International Journal of Scientific Engineering and Technology
Volume No. 6, Issue No. 8, PP : 307-312

ISSN : 2277-1581
1 Aug. 2017

Analysis of Machinability on Al6061 using Single Point Cutting Tool

[1]S Gajanana, [2]B SureshKumar Reddy, [3]A Krishnaiah
[1,2]Department of Mechanical Engineering, MVSR Engineering College, Nadergul, Hyderabad-501510,
[3]Department of Mechanical Enigneering,CoE, Osmania University, Hyderabad
Corresponding Email:g_saparey@rediffmail.com

Abstract -***The emerging trend of machining to produce low cost and high quality products in least possible time has given a real challenge in machining aluminium and its alloys. The chemical affinity of aluminium to different coating materials and its low melting point made this a critical one for machining. Many researches are still going on to find out the best compatible procedures for machining aluminum and its alloys. The main problem in machining the aluminum is the formation of built-up edge formation due to the adhesion to the tool materials resulting in an adverse effect on surface quality of the work piece. This can be prevented to an extent by giving suitable process parameters. Hence there is a need for optimization of process parameters for optimized production. Cutting parameters such as speed, feed and depth of cut that are significant in machining process are estimated and analyzed. The main objective is to optimize the process parameters namely- cutting speed, feed and depth of cut on machining AL6061 alloy using single point cutting tool. The Experimentation is carried out after choosing a set of trials that are compatible with the lathe machine used. Surface roughness, Material removal rate and cutting forces are measured using instruments and are incorporated into Design Expert software. An equation is generated for each parameter and inputs to achieve better results are estimated. In the present work, Design of Experiments techniques(full factorial & RSM) are used in order to find the effect of input parameters on cutting force and surface roughness and metal removal rate. Contribution of each factor is determined by ANOVA (Analysis of Variance).***

***Keywords*— Cutting Force, Surface Roughness, MRR, DOE, RSM, ANOVA**

I. Introduction

The challenge of modern machining industries is mainly focused on the achievement of high quality, in term of work dimensional accuracy, surface finish. Surface texture is concerned with the geometric irregularities. The quality of a surface is significantly important factor in estimating the productivity of machine tool and machined parts. The surface roughness of machined parts is a significant effects on some functional attributes of parts, such as, contact causing surface friction, wearing, light reflection, ability of distributing and also holding a lubricant, load bearing capacity, coating and resisting fatigue. In manufacturing industries, manufacturers attentive on the quality and Productivity of the product. There are many factors which affect the surface roughness and material removal rate (MRR) i.e. cutting conditions, tool variables and work piece variables. Cutting conditions include speed, feed and depth of cut and also tool variables include tool material, nose radius, rake angle, cutting edge geometry, tool vibration, tool overhang, tool point angle etc. and work piece variable include hardness of material and mechanical properties. In turning operation, it is difficult to select the cutting parameters to achieve the high surface finish and material removal rate. SohailAkram[1] in his study determinedthe sensitivity of residual stresses to cutting speed and feed rate using finite element method. The simulation results showed that residual stresses were insensitive to changes in cutting speed, however, residual stresses were clearly affected by the change in feed rate. Kannan Nair M R and ShyamSundarV [2] experimented with turning operation and finite thermal analysis and found that cutting speed is the main variable which affects the chip tool interface temperature and later the thermal and mechanical performances with cutting speed were analysed. NitinSawarkar&Ghanshyam [3] concluded that graphical analysis of residual stress vs machining parameters can be done, from which decision about selection of optimum machining process, to improve component life can be made. MeenuSahu and KomeshSahu [4] predicted the optimal range of tool wear, w/p surface temperature and MRR. Finally, the relationship between factors and the performance measures were developed by using multi regression analysis.

