# Optimization of CNC Turning Process Parameters on ALUMINIUM 6061 Using response surface methodology

**N.zeelan basha,**
**Department of Mechanical Engineering,**
**Anna University, regional Centre, Coimbatore,**
**Tamil Nadu, India.**

**S.vivek,**
**Assistant Professor,**
**Department of Mechanical Engineering,**
**Anna University, regional Centre**
**Coimbatore,**
**Tamil Nadu, India.**

***Abstract***

This paper presents the effect of process parameter in turning operation to predict surface roughness. The turning process by using CNC turning lathe is widely used in industry because of its versatility and efficiency. Applications of the turning process can be found in many industries ranging from large engine manufactures to small die shops. The parameters that affect the turning operation are vibration, tool wear, surface roughness etc. Among this surface roughness is an important factor that affects the quality in manufacturing process. The main objective of this paper is to predict the surface roughness on aluminium 6061, by optimizing the input parameters such as spindle speed, feed rate and depth of cut by using coated carbide tool. A second order mathematical model is developed using regression technique and optimization is carried out using Box-Behnken of response surface methodology. The application of response surface methodology for optimizing the input parameters such as spindle speed (rpm), feed rate (mm/min) and depth of cut (mm), the output parameter surface roughness can also be optimized for economical production. Therefore, this study attempts the application of response surface methodology to find the optimal solution of the cutting conditions for giving the minimum value of surface roughness using design- expert 8.0 software.

***Key words**: spindle speed, depth of cut, feed rate, Surface roughness, RSM, optimization, Anova, CNC Machine.*

## I. INTRODUCTION

Aluminum 6061 is good electrical and thermal conductivities as well as good ductility and malleability alloy, is mainly used in application such as aircraft and aerospace components, marine fittings, transport, bicycle frames, camera lenses, drive, shafts, electrical fittings and connectors, brake components, valves, couplings. But some of the limitations during machining of aluminum 6061 are lower strength at elevated temperatures and limited formability affects quality of desired output.

Response Surface Methodology (RSM): Response surface methodology is a specialized DOE technique that may be used to detail and optimize transfer functions of a DFSS project .The method can be used in the optimization phase of the DFSS algorithm. Response surface methodology (RSM) is a combination of statistical and optimization methods that can be used to model and optimize designs. It has many applications in design and improvement of products and processes. And it is a fundamental method to derive the relationship between the different parameters affecting the process. RSM works by applying different designed experiments to obtain a polynomial model of the process keeping the independent variable as the system output which is minimized. A comprehensive algorithm of the calculations involved. These approaches comprise a systematic method of scheduling experiments as well as gathering and analyzing records with a near-optimum use of resources. The most widely employed methodologies for surface roughness prediction in terms of machining parameters are the Response Surface Methodology (RSM). The various forms of regression analysis concentrate on using existing data to predict future results. It is used to examine the relationship among several factors and the results. Regression is applied to create models to predict the results when combinations of factors interact under various conditions. It is one of the most widely used statistical tools because it provides a simple method of establishing a functional relationship among variables. The relationship is expressed in the form of an equation connecting the response or dependent variable (y),and one or more independent variables,$x_1,x_2,x_3,\ldots\ldots.x_n$.

## II. LITERATURE REVIEW

[**1**]An experiment has been conducted to observe the significance of process parameters and influence of the radial rake angle of the tool in end mill cutter. Mathematical model has been developed to predict surface roughness in terms of machining parameters such as spindle speed, feed rate, radial, axial depth of cut, and rake angle of cutting tool. The second-order mathematical models, in terms of the machining parameters, have been developed using Response surface methodology (RSM). The experiment is conducted on aluminum Al 6063 by HSS end mill cutter, the surface roughness is measured by using Surf tester SJ- 201

**[2]** The influence of machining process parameters such as cutting speed (X1, m/min), feed rate(X2, mm/rev), and depth of cut (X3, mm) on the output parameters such as material removal rate and surface roughness can also be optimized. Relationship between material removal rate and input parameters and between surface roughness and input parameters are arrived through Minitab software. These regression equations are solved using genetic algorithm tool called user interface method and the optimum combinations of input parameter for input parameters for maximum material removal rate (MRR) and minimum surface roughness (Ra) had been arrived using mat lab software. The optimum combination of input parameters for maximization of material removal rate is found to be cutting speed 79.99m/min, feed rate 0.25mm/rev, depth of cut 0.1mm and best fitness value is 2122.23 mm3/min. and the optimum combination of input parameters for minimization of surface roughness found to be cutting speed 79.9m/min, feed rate 0.15mm/rev, depth of cut 0.1mm and Best fitness for minimization of surface roughness is 0.69 µm.

