Optimization of Machining Parameters during CNC turning of Aluminium 6061 with CNMG EN-TM (H20TI) insert using Response Surface Methodology (RSM)

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Abstract - **During this work, the effects of various machining parameters such as feed rate,cutting speed, and depth of cut on surface roughness were experimentally observed during dry turning process. Aluminium 6061 alloy is machined using CNMG 120408 EN-TM (H20TI) CNC turning inserts. Response Surface Methodology (RSM) is used to design the experiment, to get regression equation and for optimization of the input parameters. Surface plots and Contour plots were generated by using RSM to check the interaction of input parameters on the surface roughness of the component. From the analysis of the experimental result it found that feed rate has maximum effect on surface roughness and cutting speed and depth of cut has minimum effect on surface roughness. The range of machining parameters are 0.1-0.2 mm/rev,124-207 m/min, and 0.05-0.8 mm for feed rate, cutting speed and depth of cut respectively. Best values of parameters are0.1 mm/rev, 165.5m/min and 0.85mm for feed rate,cutting speed and depth of cut respectively.**

Keywords - **Dry turning, Response Surface Methodology (RSM), ANOVA, Al 6061.**

I.INTRODUCTION

Now a days , in manufacturing industry alloys are preferred over the pure metals. This is because of better properties of the alloys such as good machining properties, high strength to weight ratio, better thermal and mechanical properties, good toughness, good machining properties etc. From them aluminium 6061 alloy is one. It is mostly used in the aerospace industry, cycle industry, valves, couplings and marine fittings. For the manufacturing of cylindrically symmetrical products turning process is used.

In the modern manufacturing industry surface finish of the product is most important with high material removal rate (MRR). To get high surface finish various processes are done on the product such as grinding, buffing and polishing. But these process are very costly and time consuming. To reduce the manufacturing time and cost we are trying to get maximum surface finish by only turning process.Because turning is the first most machining operation to get finished surface. Automated and flexible manufacturing system is used in the industries.CNC machines are used because they are capable of achieving repeatability and high accuracy. There are many factors that affect the surface roughness of the product for example cutting speed, feed rate, depth of cut, coolant used, tool geometry, chattering, material properties of work piece and cutting tool used.

We considercutting speed, feed rate and depth of cut as input parameters and surface roughness as response variable. Surface roughness is a measure of the technological quality of a product and a factor that greatly influence manufacturing cost. It describe the geometry of the machined surface and combined with the surface texture[1].Aouici H. *et al* (2012) took AlSl H11 hardened steel (40; 45 and 50 HRC) to be machined with cubic boron nitride tool. RSM and ANOVA was used to investigate the effect of cutting parameters on surface roughness. They investigated that both feed rate and work piece hardness have significance on surface roughness. The best surface roughness was achieved at the lower feed rate and highest cutting speed [2].Suresh R. *et al* (2012) performed the turning of AlSl 4340 steel with multilayer coated carbide tool. Taguchi technique, ANOVA and linear regression models are used to optimize parameters and for mathematical model formation. They investigated that feed rate has highest influence on surface roughness. The combination of low feed tare and high cutting speed is necessary for minimizing the surface roughness [3].Barik C. R. *et al* (2012)did machining of EN31 steel was done with tool inserts of carbide tool insert CNMG 120408EN-TMR by the researcher. ANOVA and Genetic algorithm was used as optimizing technique. They investigatedthat for optimum results cutting speed, feed rate and depth of cut should be 2000rpm, 0.1mm/rev and 0.10001mm respectively. Experimental response was very close to predicted [4].Genesan H. *et al* (2013) performed the machining of work piece of EN 8 material with CNMG tools. Multi-objective optimization and Genetic Algorithm was used to optimize the machining parameters. They investigated the optimum speed(1254.762rpm), feed rate (0.375mm/rev) and depth of cut(0.51mm) obtained from GA for minimum operation time and minimum production cost and minimum tool wear [5].Gulhane U.D. *et al* (2013)didthe shaping of Al6061 by using high speed steel tool was done by the researcher. ANOVA technique was used as a optimizing technique. They investigated that feed rate is significant influencing factor than depth of cut. For surface finish cutting speed, feed rate and depth of cut should be 31.3rpm,0.3mm/rev and 0.5mm respectively. For MRR they should be 70rpm, 0.4mm/rev and0.5mm [6].Syed Azuan*et al* (2013**)** performed the turning operation on Al6061 with the CVD and PVD tool inserts.They investigated that feed rate has most significant influencing parameter. Higher feed rate produces high tool wear range. CVD coated carbide tool have lower tool wear than PVD coated carbide tools [7].Makadia A. J. *et al* (2013**)** experimented on AlSl 410 steel with the ceramics tool inserts by performing turning operation. ANOVA and RSM technique was used as the parameter optimizing technique and for mathematical modeling. They found that feed rate is significant factor influencing surface roughness. Cutting speed, feed rate and depth of cut and nose radius should be 255.5rpm, 0.1mm/rev, 0.3mm and 1.2mm respectively for optimum result [8].Das S. R. *et al* (2013**)** performed the turning of AlSl4340 steel with CVD multilayer coated carbide tool inserts. Factorial design and ANOVA was used as the optimizing technique. They found that feed rate is significant factor influencing surface roughness. Cutting speed was set at 150m/min, feed rate 0.05mm/rev to get optimum result [9].Lin C. L. *et al* (2013) did the turning of AlSl4340 steel by taking CVD multilayer coated carbide tool. Grey relation and ANOVA were used as the optimizing techniques. They investigated that the feed rate is the most significant cutting factor for affecting multilayer performance characteristics [10].Das B. *et al* (2013) performed the turning operation on Al-5Cu alloy by using high speed steel tool. By the experiments they got a result that roughness increases with increase in feed tare. After reaching certain value it starts decreasing [11].Sahoo A. K. *et al* (2013**)** performed the turning operation on Al/SiCp reinforced metal by using multilayer tin coated carbide inserts. They used Taguchi method, Regression Analysis and Grey Relation for the mathematical modeling and parameter optimization. They investigated that feed rate is found to be the most significant parameter for surface roughness. Cutting speed of (180m/min), feed rate of (0.05mm/rev) and depth of cut at (0.4mm) are optimal parameters [12].

