OPTIMIZATION OF MACHINING PARAMETERS ON TEMPERATURE RISE IN CNC TURNING PROCESS OF ALUMINIUM 6061 USING RSM AND GENETIC ALGORITHM

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Abstract: In this present study, the predictive model is developed to observe the effect of nose radius to predict temperature rise on the CNC turning process and to better understanding on the effect of the machining parameters such as cutting speed, feed rate, depth of cut and nose radius. The experiments are conducted as per design of experiments of response surface methodology (RSM) by taking into consideration of aluminium - Al 6061 as workpiece material and Al_2O_3 coated carbide tool as a cutter. A second order mathematical model was developed. The Analysis of Variance (ANOVA) was used to study the performance characteristics of turning operation. The value of probability (F) is less than 0.05 indicates, the model conditions are significant. The cutting speed is the most significant influencing parameter compared to the other parameters. For the optimum cutting parameter leading to temperature rise, the genetic algorithm model is trained and tested in MAT Lab. The genetic algorithm recommends 23.94°C as the best minimum predicted value. The confirmatory test shows the predicted values which were found to be in good agreement with observed values.

Key words: Aluminium 6061, Cutting speed, Feed rate, Depth of cut, Nose radius, Genetic Algorithm, Response surface methodology, Temperature rise.

1. INTRODUCTION

Machining is the term used for removal of material from the workpiece, for cutting the workpiece generally single point cutting tool or multi point cutting tool is used. Surface roughness, tools wear, chip morphology, residual stresses and temperature generated during machining is suggested by many researchers (Powar and Raval, 2016). During machining, the cutting zone temperature is very high and the majority of the heat from the cutting operation carried out by the chip. Tremendous amount of temperature increases tool wear, reduces tool life and poor surface finish, so proper selection of cutting conditions and careful attention must be well thought-out while selecting cutting speed, depth of cut, feed rate, type of lubrication, cutting tool material, cutting tool angle etc. The high-quality machinability improves the reduction of the tool wear, cutting forces, cutting temprature, and a better control of the chip. An improvement in machinability produces a considerable improvement of the surface finish. During the cutting operation, cutting tools are subjected to friction which results temperature rise, less accuracy and poor surface roughness Santos et al., (2011). According to the relative motion between the tool and workpiece, the tool, workpiece surface integrity and machining precision are directly affected by the cutting temperature, (Ming et al., 2003).

Temperature in the cutting zone depends on contact length between tool and chip, cutting forces and friction between tool and work material (Ejieji et al., 2018). The quality of machined surface and optimal cutting temperature decide by the combination of tool and work material, the geometry of cutting tool, chip control, magnitude and the direction of cutting force, stabilized cutting force. (Astakhov, 2010) used a technique to investigate the influence of temperature on the tool wear, during high speed turning of Inconel 718 and high - speed milling of Ta6V alloys. The thermocouple consisted of a tungsten wire, which was embedded in the tool. (Sullivan and Cotterell, 2001) measured by using two thermocouples of temperatures while turning of aluminum 6082-T6. They indicated that an increase in cutting speed resulted in a decrease of the temperature in machined surface. The author recognized the reduction in temperature at higher metal removal rate, which results more heat dissipated away by the chip and results less heat being by the workpiece. The author Ceau et al., (2010) investigated that the turning operation of unalloyed steel, the natural and artificial thermocouple, infrared camera and optical pyrometer is used to measure the temperature of the tool and suggests that the temperature depend on the parameters of the cutting process. To analyze the influence of the cutting parameters the mathematical regression technique was used to predict temperature.

