Analysis of Tool-Chip Interface Temperature of Aluminum Alloy in Turning Operation by using Response Surface Methodology

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Abstract - *In metal cutting process most of heat generated on the cutting tool tip is necessary for the reliable performance of the tool and quality of the finished product. The effect of the cutting temperature, when it is high, is mostly detrimental to both tool and work piece. The machining process and tool life can be improved by the knowledge of cutting temperature and cutting speed. In this paper we have studied the measurement of temperature developed on tool tip during turning operation under different parameter. The metal cutting parameter like, cutting speed, feed rate, depth of cut. in this whole experiment we used k type thermocouple with digital temperature indicator for measuring the various temperature reading during the operation .The tool is used is of high carbon tip, cast iron shank and work piece is used cylindrical aluminum alloy rod. The main reason behind using aluminum alloy is to aluminum alloy has large variety of applications, with light in weight, highly corrosion resistance good electrical and thermal conductivity also good ductility and non magnetic property. In this study Response surface methodology [RSM] is used to analyse machining effect on aluminium material. On the basis of data collected during experiment, we have seen the effect of different cutting parameters on temperature developed on tool tip and suitable turning conditions for obtaining maximum material removal rate at lower temperature. The obtained results are well tabulated and analyzed graphically*.

***Key words*: Depth of cut, Cutting tool, feed rate, Machining, Parameter, Speed and Thermocouple.**

1. INTRODUCTION

When cutting of metals and alloys most of the energy required to form the chips is converted into heat. Therefore, the temperatures generated in the cutting zone are an important factor to take into consideration. This factor is of a major importance to the performance of the cutting tool and quality of the work piece. Temperature in the cutting zone depends on contact length between tool and chip, cutting forces and friction between tool and work piece material. A considerable amount of heat generated during machining is transferred into the cutting tool and work piece. The remaining heat is removed with the chips. The highest temperature is generated in the flow zone. Therefore, contact length between the tool and the chip affects cutting conditions and performance of the tool and tool life for the improvement of cutting performance, the knowledge of temperature at the tool-work interface with good accuracy is essential. The RSM is practical, economical and relatively easy for use and it was used by lot of researchers for modeling machining processes. Response surface methodology (RSM) is a combination of experimental and regression analysis and statistical inferences. The concept of a response surface involves a dependent variable y called the response variable and several independent variables x1, x2,. .., xk. If all of these variables are assumed to be measurable, the response surface can be expressed as y = f (x1; x2; . . . ; xk) Optimizing the response variable y, it is assumed that the independent variables are continuous and controllable by the experimenter with negligible error. The response or the dependent variable is assumed to be a random variable. in this experiment turning operation was selected due to it is necessary to find a suitable parameter like cutting speed (x1=V), Feed (x2=f), depth of cut (x3=d) that optimizing the cutting temperature (y=t)

1.1 Heat generation zone in machining

In the metal cutting process, a tool performs the cutting action by overcoming the shear strength of the work piece material. This generates a large amount of heat in the work piece resulting in a highly localized thermo mechanically coupled deformation in the shear zone. Temperature in the cutting zone considerably affects the stress-strain relationship, fracture and the flow of the work piece material.

The main region where heat is generated during orthogonal cutting process as shown in Fig.1.1

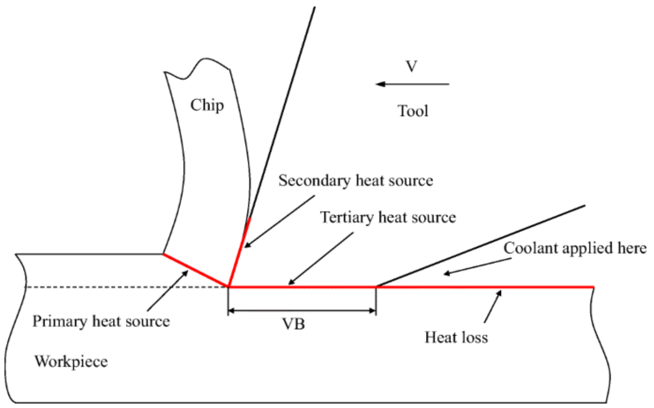

Fig.1.1 Sources of heat generation in orthogonal cutting process.