**[5]** To determine the optimum cutting conditions leading to minimum surface roughness in milling of mold surfaces by coupling response surface methodology (RSM) with a developed genetic algorithm (GA). RSM is utilized to create an efficient analytical model for surface roughness in terms of cutting parameters: feed, cutting speed, axial depth of cut, radial depth of cut and machining tolerance. RS model is further interfaced with the GA to optimize the cutting conditions for desired surface roughness. The GA reduces the surface roughness value in the mold cavity from 0.412µm to 0.375µm corresponding to about 10% improvement.

**[9]** The effects of cutting speed, feed rate, work piece hardness and depth of cut on surface roughness and cutting force components in the hard turning were experimentally investigated. Four-factor (cutting speed, feed rate, hardness and depth of cut) and three-level fractional experiment designs completed with a statistical analysis of variance (ANOVA) were performed. Mathematical models for surface roughness and cutting force components were developed using the response surface methodology (RSM). the ranges for best cutting conditions are proposed for serial industrial production are feed force (Fa) and the cutting force (Fv) are strongly influenced by the depth of cut, (56.77%) and (31.50%) respectively. On the opposite, the cutting speed has a very small influence (0.14%). The best surface roughness was achieved at the lower feed rate and the highest cutting speed.

**[12]** Two independent data sets were obtained on the basis of measurement: training data set and testing data set. Spindle speed, feed rate, depth of cut, and vibrations are used as independent input variables (parameters), while surface roughness as dependent output variable. On the basis of training data set, different models for surface roughness were developed by genetic programming. Accuracy of the best model was proved with the testing data. It was established that the surface roughness is most influenced by the feed rate, whereas the vibrations increase the prediction accuracy.

**[13]** In order to find out the effect of tool geometry parameters on the surface roughness during turning, response surface methodology (RSM) was used and a prediction model was developed related to average surface roughness (Ra) using experimental data. The results indicated that the tool nose radius was the dominant factor on the surface roughness. In addition, a good agreement between the predicted and measured surface roughness was observed. Therefore, the developed model can be effectively used to predict the surface roughness on the machining of AISI 1040 steel within 95% confidence intervals ranges of parameters. Tool nose radius is the most significant factor on surface roughness with 51.45% contribution in the total variability of model. Also, approach angle and rake angle are significant factors on surface roughness with 18.24% and 17.74% contribution in the total variability of model. Using response optimization show that the optimal combination of machining parameters are (0.4 mm, 60°, -3°) for tool nose radius, approach angle and rake angle.

## III. METHODOLOGY

### A. FOR EXPERIMENTAL WORK

i) The material and tool inserts are selected based on the problem identification study.
ii) Identifying different ranges of input parameters and their levels.
iii) Measuring surface roughness (Ra) using surface roughness tester SJ-210.

### B. FOR THEORETICAL WORK

i) Formation of regression equation using design-expert 8.0 software.
ii) Calculation of predicted readings of surface roughness (Ra)

### C. FOR ANALYSIS WORK

i) Checking the adequacy of the models developed
ii) Comparing the optimization results with the experimental results and finding out the percentage error between them.
iii) Presenting the effects of the process parameters on the mechanical properties in graphical form and analyzing the results.
iv)Validation of results.

## IV. EXPERIMENTAL DETAILS

### A. WORK PIECE MATERIAL

The work material used was aluminium 6061 and its chemical composition and hardness are tested and hardness value is found to be 43 HRC. The table below shows the chemical composition of aluminium 6061.