1.1 Influence of nose radius in turning tool

The point of intersection of tool point **(**rake surface, principal flank surface, auxiliary flank surface) surfaces gives rise to the tool tip. A small radius provided in the tool is known as nose radius and it determines the strength of the tool point. The larger nose radius will better resist mechanical failure. (Chou and Song, 2004) conducted an experimental investigation while turning of hardened AISI 52100 steels and suggests that the larger nose radius results better quality surface finish. (Parida and Maity, 2017) conducted an analysis by considering the variation in nose radius on cutting forces, cutting temperature and stress using finite element modeling on turning of Inconel 718. Hua and Liu (2018) investigated the effect of nose radius on machined surface on Inconel 718. Kimakh et al., (2018) conducted the experiment by considering the cutting speed, feed rate and nose radius of the tool, the author suggests that the tool nose radius have a slight influence on the surface state compared to increase of cutting speed and decrease of feed rate. This paper presents an experimental and theoretical study of temperatures of the machined surface of steel workpieces in metal cutting. The author (Silva and Wallbank, 1999) measured the surface temperature by considering the parameters such as cutting speed, feed rate, and tool nose radius and its effect.

1.2 Genetic algorithm (GA)

Genetic algorithms use biologically optimistic method such as genetic inheritance, natural selection, mutation and sexual reproduction (recombination or crossover). Genetic algorithms are normally carried out using computer simulations. The optimization problems are carried by using biologically inspired operators such as mutation, crossover and selection (Goldberg, 1989). (Abburi and Dixit, 2007) conducted an experiment to minimize the production time by using multi objective optimization of multi pass turning operation. The genetic algorithm is used for optimization. (Reddy and Rao, 2006) conducted an experiment in end milling operation by considering tool geometry - radial rake angle and nose radius and cutting conditions - cutting speed and feed rate as input parameters. The optimization was carried out using genetic algorithm.

2. TEMPERATURE MEASUREMENT

A lot of attempts are made by the researchers to determine the temperature at the tool chip interface by direct measurement and indirect measurements. . Longbottom and Lanham, (2005) reviewed practically by considering the various temperature measurement methods in metal cutting. (Takeuchi et al., 1982) demonstrated that while turning, the cutting tool is subjected to tool wear, thermal deformation results reduction in surface roughness under high cutting temperatures of the tool. (Li and Liang, 2005) conducted an experiment by using heat source method to model the temperature distributions under dry cooling conditions. The author suggests that cutting speed is amost influencing factor compared to other factors such as feed rate and depth of cut. (Lazoglu and Altintas, 2002) examine a numerical model approach based on the finite difference method to predict tool and chip temperature while machining.

3. EXPERIMENTATION DESIGN

Response surface methodology is the most effective tool to analyze the results obtained from factorial experiments. It is an excellent resourceful tool in engineering field to solve, analyze and to model and also provides adequate information with fewer number of experiments (Box and Behnken, 1960).
The response temperature rise T can be expressed as a function of process parameters cutting speed (υ_c), feed rate (f_z), depth of cut (a_p) and nose radius (r_n), equation (1).

$$\text{Temperature Rise} = \phi\left(v_c, f_z, a_p, r_n\right) + eui \qquad (1)$$

where ‘ϕ’ is the response surface, ‘e’ is the residual, ‘u’ is the number of observations in the factorial experiment and ‘i’ represents level of the ‘i^{th}’ factor in the ‘u^{th}’ observation. When the mathematical form of ‘ϕ’ is unknown, this function can be approximated satisfactorily within the experimental region by polynomials in terms of the process parameter variable.

3.1 Identification of process parameter and development of design matrix

A central composite design is the most commonly used in response surface designed experiment. Central composite designs are a factorial design with center points and star points. The parameters are cutting speed, feed rate, depth of cut, and nose radius are selected and its ranges are identified using American Society for Metals (ASM) hand book. The upper factorial level is +2 and lower factorial level is −2 of all the four variables as shown in Table 1. The intermediate levels of 0 for all the variables are calculated by interpolation. The temperature of the tool is the output response. The design matrix chosen to conduct the experiments was a four-factor central composite rotatable design (CCD) consisting of 30 sets of coded conditions as shown in Table 2. where β_0 is a constant, β_1, β_2, β_3 is the linear term coefficient, β_{11}, β_{22} is the quadratic term coefficient and β_{12} is the interaction term coefficient.
An accurate analysis is carried out with the observed reading using DESIGN EXPERT V12 software. A second order quadratic model is developed for the prediction of temperature. The model is verified for