II. Material and Methodology

2.1 Introduction:

Aluminium and its alloys have gained their importance in automobile and aerospace industries due to their high strength to weight ratio. They have excellent corrosion resistance. The fabrication of Aluminium parts is relatively easy because of its good weldability and brazability. Aluminium has good machinability. Al6061 is a cast aluminium alloy with magnesium and silicon as its major alloying elements. Hence they yield cost effective products than other aluminium alloys. It can be fabricated by virtually all methods, it has excellent spot and fusion weldability and it can also be furnace brazed. Available as a clad alloy for even better corrosion resistance. Al6061 is a precipitation hardening aluminium alloy, containing magnesium and silicon as its major alloying elements. The Al6061 alloy used for machinability study is manufactured using Die casting process. Evaluation of cutting forces becomes essential in machinability study of advanced material, dynamometers plays a key role in the measurement of these cutting forces. A multi component type Piezo Electric type Dynamometer (model 9265B) is used to measure the forces. Surface finish was measured using Talysurf Intra – Ultra 6.0.

ISSN : 2277-1581
1 Aug. 2017

2.2 Casting of Work Material: The maximum and minimum limits of each alloying element are taken from the standard composition of Al6061and incorporated in Taguchi Technique to obtain the optimum composition with highest yield strength. Al 6061 has eight alloying elements in its composition and two levels are defined for each element. Hence L8 orthogonal array is obtained from Taguchi Technique. Optimum composition obtained is shown in Table 1.

Table1 AL-6061 Composition with optimum Yield Strength

S.No	Material	Amount (wt. %)
1	Aluminium	98.46
2	Magnesium	0.8
3	Silicon	0.4
4	Copper	0.15
5	Zinc	0.05
6	Manganese	0.05
7	Iron	0.05
8	Chromium	0.04

Al6061 Composition with optimum Yield Strength/ Highest yield strength of the composition is 97 MPa. Die casting is performed for the above composition to obtain cylindrical rods of Al 6061.

2.3 Experimentation:

Experiments were performed on HMT- NH 26Lathe machine and HSS single point cutting tool is used for machining. The number of trails that are required for experimentation are found by using DoE techiniques. The forces that are generated during machining are measured by using piezoelectric dynamometer, which measures the forces in all directions and after each trail the surface finish value of the machined part is measured with the help of TALYSURF and from this the values of surface roughness are noted.

The metal removal rate (MRR) was calculated by measuring the difference between the weight of the work piece before and after each run and all these values are tabulated.

MRR = (weight of work piece before machining - weight of work piece after machining) / time

The process parameters (speed, feed and depth of cut) each are varied between two limits (lower and upper) and the number of trails are obtained from design expert full factorial method. The required number of trails from Design Expert (Full-factorial and RSM).

2.4 Design of Experiments: A two level full factorial design of experiments was adopted for calculating the main and the interaction effects of the three factors at two levels; 2^3=8 experiments are conducted to fit an equation. The design plan with high and low limits as indicated is utilized looking into practical considerations of the turning operation as in table 3.The first order model is assumed with two and three factor interactions which can be expressed as,

$$Y = b_0+b_1X_1+b_2X_2+b_3X_3+b_{12}X_1X_2+b_{13}X_1X_3+b_{23}X_2X_3+b_{123}X_1X_2X_3$$

where 'Y' represents the response (Cutting Force, Surface Finish, MRR) X_1,X_2,X_3 represent the coded values of speed(v), feed(f), depth of cut(d) respectively; $b_0,b_1,\dots,b_{123}$ are the regression coefficients of polynomial to be determined.

Table 3 Cutting parameters and levels

Factor s	Units	Designation		Test levels		Av g	VI
		Natur al	code d	Lo w(-1)	High (+1)		
Speed	rpm	N	X_1	715	1210	96 0	245
Feed	mm/re v	f	X_2	0.1	0.2	0.1 5	0.05
DoC	mm	d	X_3	0.1	1	0.5 5	0.45

2.4 Mathematical Model Development:

Design matrix for a given 2-level and 3-factor is generated and the regression coefficients are calculated. Here the number of replications for the response i.e.; y_1 and y_2 and average of these is 'y'. Regression coefficients b_0, b_1, b_2, b_{12}, $b_{23,}$ …etc. are calculated by using the formula.

$$b_j = \frac{[\sum_{i=1}^{N} X_{ij} Y_i]}{N}$$

Fisher test for adequacy of model (f-test for 5% significance level)

Variance for reproducibility = $S_y^2 = [2\sum(dely)^2]/N$

N=number of trails, dely = (y1-y)

Variance of adequacy = $S_{ad}^2=[2\sum(y-yp)^2]/DoF$

y_p = predicted response.