**Table 1 chemical composition for alumunium 6061**

| **Weight (%)** | **6061** |
|---|---|
| Al | Bal |
| Si | 0.40-0.80 |
| Fe | 0.70 max |
| Cu | 0.15-0.40 |
| Mn | 0.15 |
| Mg | 0.8-1.2 |
| Cr | 0.04-0.35 |
| Zn | 0.25 max |
| Ti | 0.15 max |
| Others each | 0.05 max |
| Others each | 0.15 max |

### B.CUTTING TOOL

AK10 Carbide Inserts for Turning Ground and Polished for Aluminium Uni-tip was used for turning.

**Figure- 1 cutting tool AK10 Carbide insert**

### C.EXPERIMENTAL SET UP AND CUTTING CONDITIONS

Machining process was carried out in CNC lathe. The machining process involved various cutting parameters such as cutting speed, depth of cut, feed rate. The measurements of average surface roughness (Ra) were taken on surface roughness Tester SJ-210.Three measurements of surface roughness were obtained at different surface of machined work piece and average value is used in the further analysis

### D. SURFACE ROUGHNESS TESTER SJ-210

The Surface roughness tester used for measuring surface roughness (Ra) in this experimental analysis is given below


**Figure- 2 Surface roughness Tester SJ-210**

### E.CNC LATHE

The CNC Lathe used for machining Purpose shown below along with specification,


**Figure- 2 CNC XL Turning Lathe**

**Specification:**
Control system-fanuc emulated
Spindle power-1Hp
Spindle speed-100 to 3000 rpm
Max. Turning dia-32mm
Rapid traverse rate-1.2m/min

F. COMBINATION OF PARAMETERS AND THEIR LEVELS

In this experimental analysis the parameters has been conducted in three levels -1, 0, 1

**Table 2 Combination of Parameters and their Levels**

| Cutting parameter | Units | Levels | | |
|---|---|---|---|---|
| | | -1 | 0 | 1 |
| spindle speed | rpm | 1000 | 1500 | 2000 |
| Feed rate | mm/min | 0.04 | 0.08 | 0.12 |
| Depth of cut | mm | 0.6 | 0.7 | 0.8 |

G. EXPERIMENTAL VALUES

1) Input parameters

**X1** -spindle speed (rpm)

**X2** -Feed rate (mm/min)

**X3**-Depth of cut (mm)

2) Output parameters

**Y** -surface roughness Ra (µm)

**Table 3 Experimental values**

| **Exp.no** | **Input Parameters** | | | **Output Parameters** |
|---|---|---|---|---|
| | $X_1$ | $X_2$ | $X_3$ | $Y_1$ |
| 1 | 1500 | 0.08 | 0.6 | 0.696 |
| 2 | 1500 | 0.06 | 0.7 | 0.687 |
| 3 | 1500 | 0.06 | 0.7 | 0.684 |
| 4 | 2000 | 0.06 | 0.6 | 0.628 |
| 5 | 1500 | 0.04 | 0.8 | 0.683 |
| 6 | 1500 | 0.06 | 0.7 | 0.688 |
| 7 | 2000 | 0.08 | 0.7 | 0.72 |
| 8 | 1000 | 0.08 | 0.7 | 0.72 |
| 9 | 1000 | 0.04 | 0.7 | 0.76 |
| 10 | 1500 | 0.04 | 0.6 | 0.67 |
| 11 | 1500 | 0.06 | 0.7 | 0.673 |
| 12 | 2000 | 0.04 | 0.7 | 0.65 |
| 13 | 1000 | 0.06 | 0.6 | 0.681 |
| 14 | 1500 | 0.06 | 0.7 | 0.672 |
| 15 | 1500 | 0.08 | 0.8 | 0.686 |
| 16 | 2000 | 0.06 | 0.8 | 0.7 |
| 17 | 1000 | 0.06 | 0.8 | 0.682 |

H.ANOVA TABLE

Analysis of Variance used to test the difference between 3 parameters which has been experimented and also it shows the significant values

**Table 4 ANOVA table**

I. REGRESSION EQUATIONS

Regression equations were formed using design-expert 8.0 software for surface roughness Ra (**Y**)