Fig. 1. Experimental set up using XLTURN- CNC lathe

3.2 Experimental Details

The experiments were conducted on a XLTURN-CNC lathe as shown in Figure 1. The work material used was aluminium –Al 6061 hardness and was tested found to be 43HRC. The chemical composition of aluminium 6061 is shown in Table 3. The workpiece material is used in rare application such as aircraft and aerospace mechanisms, marine accessories etc. The test specimen of diameter 40 mm and length 100 mm is taken for experimentation. A tool of Al_2O_3 coated carbide tool was used for turning under dry condition, by considering the process parameters such as cutting speed, feed rate, depth of cut and nose radius. A_1 mm hole is drilled in workpiece at 10 mm below the machining surface and the temperature is measured by using K-type thermocouple and the observations are tabulated to obtain the mathematical model.

Table 2. Experimental values with responses

Al 6061	**Al**	**Si**	**Fe**	**Cu**	**Mn**	**Mg**	**Cr**	**Zn**	**Ti**
Weight (%)	Bal	0.40-0.80	0.70 max	0.15-0.40	0.15	0.8-1.2	0.04-0.35	0.25 max	0.15 max

Table 3. Chemical composition for aluminium - Al 6061

Trail. No.	**Cutting speed (m/min)**	**Feed rate (mm /rev)**	**Depth of cut (mm)**	**Nose radius (mm)**	**Temperature rise °C To (observed)**	**Temperature rise °C Tp (predicted)**
1.	120	0.36	0.6	0.4	28.8	28.80
2.	90	0.18	0.6	0.4	29.8	29.85
3.	105	0.27	0.8	0.6	26.6	26.49
4.	105	0.27	0.4	0.6	25.8	26.10
5.	90	0.36	0.6	0.8	24.9	24.68
6.	105	0.27	0.4	0.2	26.8	26.83
7.	120	0.36	0.6	0.8	29.7	30.11
8.	105	0.27	0.4	0.6	28.2	26.10
9.	75	0.27	0.4	0.6	29.3	29.61
10.	90	0.18	0.2	0.4	27.1	26.80
11.	90	0.36	0.6	0.4	28.6	28.56
12.	105	0.27	0.4	0.6	25.6	26.10
13.	105	0.27	0	0.6	29.6	29.69
14.	120	0.18	0.6	0.8	29.8	29.75
15.	120	0.18	0.2	0.4	30.1	30.23
16.	105	0.27	0.4	0.6	25.6	26.10
17.	90	0.36	0.2	0.8	27.8	27.83
18.	90	0.36	0.2	0.4	27.2	27.16
19.	105	0.27	0.4	1	27.1	27.06
20.	120	0.18	0.2	0.8	34.2	34.35
21.	90	0.18	0.2	0.8	25.8	25.71
22.	105	0.45	0.4	0.6	27.6	27.56
23.	105	0.09	0.4	0.6	26.8	26.83
24.	120	0.36	0.2	0.4	30.4	30.50
25.	105	0.27	0.4	0.6	25.8	26.10
26.	120	0.18	0.6	0.4	30.1	30.18
27.	135	0.27	0.4	0.6	38.8	38.48
28.	90	0.18	0.6	0.8	24.2	24.21
29.	120	0.36	0.2	0.8	36.5	36.36
30.	105	0.27	0.4	0.6	25.6	26.10

3.3 Response surface model for the prediction of Temperature

(Sivasakthivel and Sudhakaran, 2013); (Mahesh et al., 2015) conducted the experiment and formed the general form of quadratic polynomial which gives the relation between response surface y and the process variable x, equation (2):

$$Y = \beta_0 + \beta_1 x1 + \beta_2 x2 + \beta_3 x3 + \beta_{11} x12 + + \beta_{22} x22 + \beta_{12} x1 \qquad (2)$$

where β_0 is a constant, β_1, β_2, β_3 is the linear term coefficient, β_{11}, β_{22} is the quadratic term coefficient and β_{12} is the interaction term coefficient.

An accurate analysis is carried out with the observed reading using DESIGN EXPERT V12 software. A second order quadratic model is developed for the prediction of temperature. The model is verified for its adequacy using analysis of variance (ANOVA). ANOVA analysis is shown in Table 4 for the prediction of temperature.