$y_p=b_0X_0[i]+b_1X_1[i]+b_2X_2[i]+ \dots$

whereDoF = degree of freedom= [N-(k+1)]

where N = number of trails

k = number of factors

F-model = S_{ad}^2/S_y^2

For given values of f1 and f2, F-table value is found from fisher table.

Here f1=N-(k+1), f2=N

If F-model ≤ F-table, model is adequate in linear form otherwise it is not adequate.

Student's t-test (for 5% significance level):

When the model is adequate in linear form, then t-test is to be conducted to test the significance of each Regression coefficient. Standard deviation of each coefficient,

$S_{bj}=\sqrt{(S_y^2/N)}$, t-ratio = $|b_j| / (S_{bj})$

for f = N , t-value is to be taken from t-table and compared with t-ratio of each regression coefficient. If t-ratio ≥ t-table corresponding regression coefficient is significant. Non-significant coefficients are to be eliminated from the model to arrive the final form of mathematical model in linear form as

$Y= b_0+b_1X_1+b_2X_2+b_3X_3+b_{12}X_1X_2+b_{13}X_1X_3+b_{23}X_2X_3+b_{123}X_1X_2X_3$

2.5 Analysis of Variance (ANOVA): Analysis of variance is carried out to find the percentage contribution of each factor and its relative significance.

Table 4 ANOVA Table

Source of variation	Sum of squares	Degrees of freedom	Mean square	F-ratio
I treatments	SS_I	a-1	$MS_I = SS_I/(a-1)$	$F_I = MS_I/MS_E$
II treatments	SS_{II}	b-1	$MS_{II} = SS_{II}/(b-1)$	$F_{II} = MS_{II}/MS_E$
Interaction	$SS_{I,II}$	(a-1)(b-1)	$MS_{I,II}= SS_{I,II}/(a-1)(b-1)$	$F_{I,II} = MS_{I,II}/MS_E$
Error	SS_E	ab(n-1)	$MS_E= SS_E/ab(n-1)$	
Total	SS_T	abn-1		

'a' and 'b' are the levels of I and II factors

$SS_I= \{Sum [x_1[i]*y_t[i]]\}^2/Nn$, $y_t = (y_1 + y_2) / 2$

$SS_T=Sum \{(y_1[i])^2+ (y_2[i])^2\}-[Sum \{(y_t[i])\}^2/Nn]$

Here N=number of trails, n = number of replications

$SS_E= (SS_T)-(SS_I)-(SS_{II})$ …

Percentage contribution of factor I = $(SS_I/SS_T)*100$

Coefficient of Determination, $R^2= (SS_{model}/SS_T)$

Where $SS_{model} = SS_I+SS_{II}+SS_{III}+\ldots$

III. Development of Model

Experimentation was carried out using the design matrix shown in table 5.

Table 5 Design Matrix (Full-factorial)

Trial No.	Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)
1	715 (-1)	0.1 (-1)	0.1 (-1)
2	1210 (+1)	0.1(-1)	0.1 (-1)
3	715 (-1)	0.2 (+1)	0.1 (-1)
4	1210 (+1)	0.2 (+1)	0.1 (-1)
5	715 (-1)	0.1 (-1)	1 (+1)
6	1210 (+1)	0.1(-1)	1 (+1)
7	715 (-1)	0.2 (+1)	1 (+1)
8	1210 (+1)	0.2 (+1)	1 (+1)

3.1Linear model for Cutting Force:

The column of each variable x_1, x_2 and x_3 are arranged in standard order. The values of regression coefficients b_0, b_1, $b_2 \ldots b_{123}$ are calculated by regression analysis.

Table 6 Design Matrix for Cutting Force

Trial no	Variables							Cutting Force (N)		
	X_1	X_2	X_3	x1x2	X2x3	X3x1	x1x2 x3	Y1	Y2	Y (Avg)
1	-1	-1	-1	+1	+1	+1	-1	50.31	50.35	50.33
2	+1	-1	-1	-1	+1	-1	+1	49.87	49.91	49.89
3	-1	+1	-1	-1	-1	+1	+1	70.24	70.28	70.26
4	+1	+1	-1	+1	-1	-1	-1	78.86	78.84	78.85
5	-1	-1	+1	+1	-1	-1	+1	147.9	147.94	149.92
6	+1	-1	+1	-1	-1	+1	-1	203.8	203.84	203.82
7	-1	+1	+1	-1	+1	-1	-1	213	213.6	213.3
8	+1	+1	+1	+1	+1	+1	+1	463.2	463.25	463.23