The regression equation for Surface Roughness Ra (**Y**) is

$$\mathbf{Y} = +0.53925-5.37950E-004*\mathbf{X_1}-7.39875*\mathbf{X_2}+2.13100*\mathbf{X_3}+2.75000E003*\mathbf{X_1X_2}+2.55000E-004*\mathbf{X_1X_3}-2.87500*\mathbf{X_2X_3}+5.14000E-008*\mathbf{X_1}^2+47.12500*\mathbf{X_2}^2-1.59000*\mathbf{X_3}^2$$

V.RESULTS AND DISCUSSIONS

The interaction effect of process parameters on the surface roughness is discussed below.

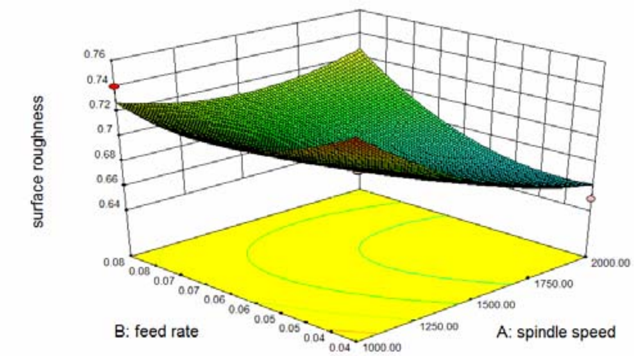


**Fig.4. Surface interaction dimensional views and direct effect views of spindle speed and feed rate over surface roughness.**

Fig.3 shows the interaction and direct effect of feed rate and spindle speed on surface roughness. The above interaction figure evidenced that the spindle speed and feed rate on the surface roughness of turning process has a significant effect. As the spindle speed increases from 1000 rpm to 2000 rpm the surface roughness value is reduced from 0.72 to 0.66 µm, where feed rate has the inverse relationship on surface roughness compared to the spindle speed. From the result it is concluded that the change in feed rate (0.04-0.08 mm/min) has a significant effect on surface roughness (0.72-0.66µm) at higher spindle speed (2000rpm) whereas the change in feed rate (0.04-0.08 mm/min) has no significant effect on surface roughness (0.71-0.72µm) at lower spindle speed (1000 rpm). The conclusion can also be verified from the ANOVA table 4.

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F | |
|---|---|---|---|---|---|---|
| Model | 0.011693 | 9 | 0.001299 | 5.689014 | 0.0160 | significant |
| A-spindle speed | 0.00324 | 1 | 0.00324 | 14.18841 | 0.0070 | |
| B-feed rate | 0.000435 | 1 | 0.000435 | 1.905399 | 0.2099 | |
| C-depth of cut | 0.001058 | 1 | 0.001058 | 4.632949 | 0.0684 | |
| AB | 0.003025 | 1 | 0.003025 | 13.24638 | 0.0083 | |
| AC | 0.00065 | 1 | 0.00065 | 2.847424 | 0.1354 | |
| BC | 0.000132 | 1 | 0.000132 | 0.579119 | 0.4715 | |
| A^2 | 0.000695 | 1 | 0.000695 | 3.044489 | 0.1245 | |
| B^2 | 0.001496 | 1 | 0.001496 | 6.551352 | 0.0376 | |
| C^2 | 0.001064 | 1 | 0.001064 | 4.661251 | 0.0677 | |
| Residual | 0.001599 | 7 | 0.000228 | | | |
| Lack of Fit | 0.000136 | 3 | 0.000453 | 7.592127 | 0.0397 | Significant |
| Pure Error | 0.000239 | 4 | 5.97E-05 | | | |
| Cor Total | 0.013291 | 16 | | | | |

| sl | Input Parameters | | | Output Parameters | | Error |
|---|---|---|---|---|---|---|
| | $X_1$ | $X_2$ | $X_3$ | $Y_1$ EXPERIMENTAL | $Y_1$ PREDICTED | |
| 1 | 1000 | 0.04 | 0.7 | 0.760 | 0.750 | 1.265 |
| 2 | 1500 | 0.04 | 0.6 | 0.670 | 0.661 | 1.304 |
| 3 | 2000 | 0.06 | 0.6 | 0.628 | 0.630 | 0.002 |