The **Model F-value** of 55.14 implies the model is significant. There is only a 0.01% chance that an F-value this large occurs due to noise.

The **P-values** less than 0.05 indicate that the model terms are significant. In this case A, C, AC, AD, BC, BD, CD, A^2, B^2, C^2 are significant model terms. The values greater than 0.1 indicates that the model terms are not significant.

The **Lack of Fit F-value** of 0.06 implies the Lack of Fit is not significant relative to the pure error. There is a 99.99% chance that a Lack of Fit F-value this large could occur due to noise. Non-significant lack of fit is good

The regression equation obtained by using Design Expert software is given below, equation (3).

In the present research, the input parameters: s cutting speed, feed rate, depth of cut and nose radius were used to develop mathematical models using the design of experiment DOE technique, response surface methodology. The calculated value of the F-ratio is more than the standard (tabulated) value of the F-ratio for temperature rise is shown in the Table 4; the model is adequate for a desired 95% level of confidence. The error found between the experimental and predicted values is acceptable level.

Table 4. ANOVA table for prediction of temperature rise

Source	Sum of squares	df	Mean Square	F-value	p-value	
Model	307.03	14	21.93	55.14	< 0.0001	**Significant**
A-Cutting speed	117.93	1	117.93	296.51	< 0.0001	
B-Feed rate	0.8067	1	0.8067	2.03	0.1749	
C-Depth of cut	15.36	1	15.36	38.62	< 0.0001	
D-Nose radius	0.0817	1	0.0817	0.2053	0.6569	
AB	0.01	1	0.01	0.0251	0.8761	
AC	9.61	1	9.61	24.16	0.0002	
AD	27.04	1	27.04	67.99	< 0.0001	
BC	2.72	1	2.72	6.85	0.0195	
BD	3.06	1	3.06	7.7	0.0142	
CD	20.7	1	20.7	52.05	< 0.0001	
A^2	108.12	1	108.12	271.85	< 0.0001	
B^2	2.04	1	2.04	5.14	0.0386	
C^2	6.8	1	6.8	17.1	0.0009	
D^2	1.21	1	1.21	3.05	0.101	
Residual	5.97	15	0.3977			
Lack of Fit	0.6258	10	0.0626	0.0586	0.9999	**not significant**
Pure Error	5.34	5	1.07			
Cor Total	313	29				

4. RESULTS AND DISCUSSIONS

4.1. Interaction Effect

The interaction effect of process parameters on the temperature rise is discussed below.

The Figure 2 depicts the interaction effect of cutting speed on temperature rise.

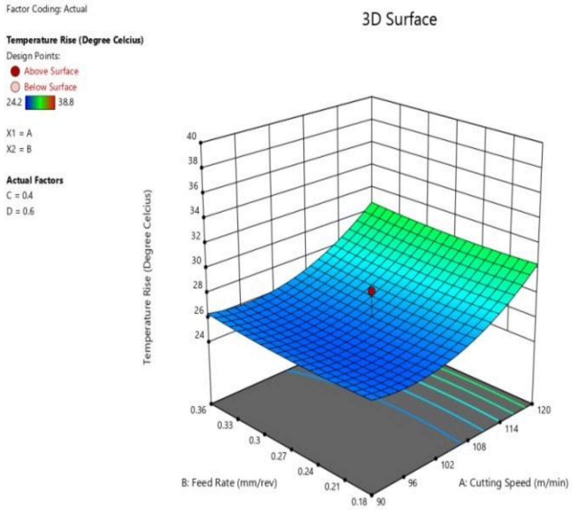

Fig. 2. Interaction effect of cutting speed and feedrate over temperature rise

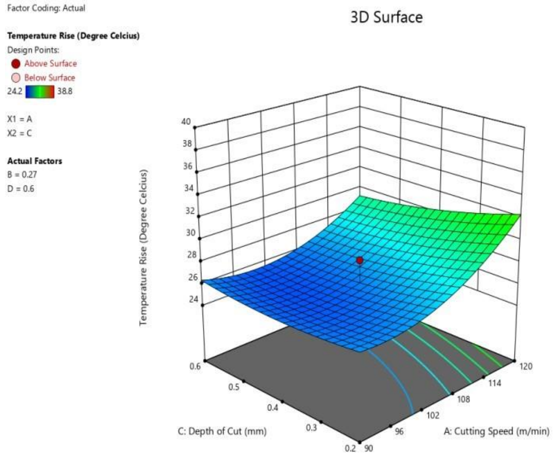

Fig. 3. Interaction effect of cutting speed and depth of cut over temperature rise