The values of regression coefficients b_0, b_1, $b_2 \ldots b_{123}$ are calculated for Cutting force are given below:

Regression coefficients for cutting force are

b_0=159.741, b_1=39.2087, b_2=46.7412, b_3= 97.406, b_{12}=25.353, b_{13}=37.168, b_{23}= 34.516, b_{123}=23.097

The adequacy of the model was then tested by Analysis of variance (ANOVA) As per this technique , F ratio of the model developed does not exceed the standard tabulated value of F ratio for a 95% confidence level. Hence, the model was adequate. The significance of the coefficients was checked by using student's t-test and only the significant coefficients were used to develop final mathematical model.

The final model in coded form for cutting force is

$Yp= 159.741+39.2087x_1+46.7412x_2+97.406x_3+37.18x_1x_3+34.516x_2x_3 +25.353x_1x_2+23.097x_1x_2x_3$

3.2Linear model for Surface Roughness:

The column of each variable x_1, x_2 and x_3 are arranged in standard order. The values of regression coefficients b_0, b_1, $b_2 \ldots b_{123}$ are calculated by regression analysis.

Table 7 Design Matrix for Surface Finish

Trail no.	Variables							Surface finish(Ra) (Micrometre)		
	X1	X2	X3	X1 X2	X2 X3	X3 X1	X1X2 X3	Y1	Y2	Y(average)
1	-1	-1	-1	+1	+1	+1	-1	2.161	2.165	2.163
2	+1	-1	-1	-1	+1	-1	+1	1.077	1.081	1.079
3	-1	+1	-1	-1	-1	+1	+1	4.771	4.775	4.773
4	+1	+1	-1	+1	-1	-1	-1	5.563	5.567	5.565
5	-1	-1	+1	+1	-1	-1	+1	9.871	9.875	9.873
6	+1	-1	+1	-1	-1	+1	-1	10.18	10.184	10.182
7	-1	+1	+1	-1	+1	-1	-1	12.118	12.122	12.12
8	+1	+1	+1	+1	+1	+1	+1	4.995	4.999	4.997

The values of regression coefficients b_0, b_1, $b_2 \ldots b_{123}$ are calculated for surface roughness are given below:

b_0=6.344, b_1=-0.8882, b_2=0.5197, b_3=2.949, b_{12}=-0.6945, b_{13}=-0.8152, b_{23}=-1.2542, b_{123}=-1.1635

The final model in coded form for Surface finish is

$Yp= 6.344-0.8882x_1+0.5197x_2+2.949x_3-0.8152x_1x_3 -1.2542x_2x_3 -0.6945x_1x_2-1.1635x_1x_2x_3$

3.3 Linear model for MRR

The column of each variable x_1, x_2 and x_3 are arranged in standard order. The values of regression coefficients b_0, b_1, $b_2 \ldots b_{123}$ are calculated by regression analysis.

Table 8 Design Matrix for MRR

Trail no.	Variables							Metal Removal Rate (gm/ min)		
	X1	X2	X3	X1 X2	X2 X3	X3 X1	X1X2 X3	Y1	Y2	Y (average)
1	-1	-1	-1	+1	+1	+1	-1	0.025	0.026	0.0257
2	+1	-1	-1	-1	+1	-1	+1	0.044	0.048	0.046
3	-1	+1	-1	-1	-1	+1	+1	0.0921	0.0963	0.0942
4	+1	+1	-1	+1	-1	-1	-1	0.058	0.06	0.059
5	-1	-1	+1	+1	-1	-1	+1	0.263	0.271	0.267
6	+1	-1	+1	-1	-1	+1	-1	0.3422	0.3444	0.3433
7	-1	+1	+1	-1	+1	-1	-1	0.4102	0.4306	0.4204
8	+1	+1	+1	+1	+1	+1	+1	0.835	0.855	0.845