Three main sources of heat can be specified when cutting they are

1. Plastic deformation by shearing in the primary shear zone.
2. Friction on the cutting face;
3. Friction between the chip and on the tool flank.

At the beginning, heat is generated in the primary deformation zone due to the plastic work done at the shear plane. The local heating in this zone results in very high temperatures, thus softening the material and allowing greater deformation. Secondly, heat is generated in the secondary deformation zone due to work done in deforming the chip and in overcoming the sliding friction at the tool-chip interface zone. Finally, the heat generated in the tertiary deformation zone, at the tool work piece interface, is due to the work done to overcome friction, which occurs at the rubbing contact between the tool flank face and the newly machined surface of the work piece. Heat generation and temperatures in the primary and secondary zones are highly dependent on the cutting conditions while heat generation in the tertiary zone is strongly influenced by tool flank wear.

1.2 Literature Review

A kannan[1] used k type thermocouple technique to measure the cutting temperature between tool tip and work piece in orthogonal cutting. Suha k. Shihab, zahid A. Khan [2] worked on cutting temperature of hardened alloy steel by using multilayer coated carbide tool. And they concluded that tool-chip thermocouple technique is the most effective method for measuring the average tool chip interface temperature during metal cutting.

A.Z.Patel [3] Worked on Experimental Analysis and Measurement of Chip-Tool Interface Temperature in Turning of Aluminium Alloy. Their result and analysis of experiment shows that Chip-tool interface temperature is closely related to cutting speed. With increase in cutting speed, friction increases, this induces an increase in temperature in the cutting zone. With the increase in feed rate consequently friction increases and chip-tool interface temperature increases.

Abhang et al. [4] investigated tool-chip interface temperature experimentally during turning of EN-31 steel alloy with tungsten carbide inserts using tool-work thermocouple technique. The result of experiments and prediction model shows that, for cutting speed increase from 39 to 189 m/min, the increase in temperature in cutting zone was 174%. Also, a 38.57% increase in temperature was observed as the feed rate increased. For depth of cut, an increase from 0.2 mm to 0.6 mm, 29% increase in temperature was observed. Whereas, as tool nose radius increases from 0.4 to 1.2 mm, 21% decrease in temperature was observed.

Punit Bhardwaj [5] they worked on FEM Analysis of Orthogonal Cutting of Aluminium Alloy using Rigid Tool and they investigated The numerical modeling of 2D plain strain orthogonal cutting is successfully carried out using finite element method. In numerical simulations of orthogonal cutting of aluminium alloy Al5057 it is found that the maximum stresses occur at the chip tool interface in shear plane. And the value if maximum stresses are increases with increases in the feed rate of tool with respect to the work piece.

Carvalho et al. [6] proposed estimation of temperature and heat flux at chip-tool interface using inverse heat conduction problem technique.

2 EXPERIMENTAL WORK

2. 1 Experimental set-up

The whole process is carried out on centre lathe machine which is manufactured by Machinery trading corporation, Mumbai as shown in Fig.2.1. In this experiment k type thermocouple with digital temperature indicator is used to measure temperature. The tool being used in this experiment is high carbon steel. The one end of thermocouple is connected to the tip of tool in such way to touches the tool tip and other end is connected to the digital temperature indicator to get the desired temperature reading. In this experiment temperature of tool tip will develop an emf which is directly shown on digital temperature indicator. The temperature reading is taken for the various cutting parameters like cutting speed (V), Feed rate (f), Depth of cut (d) Etc.

Fig.2.1 Centre lathe machine

Thermocouples are known to be very popular transducers for measuring temperature as shown in fig 2.2 (a). The k-type thermocouple was chosen for measuring the temperature in this work. This technique was preferred as it is inexpensive, easy to calibrate, has a quick response time and good repeatability during experiments.

The readings from thermocouple are in the form of emf and for measuring this emf we are using a digital temperature indicator with digital display as shown in fig 2.2 (b).