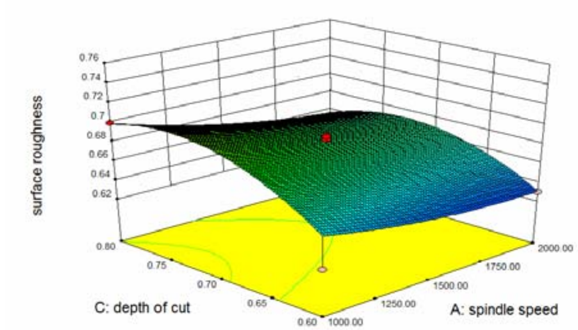


**Fig.5. Surface interaction dimensional views and direct effect views of spindle speed and depth of cut over surface roughness**

Fig.4 shows the interaction and direct effect of depth of cut and spindle speed on surface roughness. The above interaction figure evidenced that the spindle speed and depth of cut on the surface roughness of turning process has a significant effect. From the Fig.4 it has been concluded that the lower spindle speed (1000 rpm) with the increase in depth of cut

(0.6 to 0.8 mm) has a significant effect on surface roughness (0.62-0.69μm) at higher spindle speed (2000rpm) whereas the increase in depth of cut (0.6 to 0.8 mm) has no significant effect on surface roughness (0.64 to 0.63μm) at lower spindle speed (1000 rpm).The conclusion can also be verified from the ANOVA table 4.

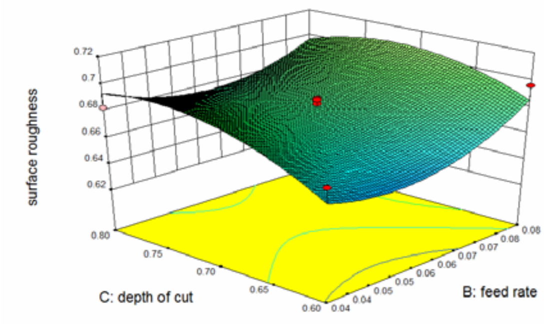


**Fig.6. Surface interaction dimensional views and direct effect views of feed rate and depth of cut over surface roughness**

Fig.5 shows the interaction and direct effect of feed rate and depth of cut on surface roughness. The above interaction figure evidenced that the feed rate and depth of cut on the surface roughness of turning process has a significant effect. From the Fig.5 it has been concluded that higher feed rate and depth of cut was increase the surface roughness whereas lower feed rate and depth of cut decrease the surface roughness. To obtain the quality surface of Ra between 0.62 and 0.64 feed rate less than 0.06 and depth of cut less than 0.70 should be preferred.

## VI. VALIDATION OF THE MODEL

The confirmatory test was conducted and regression model has been developed using Box-Behnken of RSM of DoE was verified. Table 5 shows the comparison of predicted versus experimental value of surface roughness. The percentage of error is found to be within ±1.5% which shows the validity of the model.

**Table 5 Validation of the model**

## VII.CONCLUSION

This investigation attempts the application of response surface methodology to find the optimal solution of the cutting conditions such as spindle speed (rpm), feed rate (mm/min) and depth of cut (mm) for giving the minimum value of surface roughness using design of experiment concept. The confirmatory test was conducted and found that the percentage of error within ±1.5%. The following conclusions are obtained by analysis of work are,

- The obtained experimental data can be used to predict the surface roughness 'Ra' by developing the regression model using DoE
- A good surface roughness was obtained at the feed rate (0.04-0.05 mm/min) and spindle speed (1700-2000 rpm).
- The change in feed rate (0.04-0.08 mm/min) has a significant effect on surface roughness (0.72-0.66μm) at higher spindle speed (2000rpm).
- The change in feed rate (0.04-0.08 mm/min) has no significant effect on surface roughness (0.71-0.72μm) at lower spindle speed (1000 rpm).
- A feed rate less than 0.06 and depth of cut less than 0.70 have been preferred for obtaining good surface finish.