The values of regression coefficients b_0, b_1, $b_2 \ldots b_{123}$ are calculated for material removal rate are given below
b_0=0.2625, b_1=0.0607, b_2=0.0920, b_3=0.2063, b_{12}=0.0366, b_{13}=0.0644, b_{23}= 0.0717, b_{123}=0.0504

The final model in coded form for Material Removal Rate is
$$Yp= 0.2625+0.0607x_1+0.092x_2+0.2063x_3+0.0644x_1x_3+0.07176x_2x_3+0.0366x_1x_2+0.0504x_1x_2x_3$$

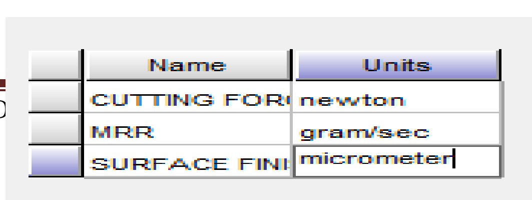
3.4 Response Surface Methodology(RSM):

Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building. By careful design of experiments, the objective is to optimize a response (output variable) which is influenced by several independent variables (input variables).The first goal for Response Surface Method is to find the optimum response. The second goal is to understand how the response changes in a given direction by adjusting. For example, in the case of the optimization of the calcination of Roman cement the engineer wants to find the levels of temperature(x1) and time (x2) that maximize the early age strength (y) of the cement. The early age strength is a function of the levels of temperature and time, as follows:

y = f (x1, x2) + e (3.1)

Where 'e' represents the noise or error observed in the response y. The surface represented by f(x1, x2) is called a response surface.

3.5Optimization of output values by RSM:



	Name	Units
	CUTTING FOR	newton
	MRR	gram/sec
	SURFACE FINI	micrometer

Figure 1 Design Expert - RSM

The input parameters and output responses after experimentation are tabulated in RSM historical data option and the optimization values are found.

The procedure for finding optimum values are as follows:

Step: 1

In this step the number of input parameters with their units are to be given and the number of rows to be selected are 11. Here the input parameters are considered as factors. They are

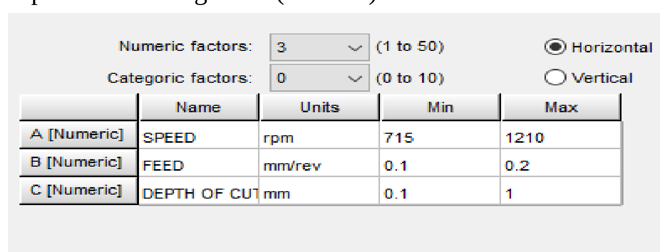
Factor 1: Speed (rpm)

Factor 2: Feed (mm/rev)

Factor 3: Depth of Cut (mm)

After giving input factors, the output responses with their units are given.

Response 1: Cutting force (Newton)



Numeric factors: 3 (1 to 50) Horizontal
Categoric factors: 0 (0 to 10) Vertical

	Name	Units	Min	Max
A [Numeric]	SPEED	rpm	715	1210
B [Numeric]	FEED	mm/rev	0.1	0.2
C [Numeric]	DEPTH OF CUT	mm	0.1	1

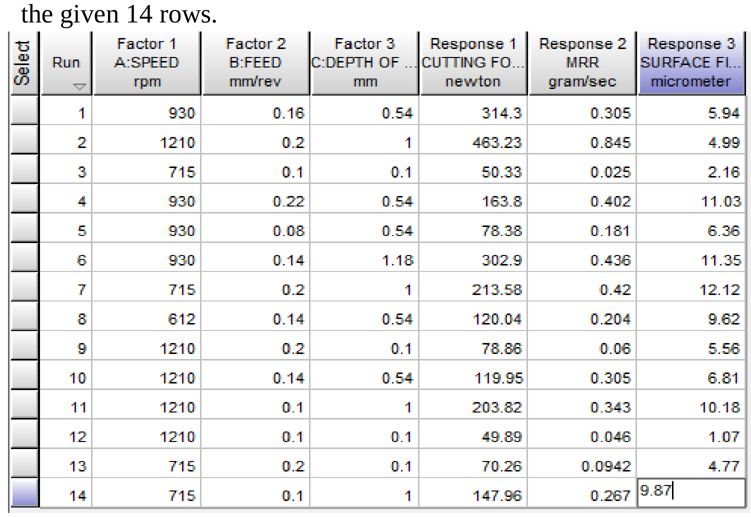
Response 2: Metal Removal Rate (gram/sec)

Response 3: Surface Finish (micrometer)

Figure 2 Process Parameters

Step: 2

In this step all the input and output data is tabulated in RSM in the given 14 rows.