Fig.2.2 (a) Thermocouple
(b) digital temperature indicator

2.2 EXPERIMENTAL PROCEDURE:

1. One end of thermocouple is directly soldered on the point of the cutting tool tip.

2. The tool is fitted on tool holder and the work piece is fixed at center of lathe machine by adjusting the three jaws chuck.

4. The one end of thermocouple is fixed on the tool tip and the other end is connected to the digital temperature indicator.

5. The main cutting parameters are considered to be feed rate in mm/rev, depth of cut in mm and cutting speed in rev/min.

6. Cutting speed can be varied by changing the gears. And Depth of cut is adjusted by using cross slide.

8. Feed rate is selected by adjusting the pitch values.

9. By setting the different values of feed rates, cutting speeds and depth of cuts, temperature is measured by digital temperature indicator.

10. Above procedure is repeated for different values of cutting speed, DOP, and feed rate.

2.3 Work Material:

Fig.2.3 Work Piece

The work material used as the test specimen was Aluminium alloy. A cylindrical bar of aluminium alloy (200 mm long and 25 mm diameter) was used for the test.

Table 2.1 Chemical Composition of aluminium alloy

Comp	si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
%	0.3 to 0.8	0.35	0.05 to 0.15	0.01 to 0.05	0.01 to 0.05	0.10	0.04 to 0.35	0.02 to 0.10	Rest

3. DESIGN OF EXPERIMENT

In design of experiment RSM is used to find combination of factor which gives the optimal response. Response surface methodology [RSM] actually it is a collection of mathematical and statistical techniques useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response. Three process parameters at three levels led to a total of 27 tests for turning operation. Three levels were specified for each of the factors as indicated in Table 3.1

Table 3.1 Factor and level

Sr.No	Parameter	Low	Medium	High
1	Depth of Cut[mm]	0.2	0.4	0.6
2	Feed Rate [mm/rev]	0.06	0.09	0.14
3	Cutting Speed[Rev/min]	40	110	190

Table 3.2 Experimental Results of cutting temperatures

Sr. No	Depth of cut [d] in mm	Cutting Speed [V] in Rev/min	Feed [f] in mm/rev	Temp. in °C
1	0.2	40	0.06	29.1
2	0.2	40	0.09	40.12
3	0.2	40	0.14	34.49
4	0.2	110	0.06	85.7
5	0.2	110	0.09	93.48
6	0.2	110	0.14	103.55

7	0.2	190	0.06	92.68
8	0.2	190	0.09	109.13
9	0.2	190	0.14	112.72
10	0.4	40	0.06	33.5
11	0.4	40	0.09	53.67
12	0.4	40	0.14	46.35
13	0.4	110	0.06	92.8
14	0.4	110	0.09	97.69
15	0.4	110	0.14	109.11
16	0.4	190	0.06	101.12
17	0.4	190	0.09	115.22
18	0.4	190	0.14	119.85
19	0.6	40	0.06	38.2
20	0.6	40	0.09	59.5
21	0.6	40	0.14	61.58
22	0.6	110	0.06	101.25
23	0.6	110	0.09	108.67
24	0.6	110	0.14	114.22
25	0.6	190	0.06	115.22
26	0.6	190	0.09	130.87
27	0.6	190	0.14	126.29

3. 1 Effect of cutting conditions on chip-tool interface temperature:

The cutting temperature is related to varying cutting speed. As the cutting speed increases the friction between cutting tool tip and work piece is also increase which affect on cutting temperature. In our experiment we have seen the maximum temperature 61.58 °C is indicated for 40 rev/min cutting speed.