The Figure 2 evidenced that the cutting speed on the temperature rise of turning process has a significant effect. The figure illustrates that the increase in cutting speed resulted in increases in temperature rise and it is minimal at the cutting speed range of 91m/min to 102m/min. Increasing the cutting speed increases the rate at which energy dissipated through plastic deformation and friction. Thus the rate of heat generation in the cutting zone increases resulted in a high cutting temperature, an increasing cutting speed results in increasing the cutting temperature rise to a point where automatic diffusion between the tool and workpiece material takes place, which in turn propagates the tool wear. The results are verified from the ANOVA table.

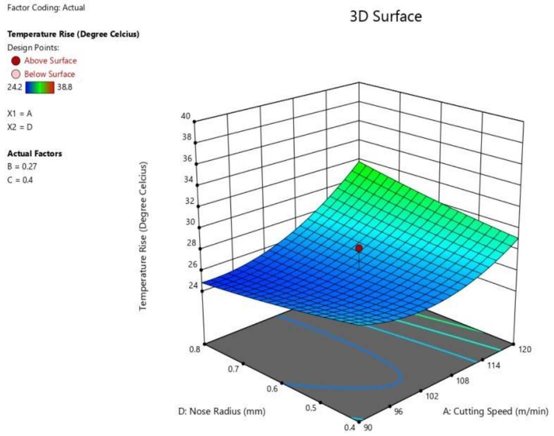

Fig. 4. Interaction effect of nose radius and cutting speed over temperature rise

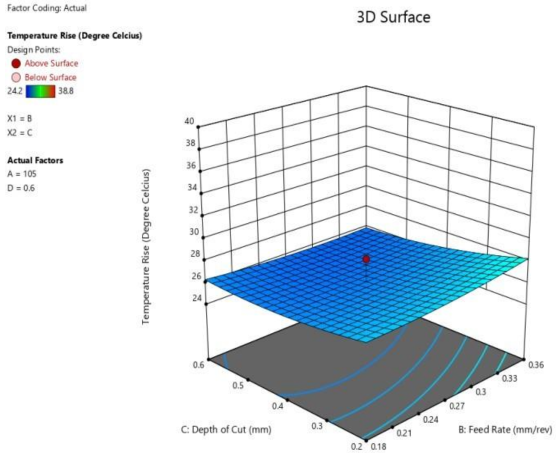

Fig. 5. Interaction effect feed rate and depth of cut over temperature rise

Figure 3 evidenced that the depth of cut on the temperature rise of turning process has a significant effect. The figure illustrates that the increase in depth of cut subsequently there is an increase in temperature rise. If there is an increase in depth of cut, the larger amount of workpiece materials to be removed, results increase in cutting temperature. At lower depth of cut, less amount of workpiece material adhere on the flank of the tool than at larger depth of the cut. This adhesion of workpiece material on the tool flank causes an increase in temperature rise. The results are verified from the ANOVA Table 4.

Figure 4 depicts the interaction and effect of nose radius on temperature rise. The above interaction figure evidenced that the nose radius on the temperature rise of turning process has not a significant effect. The conclusion can also be verified from the ANOVA Table 4. The cutting temperature mainly affected by the nose radius, the larger nose radius, the greater the deformation and the cutting force and more heat will be generated in chip formation. However, the increases nose radius results in increased length of the active part of the cutting edge and the mass of the tool point.

Figure 5 evidenced that the increase in feed rate and depth of cut, the temperature rise of turning process has a slight significant effect.