Run	Factor 1 A:SPEED rpm	Factor 2 B:FEED mm/rev	Factor 3 C:DEPTH OF ... mm	Response 1 CUTTING FO... newton	Response 2 MRR gram/sec	Response 3 SURFACE FI... micrometer
1	930	0.16	0.54	314.3	0.305	5.94
2	1210	0.2	1	463.23	0.845	4.99
3	715	0.1	0.1	50.33	0.025	2.16
4	930	0.22	0.54	163.8	0.402	11.03
5	930	0.08	0.54	78.38	0.181	6.36
6	930	0.14	1.18	302.9	0.436	11.35
7	715	0.2	1	213.58	0.42	12.12
8	612	0.14	0.54	120.04	0.204	9.62
9	1210	0.2	0.1	78.86	0.06	5.56
10	1210	0.14	0.54	119.95	0.305	6.81
11	1210	0.1	1	203.82	0.343	10.18
12	1210	0.1	0.1	49.89	0.046	1.07
13	715	0.2	0.1	70.26	0.0942	4.77
14	715	0.1	1	147.96	0.267	9.87

Figure 3 Input and Output values

ISSN : 2277-1581
1 Aug. 2017

Step: 3

In this step, for each output response by using process parameters the equation is developed.

3.5 ANOVA: Analysis of Variance

ANOVA is done to find out the percentage contribution of each factor and their relative significance of each factor.

By using the experimented values the equation values for cutting force is found by using process model as Linear (suggested) and the equation as follows:

CUTTING FORCE in terms of coded factors = 162.76 + (27.74* A) + (44.37 * B) + (98.89 * C)

Response 1 CUTTING FORCE

ANOVA for Response Surface Linear model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1.271E+005	3	42366.51	6.91	0.0084	significant
A-SPEED	*8459.29*	*1*	*8459.29*	*1.38*	*0.2675*	
B-FEED	*23746.26*	*1*	*23746.26*	*3.87*	*0.0775*	
C-DEPTH OI	*96128.18*	*1*	*96128.18*	*15.67*	*0.0027*	
Residual	61353.25	10	6135.32			
Cor Total	1.885E+005	13				

The Model F-value of 6.91 implies the model is significant. There is only a 0.84% chance that an F-value this large could occur due to noise.

By using the experimented values the equation values for metal removal rate is found by using process model as Linear (suggested) and the equation as follows:

MRR = 0.27 - (0.054* A) + (0.089* B) + (0.19* C)

Response 3 MRR

ANOVA for Response Surface Linear model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	0.48	3	0.16	13.61	0.0007	significant
A-SPEED	*0.032*	*1*	*0.032*	*2.74*	*0.1288*	
B-FEED	*0.095*	*1*	*0.095*	*8.01*	*0.0179*	
C-DEPTH OI	*0.36*	*1*	*0.36*	*30.50*	*0.0003*	
Residual	0.12	10	0.012			
Cor Total	0.60	13				

The Model F-value of 13.61 implies the model is significant. There is only a 0.07% chance that an F-value this large could occur due to noise.

By using the experimented values the equation values for surface finish is found by using process model as 2FI (suggested) and the equation as follows:

SURFACE FINISH = 6.98 – (1.01 * A) + (0.82* B) + (3.0*C)

Response 5 SURFACE FINISH

ANOVA for Response Surface Linear model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	106.42	3	35.47	7.04	0.0079	significant
A-SPEED	*11.14*	*1*	*11.14*	*2.21*	*0.1679*	
B-FEED	*8.13*	*1*	*8.13*	*1.61*	*0.2329*	
C-DEPTH OI	*88.73*	*1*	*88.73*	*17.61*	*0.0018*	
Residual	50.38	10	5.04			
Cor Total	156.80	13				

The Model F-value of 7.04 implies the model is significant. There is only a 0.79% chance that an F-value this large could occur due to noise.

Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case C is a significant model term.