The graphs were plotted using these values to obtain the relationship between the temperature and the various parameters

3.1. 1 Temperature v/s Cutting speed at varying feed rate:

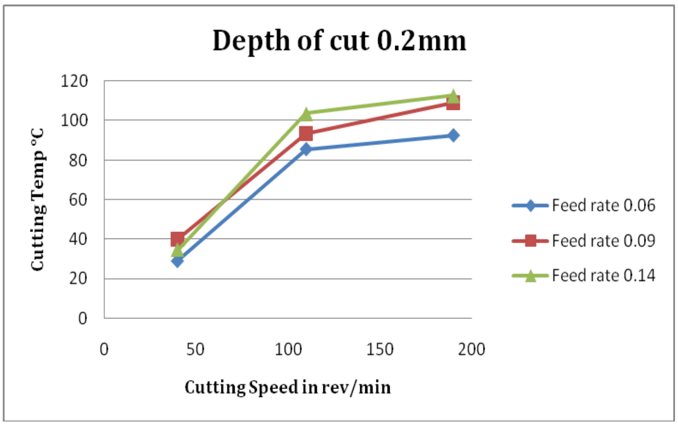

Fig 3. 1 Temperature v/s cutting speed at varying feed rate on depth of cut = 0.2mm

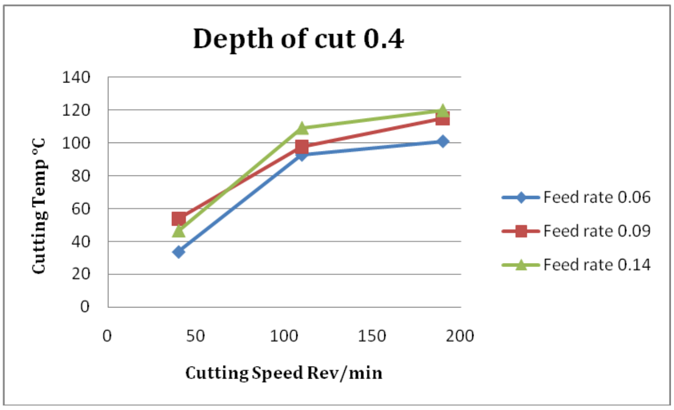

Fig 3. 2 Temperature v/s cutting speed at varying feed rate on depth of cut = 0.4mm

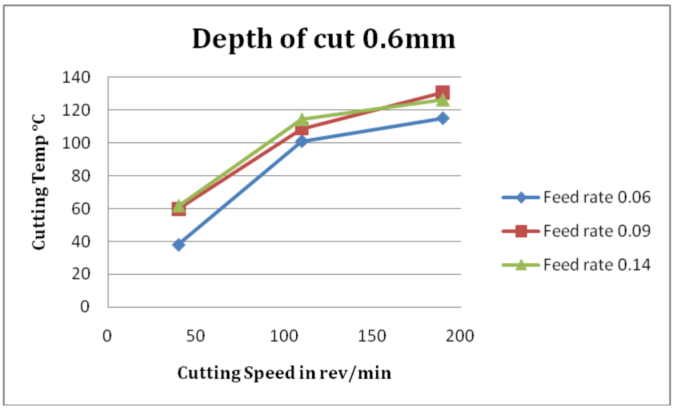

Fig 3. 3 Temperature v/s cutting speed at varying feed rate on depth of cut = 0.6mm

3.1. 2 Temperature v/s Cutting speed at varying Depth of cut:

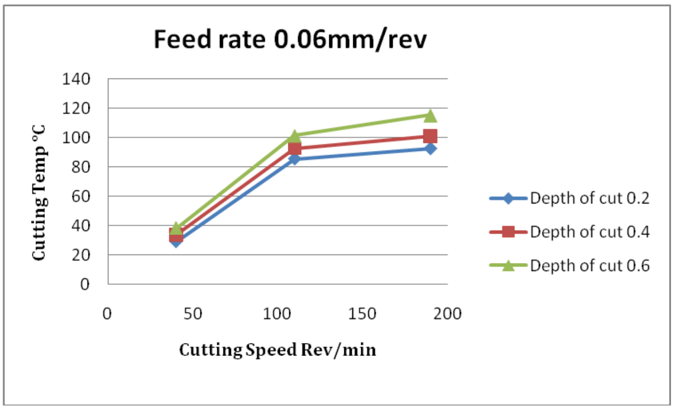

Fig 3. 4 Temperature v/s cutting speed at varying Depth of cut on Feed rate = 0.06mm/rev