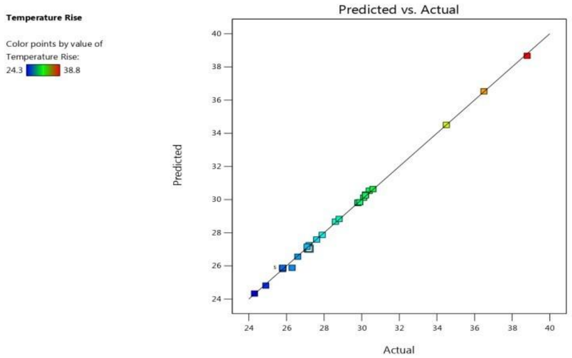

Fig. 6. Relationship between predicted vs actual

5. OPTIMIZATION BY USING GENETIC ALGORITHM

(Suresh et al., 2002) suggested the use of genetic algorithm using MATLAB. The selection of cutting parameters for optimization using Genetic algorithm by using MATLAB minimizes the cutting temperature. In this study, an attempt is made to determine the optimum cutting values of cutting parameters to obtain the best possible temperature within the specified range. The minimization of temperature by using genetic algorithm can be expressed as:

Minimize: T_0 (υ_c, $f_{z,}$ $d_{c,}$ r_n)

Within ranges of cutting parameters,
90m/min $\leq \upsilon_c \leq$ 120m/min
0.18mm/rev $\leq f_z \leq$ 0.36mm/rev
0.20mm $\leq a_p \leq$ 0.60mm
0.40mm $\leq r_n \leq$ 0.80mm

To obtain the best possible optimal results, the number of the initial population size, Scaling function rank, mutation rate, crossover rate, the type of selection function and generations to be considered as shown in Table 5.

Table 5. GA parameters

Parameters	**Setting values**
Population size	100
Scaling function	Rank
Function	Stochastic uniform
Mutation function	Gaussian
Mutation rate	0.1
Crossover function	Scattered
Crossover rate	1.0
Generations	1000

Figure 7 shows the results obtained by running the genetic algorithm solver for minimizing temperature rise. In Figure 7 it is evident that the minimum temperature rise occurs at the 52th generation and the value is 23.94°C.

Figure 8 shows the performance of fitness value with generation using GA and the run solver view results from MATLAB software shows the best individual performances of variables in coded form.

5.1 Validation of the model

Table 2 shows that a regression model and equation (2) shows the mathematical equation to predict temperature are developed using Central Composite Design by using Response Surface Methodology (RSM) of Design of Experiments. Table 6 shows the predicted vs experimental value of temperature rise. The optimization is carried out using Genetic Algorithm with the aid of MATLAB R2013asoftware to validate with physical measured temperature rise. The percentage (%) of error is within ±2%, so the model is validated. The experimental values and results of temperature rise are in optimum for the cutting parameter as predicted by Genetic Algorithm shows excellent agreements shown in Table 6.

Table 6. Optimized process parameter predicted by GA

Trail No.	Cutt-ing speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Nose radius (mm)	Confirmatoy test		Error (%)
					Optimum value (GA)	Observed value	
1	93.23	0.23	0.59	0.8	23.95	23.69	0.2
2	94.49	0.23	0.6	0.8	23.97	23.99	-0.08
3	94.82	0.24	0.59	0.79	24.0	23.94	0.25

6. CONCLUSIONS

The experimentation are employed using central composite method for predicting temperature rise in turning operation of Aluminum 6061 workpiece material using Al_2O_3 coated carbide tool by considering the input parameter as cutting speed, feed rate, depth of cut and nose radius. The optimization is done by using Surface Response Methodology (RSM) and Genetic Algorithm (GA). The cutting speed is the greatest significant parameter for temperature rise in turning process. The temperature rise is minimal between 91m/min and 98m/min cutting speed. It is clear from this study that the best minimum temperature values in between 0.6mm to 0.8mm of nose radius in cutting tool. The optimization carried out by using RSM and Genetic algorithm, results a good agreement between the actual temperature rise and the predicted temperature rise. The genetic algorithm recommends that the minimum temperature is 23.94°C and corresponding cutting variables values are 93.95m/min, 0.232mm/rev, 0.592mm and 0.80mm for cutting speed, feed rate, depth of cut, nose radius respectively. The confirmatory test showing the predicted value is found to be in good agreement with observed values.

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