Optimum Solutions and Graphs

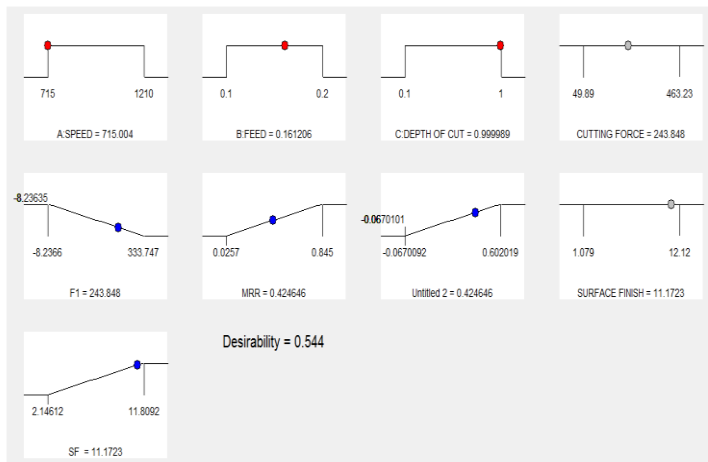


Figure 4 Optimum Solutions in Ramp form

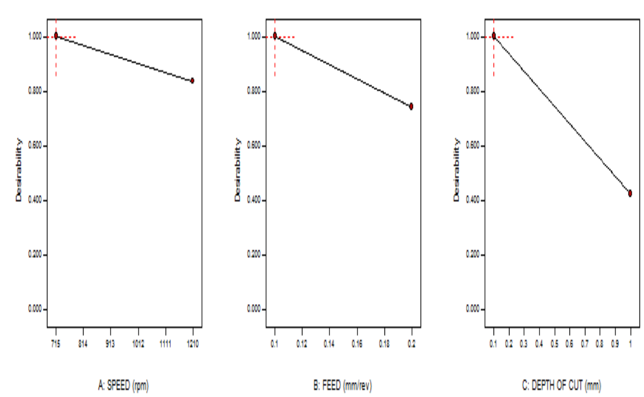


Figure 5 Graphs of Speed vsDesirability, Feed vs Desirability, Depth of Cut vs Desirability

DOI : 10.5958/2277-1581.2017.00043.2

ISSN : 2277-1581
1 Aug. 2017

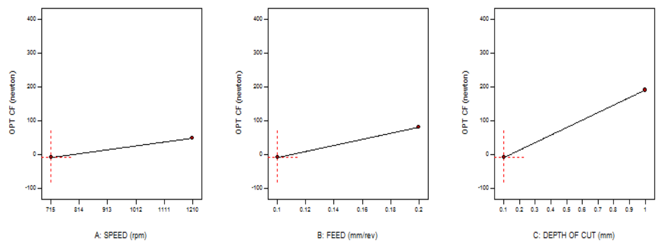


Figure 6 Graphs of Speed vsCutting force, Feed vs Cutting force, Depth of Cut vs Cutting Force

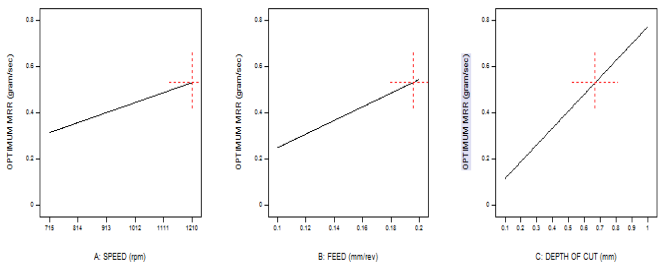


Figure 7 Graphs of Speed vs MRR, Feed vs MRR, Depth of cut vs MRR

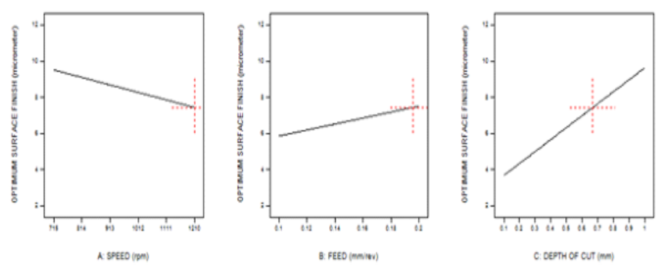


Figure 8 Graphs of Speed vs Surface Finish, Feed vs Surface Finish, Depth of cut vs Surface Finish