II.DESIGN OF EXPERIMENT

First step in the research is to design the experiment. Taguchi orthogonal array and Response Surface Methodology (RSM) is commonly used to design the experiment. We design the experiments using CCD method of Response Surface Methodology (RSM) in the coded form using minitab16.1 software.RSM is a combination of mathematical and statistical technique. It gives mathematical relation between input parameters and output parameters. It saves time and efforts by reducing the number of experiments. If we are taking k no. of factors than no. of experiments designed by RSM is equal to 2^k+2k+6. For example we are considering 3 factors than RSM design 20 experiment as 2^3+2*3+6=20.It automatically divides the range of every factor into five levels. Table 1shows the input variables and their levels.

Table 1: Independent variables and level for model body

Factor	Level 1	Level 2	Level 3	Level 4	Level 5
Cutting speed	124	144.75	165.5	186.25	207
Feed rate	0.1	0.125	0.15	0.175	0.2
Depth of cut	0.05	0.2375	0.425	0.6125	0.8

After putting the values of range of every factor in the minitab 16.1, it gives the following table to perform experiment.

Table 2: Showing Different combinations of parameters

Sr. No	Cutting speed	Feed rate	Depth of cut
1	186.25	0.125	1.225
2	165.5	0.15	0.85
3	165.5	0.15	0.85
4	207	0.15	0.85
5	165.5	0.2	0.85
6	165.5	0.15	0.85
7	165.5	0.15	0.1
8	165.5	0.15	1.6
9	165.5	0.15	0.85
10	165.5	0.1	0.85
11	144.75	0.175	0.475
12	144.75	0.125	1.225
13	165.5	0.15	0.85
14	144.75	0.175	1.225
15	165.5	0.15	0.85
16	186.25	0.175	0.475
17	124	0.15	0.85
18	186.25	0.175	1.225
19	186.25	0.125	0.475
20	144.75	0.125	0.475

III.EXPERIMENTAL WORK

Experiments are performed using high speed CNC turning center available with CSIR-CSIO Chandigarh. Turning operation is performed on rod of aluminium 6061 alloy having diameter 25.4mm and Length 55mm. CNMG 120408 EN-TM (H20TI) CNC insert is Drawing of the component is given bellow:

Figure 1: CNC turning machine

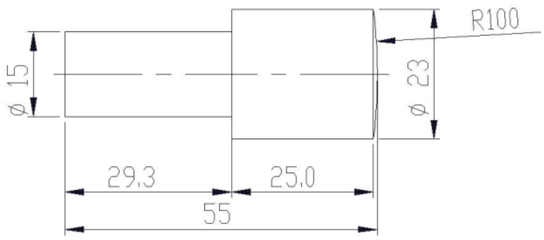

Figure 2: Lens supporting tool

IV.RESULT AND DISCUSSION

After the experimentation surface roughness is checked of both the turned and faced surface on the Taylor/Hobson contact type profilometer having the stylus radius of 2µm. Average surface roughness (Ra) is taken for the analysis. Table 3 showing the result of surface roughness of every experiment.

