sec)	CUTTING SPEED (rpm)	DEPTH OF CUT (mm)
Slow	1	540	.5
			1
Medium		750	1.5
High		940	2

Table below shows the results obtained from the experiment at three different speeds slow, medium and high by varying depth of cut are as follows:

Table-2: Results Obtained Experimentally Using HSS Tool

Exp. No.	Speed (v) (RPM)	Depth of cut (d) (mm)	Experimental Temperature (T in °C)
1	540	0.5	128.65
2		1	145
3		1.5	152.2
4		2	163
5	750	0.5	144.52
6		1	156.72
7		1.5	164.2
8		2	176
9	940	0.5	151.26
10		1	163.68
11		1.5	177.36
12		2	193.48

The graph is plotted using these experimental values to obtain the relationship between the temperature and the cutting parameters.

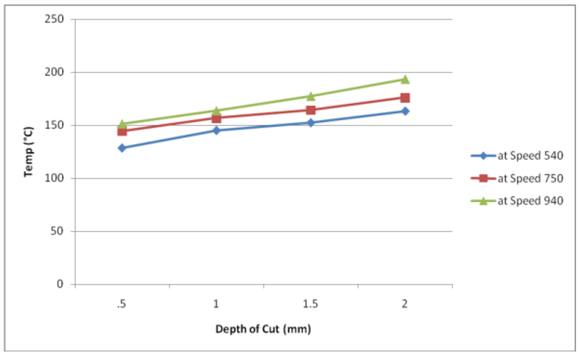

Chart-1: Temp Vs Depth of Cut at varying speed

Graph shows that as depth of cut increases temperature on tip of cutting tool increases with increase of speed. Temperature is more on cutting tool at high speed as compared to slow and medium speed.

5. MODELLING OF SINGLE POINT CUTTING TOOL

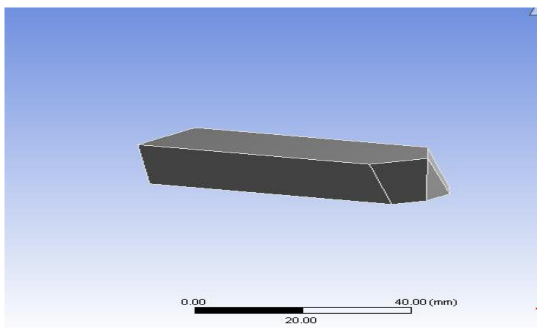

Fig.-3: CATIA Model of Cutting Tool Imported in IGES Format in ANSYS for Analysis

6. ANALYSIS OF CUTTING TOOL

6.1 STEADY STATE THERMAL ANALYSIS OF CUTTING TOOL

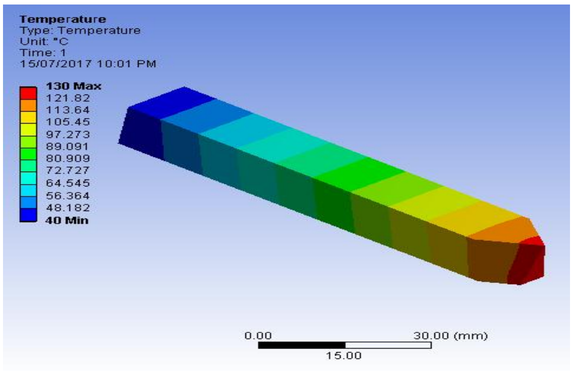

Fig.-4: Temperature Distribution on Cutting Tool

6.2 ANALYTICAL CALCULATION OF FORCES ON CUTTING TOOL

Analytically cutting forces and thrust forces are calculated by using different depth of cut (d) and feed rate (f) are as follows:

For d = 0.5 mm and f = 0.5 mm/rev

$Fc = 1593 \times f^{0.85} \times d^{0.98}$ N
$= 1593 \times 0.5^{0.85} \times 0.5^{0.98}$
Fc = 448.05 N
Where d = Depth of Cut
f = Feed rate
Fc = Cutting Force

Thrust Force Calculation:

Average co-efficient of friction on the tool face, μ = 0.7
Rake angle, α = 12

$$\mu = \frac{Fc \tan\alpha + Ft}{Fc - Ft \tan\alpha}$$

$$0.7 = \frac{448.05 \tan 12 + Ft}{448.05 - Ft \tan 12}$$

Thrust Force, Ft = 190.11 N

Similarly other calculations are done by using above formulae for different depth of cut and feed rate are tabulated as follows:

Table-3: Calculated Force Fc and Ft

Feed Rate (mm/rev)	Depth of Cut (mm)	Cutting Force Fc (N)	Thrust Force Ft (N)
0.5	0.5	448.05	190.11
	1	883.77	374.99
	1.5	1314	557.54