IV.Results and Conclusion

PercentageContribution of Input Parameters:

Percentage contribution of the Factors and their Interactions for Cutting force:

Table9 Percentage contribution of the Factors and their Interactions for Cutting force

Factor	**X1**	**X2**	**X3**	**X1X2**	**X2X3**	**X1X3**	**X1X2X3**
Contribution (%)	9.1	12.9	55.95	3.8	7.02	8.14	3.14

Percentage contribution of the Factors and their Interactions for Surface Finish:

Table 10 Percentage contribution of the Factors and their Interactions for Surface Finish

Factor	**X1**	**X2**	**X3**	**X1X2**	**X2X3**	**X1X3**	**X1X2X3**
Contribution (%)	5.7	1.95	62.88	3.49	11.37	4.80	9.79

Percentage contribution of the Factors and their Interactions for MRR:

Table 11 Percentage contribution of the Factors and their Interactions for MRR

Factor	**X1**	**X2**	**X3**	**X1X2**	**X2X3**	**X1X3**	**X1X2X3**
Contribution (%)	5.43	12.47	62.65	1.97	7.56	6.11	3.75

It is observed from the table -9 that DoC has major contribution on Cutting force and next comes to feed. Table-10 focues that surface finish on work is highly influenced by depth of cut and other parameters have relatively less influence . From the table-11 it is shown that contribution of DoC is high on MRR.

References

i. *SohailAkram, Syed Husain Imran Jaffery, Mushtaq Khan, AamirMubashar, and Liaqat Ali.2015,A Numerical Investigation of Effects of Cutting Velocityand Feed Rate on Residual Stresses in Aluminum AlloyAl-6061,International Journal of Materials, Mechanics and Manufacturing, Vol. 3, No. 1, February 2015*

ii. *Kannan Nair M R , ShyamSundar V.2015,Optimization Of Tool Chip Contact Area In Turning Operation Using Finite Element Thermal Analysis, International Journal of advanced research in science and Engineering,Vol No 4, Issue 11, Nov 2015.*

iii. *NitinSawarkar,.Ghanshyam Boob.2014,Finite Element based Simulation of Orthogonal Cutting Process to Determine Residual Stress Induced,International Journal of Computer Applications (0975 – 8887).*

iv. *Meenu Sahu1 and Komesh Sahu.2014, Optimization of Cutting Parameters on Tool Wear,Workpiece Surface Temperature and MaterialRemoval Rate in Turning of AISI D2 Steel,International Journal of Advanced Mechanical Engineering.ISSN 2250-3234 Volume 4, Number 3, pp. 291-298.*

v. *Thamizhmanii S. Saparudin S. and Hasan S., 2007, Analysis of Surface Roughness by Using Taguchi Method, Achievements in Materials and Manufacturing Engineering, Volume 20, Issue 1-2, pp. 503-505.*

vi. *Singh H. and Kumar P., (2006), "Optimizing Feed Force for Turned Parts through the Taguchi Technique", Sadhana, Volume 31, Number 6, pp. 671–681.*

vii. *Lin W. S., Lee B. Y., Wu C. L., 2001, Modelling the surface roughness and cutting force for turning, Journal of Materials Processing Technology, Volume 108, pp. 286-293.*

viii. *Srikanth T. and Kamala V.2008,A Real Coded Genetic Algorithm for Optimization of Cutting Parameters in Turning IJCSNS, International Journal of Computer Science and Network Security, Volume 8 Number 6, pp. 189-193.*

ix. *Thamma R., 2008, Comparison between Multiple Regression Models to Study Effect of Turning Parameters on the Surface Roughness. Proceedings of the 2008 96IAJC-IJME International Conference, ISBN 978-1-60643-379-9, Paper 133, ENG 103 pp. 1-12.*

x. *Gajanana.S, 2007, Development of Mathematical Model for EDM Using Two Factorial Design of Experiments XXIII National Convention of Mechanical Engineers and National Seminar on 'Emerging Trends In Manufacturing Systems and Technologies', Hyderabad, September 10-12, 2007.*