## VII.REFERENCES

[1]Mahesh, G.; Muthu, S.; Devadasan, S. R. “Experimentation and Prediction of Surface Roughness of the Machining Parameter with Reference to the Rake Angle in End Mill”,International Review of Mechanical Engineering;Nov2012, Vol. 6 Issue 7, pp.1418-1426

[2]K.Saravanakumar, M.R.Pratheesh Kumar, Dr.A.K.ShaikDawood, “Optimization of CNC Turning Process Parameters on INCONEL 718 Using Genetic Algorithm”, IRACST – Engineering Science and Technology: An International Journal (ESTIJ)Vol.2, No.4, August 2012,pp.532-537

[3]Mr.Ch.Madhu.V.N, .Prof., A.V.N.L. Sharma, Dr.K.VenkataSubbiah, “Optimization of cutting parameters for surface roughness prediction using artificial neural network in CNC Turning”, IRACST – Engineering Science and Technology: An International Journal (ESTIJ), Vol.2, No. 2, April 2012,pp.207-214

[4]J.S.Senthilkumaar1; P.Selvarani2 and RM.Arunachalam3, “Selection of Machining Parameters Based On the Analysis Of Surface Roughness And Flank Wear In Finish Turning And Facing Of Inconel 718 Using Taguchi Technique”, Emirates Journal for Engineering Research, November 2010,pp.1-19.

[5]Oktem a, T. Erzurumlu b, H. Kurtaran b, “Application of response surface methodology in the optimization of cutting conditions for surface roughness”, Journal of Materials Processing Technology, 12 April 2005, pp.11-16

[6]Mathew.A.Kuttolamadom,SinaHamzehlouia, M. LaineMears, “Effect of Machining Feed on Surface Roughness in Cutting 6061Aluminum”, Clemson University - International Center for Automotive Research,2010,pp.1-19.

[7]H.M.Somashekara, "Optimizing Surface Roughness in Turning Operation Using Taguchi Technique And Anova" ,International Journal Of Engineering Science And Technology (IJEST)ISSN, Vol. 4 No.05 May 2012,pp.1962-1973.

[8]S.S.K. Deepak, "Applications of Different Optimization Methods for Metal Cutting Operation"– A Review, Research Journal of Engineering Sciences,Vol. 1(3), Sept.2012,pp. 52-58

[9]HamdiAouici, Mohamed AthmaneYallese, KamelChaoui, TarekMabroukic, Jean-François Rigal, "Analysis of surface roughness and cutting force components in hard turning with CBN tool", Prediction model and cutting conditions Optimization, Measurement 45 (2012),pp.344–353.

[10]MaciejGrzendaa, Andres Bustillo, "The evolutionary development of roughness prediction models", Applied Soft Computing (2012), pp.1-10.

[11]Arokiadass, K. Palaniradja, N. Alagumoorthi, "Prediction and Optimization of End Milling Process Parameters Of cast Aluminium Based MMC.", Trans. Nonferrous Met. Soc. China, 21 February 2012, pp. 1568-1574.

[12]M. Brezocnik, M. Kovacic, M. Ficko, "Prediction of surface roughness with Genetic programming",Journal of Materials Processing Technology, 2004,pp.28-36

[13]SuleymanNeseli, SuleymanYaldız, ErolTurkes,"Optimization of tool geometry parameters for turning operations based on the response surface methodology", Measurement 44 2011, pp. 580–587.

[14]*Chen Lu*, "Study on prediction of surface quality in machining process", journal of materials processing technology, 24 November 2007, pp.439-450

**N.Zeelan basha** is post graduate in Production Engineering from Anna University, regional Centre, Coimbatore which is affiliated to Anna University, Chennai. He published 2 papers in National Conference.

**S.Vivek** is a post graduate in manufacturing technology, from Anna University, regional Centre, and Coimbatore which is affiliated to Anna University of technology. He published 7 papers in National Conference. Presently he is working as an Assistant Professor in Department of Mechanical Engineering, Anna University, regional Centre, and Coimbatore