6.3 Analytical Calculation for Stresses on Cutting Tool

For Depth of Cut = 0.5 mm

$$\text{Shear angle } \varphi = \frac{r\cos\alpha}{1 - r\sin\alpha}$$

$$\varphi = \frac{0.568\cos 12}{1 - 0.568\sin 12}$$

φ = 32.21°

$$\text{Normal Force } Fn = Fc\sin\varphi + Ft\cos\varphi$$

$$Fn = 448.05\sin 32.21 + 190.11\cos 32.21$$

Fn = 399.67 N

$$\sigma = \frac{Fn}{As}$$

$$\sigma = \frac{399.67\sin 32.21}{0.5 \times 0.5}$$

σ = 852.134 Mpa

Similar to above calculation all stresses for depth of cut 1 mm and 1.5 mm are calculated which are tabulated are as follows:

Table 4: Calculated Stresses on cutting tool

Feed Rate (mm/rev)	Depth of Cut (mm)	Stress (Mpa)
0.5	0.5	852.134
	1	1544.09
	1.5	2168.22

6.4 STRUCTURAL ANALYSIS OF SINGLE POINT CUTTING TOOL

Following are the stresses on single point cutting tool by applying cutting force as well as thrust force are as follows:

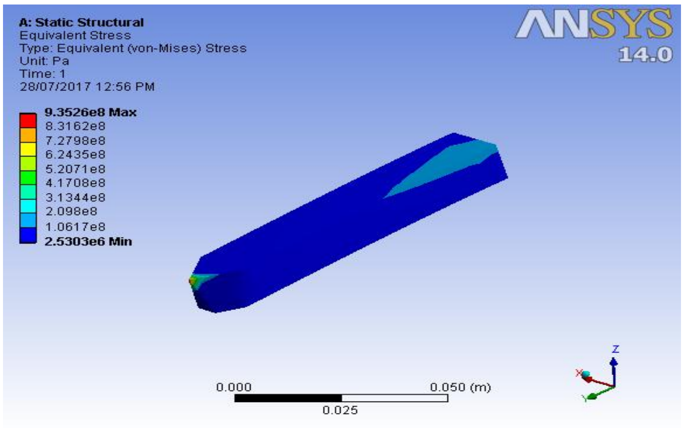

Fig-5: Von-misses Stress Contour for Tip of Tool

Comparison of Analytical and FE Analysis Results for Cutting Tool

TABLE 5: Comparison of Analytical and FEA Results

Analysis For DOC (mm)	Analytically Calculated Stress (Mpa)	Stress by FEM Analysis (Mpa)
0.5	852.134	935.26
1	1544.09	1844
1.5	2168.22	2742.8

From above table it is seen that stresses on cutting tool by analytical and FEA are nearly same

By applying forces at various conditions we get stresses on tip of cutting tool are as follows:

No.	Feed rate (mm /rev)	DOF (mm)	Force (N)	Von-mises stress (MPa)	Deformation (mm)
1	0.5	0.5	Fc & Ft	935.26	0.3983
2			Fc	853.03	0.3647
3			Ft	377.86	0.3983
4		1	Fc & Ft	1844	0.7858
5			Fc	1684.5	0.7194
6			Ft	745.65	0.3167
7		1.5	Fc & Ft	2742.8	1.168
8			Fc	2501.7	1.0696
9			Ft	1108.1	0.4709

Graph is plotted from above table is as follows which states that comparison of stresses at different conditions of application of forces:

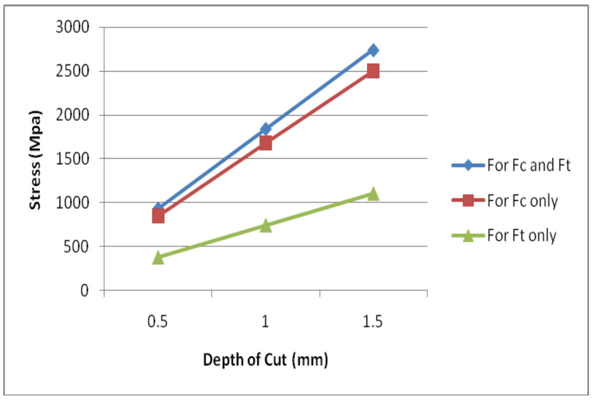

Chart-2: Variation of Von-mice Stress on Cutting Tool by Applying Fc, Ft,

From graph it is clear that with increase in depth of cut stress on cutting tool also increases. When both Fc and Ft applied on cutting tool is stress maximum. Stress is nearly equal when both Fc and Ft and only Fc are applied. But stress on cutting tool due to thrust force is less as compared to cutting force.

7 CONCLUSION AND FUTURE SCOPE

It can be observed from experimental analysis 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.

It is observed that as depth of cut increases, the von-mises stresses developed in the tool increases and also deformation of tool tip increases which are the main reason of tool failure. Effect of cutting force is more as compared to thrust force on single point cutting tool.

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