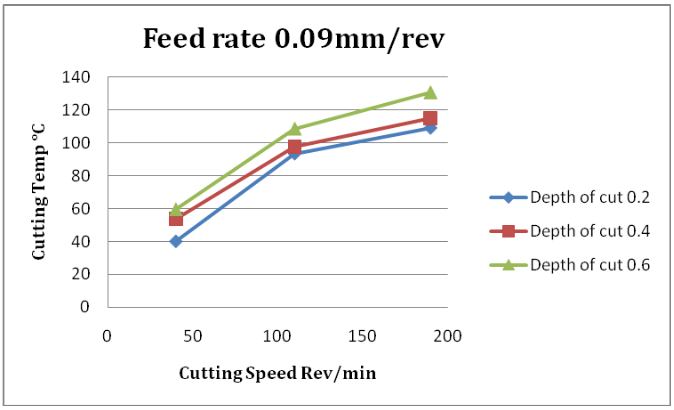

Fig 3. 5 Temperature v/s cutting speed at varying Depth of cut on Feed rate = 0.09mm/rev

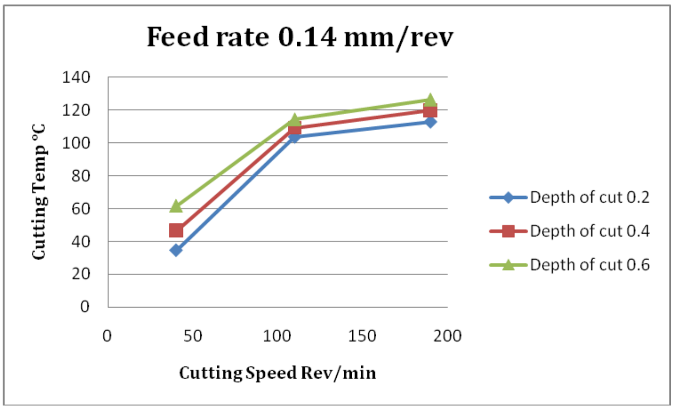

Fig 3. 6 Temperature v/s cutting speed at varying Depth of cut on Feed rate = 0.14mm/rev

3. 2 Regression Analysis:

The regression equation is

T = 0.4 + 43.0 d + 0.453 v + 176 f

Predicator	Coefficient	SE Coefficient	T	P
Constant	0.44	11.25	0.04	0.969
d	43.01	15.89	2.71	0.013
v	0.45301	0.04237	10.69	**0.000**
f	175.61	78.87	2.23	0.036

S = 13.4801 R-Sq = 84.9% R-Sq (adj) = 82.9%

The machining parameters which have p-value less than 0.05 are considered most significant (shown in bold). In this study it is observed that cutting speed is the most significant parameter. These parameters have major influence on the temperature.

R^2 is the percentage of total variation in the response which depends on the factors in the model. The higher the value of R^2, the better the model fits the data.

The adjusted R^2 accounts for the number of predicators or factors in the model. It is useful for comparing models with different number of predicators or factors. It may decrease when another predicator or factor is added to the model.

4. RESULTS AND DISCUSSION

The main purpose of analysis of variance [ANOVA] is to find out which cutting parameters significantly affect the performance characteristics.

Table.4.1 ANOVA Results for cutting temperature

Source	DF	SS	MS	F	P
Regression	3	23409.0	7803.0	42.94	0.000
Residual error	23	4179.4	181.7		
Total	26	27588.4			

The calculated F-ratio values (42.93) are higher than the tabulated F-ratio values (3.054) for 95 % confidence. The factors which have an F ratio larger than the criterion (F ratio from the tables) are believed to influence the average value for the population, and factors which have an F ratio less than the criterion are believed to have no effect on the average.

The estimated response surfaces for the cutting temperature components are illustrated in figure 4.1. From the response surface plots, it is noted that depth of cut increases cutting temperature also increases drastically; also increase in feed rate will lead to produce more temperature. The main factor which affects the cutting temperature is depth of cut. The factor cutting speed was the less influence for cutting temperature.

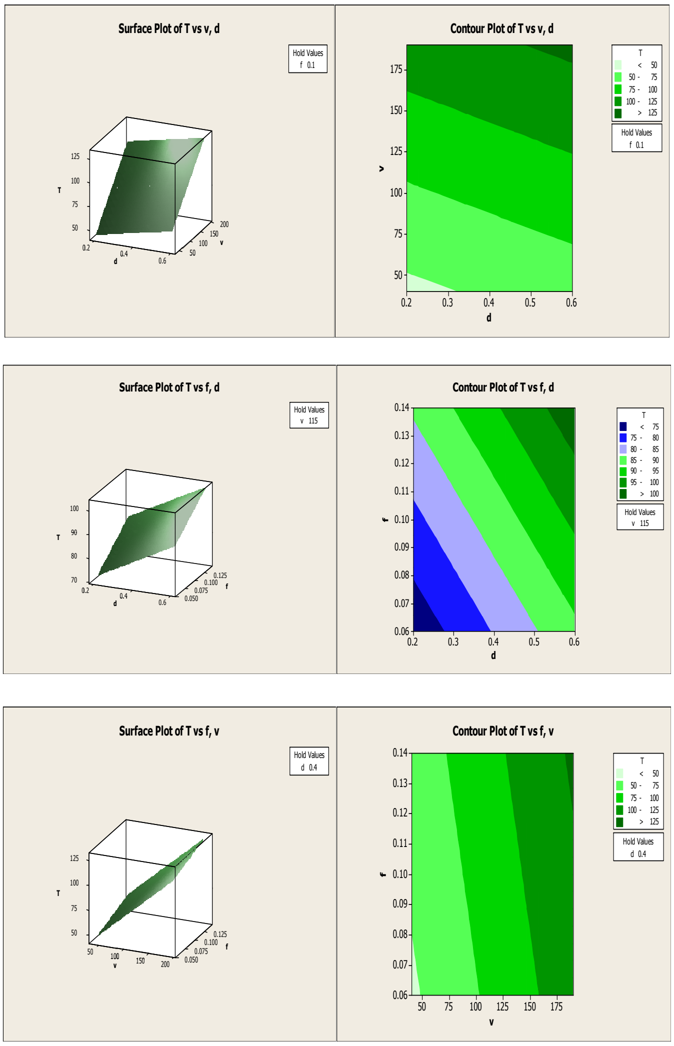

Fig.4.1 Estimated response surface for cutting temperature

5. ANALYSIS OF CUTTING TEMPERATURE

In this analysation is done for various cutting parameters to maximize the response after experiment and determination of mathematical model with best fits. The minimum optimization level of cutting of aluminium alloy in centre lathe machine to obtain minimum temperature and best machining condition at a cutting speed of 190 rev/min ,Depth of cut [DOP] 0.2 mm and feed rate of 0.06 mm/rev. The minimum optimized condition is obtained In table 5.1

Table 5.1 optimized parameters for cutting operation.

Cutting speed in [Rev/min]	Feed rate in [mm/rev]	Depth of cut in [mm]
190	0.06	0.2

6. CONCLUSIONS

Heat generation in primary deformation zone, secondary deformation zone and tertiary deformation zone during machining, causes the temperature distribution in tool-chip interface, tool-work piece interface and in primary zone. There are many parameters by which cutting temperature influenced i.e. too-chip interface temperature.

Following conclusions are derived from the above study:

1. Cutting speed is the major parameter on which temperature depends. For turning operation, as cutting speed increases the tool-chip interface temperature also increases significantly with constant feed rate and depth of cut.
2. Feed rate also affects the temperature in machining. Generally, for turning operation, as the feed rate increases, the tool-chip interface temperature also increases, but the increase is much less when cutting speed increases.
3. It was verified that the cutting temperature was greatly affected by the individual variation of the factors (ALLOY, Cutting speed, DOP, Feed rate), as well as by their interactions.
4. Depth of cut also has less effect than feed rate on cutting temperature. As depth of cut increases, temperature also increases.
5. When turning is performed at a cutting speed of 190 rev/min, depth of cut of 0.20mm and feed rate of 0.06 mm/rev minimum cutting temperature can be achieved.

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