Table 3: Table shows the values of surface roughness (Ra) in both turning and facing operation

Sr. No.	Cutting speed	Feed rate	Depth of cut	Ra Turning	Ra Facing
1.	186.25	0.125	1.225	0.8400	0.8317
2.	165.5	0.15	0.85	0.9581	1.0733
3.	165.5	0.15	0.85	0.9620	1.0461
4.	207	0.15	0.85	0.9535	1.0094
5.	165.5	0.2	0.85	1.5060	1.5497
6.	165.5	0.15	0.85	0.9615	1.0488
7.	165.5	0.15	0.1	0.9327	1.0020
8.	165.5	0.15	1.6	0.9036	0.9697
9.	165.5	0.15	0.85	0.9549	1.0298
10.	165.5	0.1	0.85	0.4348	0.4727
11.	144.75	0.175	0.475	1.1221	1.2765
12.	144.75	0.125	1.225	0.7148	0.7645
13.	165.5	0.15	0.85	0.9457	1.1533
14.	144.75	0.175	1.225	1.2528	1.3646
15.	165.5	0.15	0.85	0.7980	1.0102
16.	186.25	0.175	0.475	1.0299	1.2186
17.	124	0.15	0.85	0.8274	0.8860
18.	186.25	0.175	1.225	1.0453	1.3500
19.	186.25	0.125	0.475	0.5654	0.7941
20.	144.75	0.125	0.475	0.6234	0.6773

To understand the effect of input parameters on the surface finish experimental results are used to develop the empirical relation using Response Surface Methodology (RSM). Analysis of results gives us regression equations for both turning and facing operation. These equations correlate the response variables with the input parameters. In these equations linear, square and interaction of the input variables are counted. These equations are quadratic in nature.

Ra turning process (μm) =

$$0.930902 - 0.00419565 * s + 0.256870 * f + 0.0339141 * d - 0.0196706 * s^2 + 0.00859599 * f^2 - 0.00987718 * d^2 - 0.0458625 * s * f + 0.00848750 * s * d - 0.0274 * f * d$$

Ra facing process (μm) =

$$1.05838 + 0.0234339 * s + 0.289407 * f + 0.0213064 * d - 0.0275581 * s^2 - 0.00510744 * f^2 - 0.0140700 * d^2 - 0.0321875 * s * f - 0.000662500 * s * d + 0.0117125 * f * d$$

Analysis of Variance (ANOVA) is used to study the effect of the input parameters on the response variable. Which shows the effect of individual parameters, their squares and their interactions on the response variable. The ANOVA table is given bellow for both turning and facing operations.

Table 4: ANOVA table for turning operation

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	0.94865	0.948648	0.105405	10.20	0.001
Linear	3	0.91685	0.916848	0.305616	29.57	0.000
Speed	1	0.00003	0.000031	0.000031	0.000	0.958
Feed	1	0.90111	0.901109	0.901109	87.18	0.000
DOC	1	0.01571	0.015708	0.015708	1.52	0.264
Square	3	0.00835	0.008352	0.002784	0.27	0.846
Speed* speed	1	0.00561	0.005576	0.005576	0.54	0.480
Feed * feed	1	0.00133	0.001065	0.001065	0.10	0.755
DOC*DOC	1	0.00141	0.001406	0.001406	0.14	0.720
Interaction	3	0.02345	0.023448	0.007816	0.76	0.544
Speed *feed	1	0.01683	0.018627	0.016827	0.63	0.231
Speed *DOC	1	0.00058	0.000576	0.000576	0.06	0.818
Feed*DOC	1	0.00604	0.006045	0.006045	0.58	0.462
Residual error	10	0.10336	0.103361	0.010336		
Lack of fit	5	0.08226	0.082265	0.016453	3.90	0.081
Pure error	5	0.02110	0.021096	0.004219		
total	19	1.05201				

This ANOVA table shows the effect of input parameters on the surface roughness at the surface generated by turning operation. The effect on response variable of individual parameters and their interactions is inversely proportional to the p value corresponding to it. Lower the p value higher the effect on the surface roughness and vise versa. In this table minimum p value is 0 which is corresponding to the feed rate, it means feed rate shows maximum effect on the surface finish. Maximum value of p is corresponding to the cutting speed it means speed has minimum effect on the surface roughness when turning operation is performed on a material,

Table 5: ANOVA table for facing operation

Source	DF	Seqss	Adjss	Adj MS	F	P
Regression	9	1.17978	1.17978	0.13109	29.49	0
Linear	3	1.15755	1.15755	0.38585	86.79	0
Speed	1	0.00750	0.00750	0.00750	0.69	0.223
Feed	1	1.14385	1.14385	1.14385	257.29	0
DOC	1	0.00620	0.00620	0.00620	1.39	0.265
Square	3	0.01284	0.01284	0.00428	0.96	0.448
Speed* speed	1	0.00979	0.01094	0.01094	2.46	0.148
Feed * feed	1	0.00020	0.00038	0.00038	0.08	0.777
DOC*DOC	1	0.00285	0.00285	0.00285	0.64	0.442
Interaction	3	0.00939	0.00939	0.00313	0.70	0.571
Speed *feed	1	0.00829	0.00829	0.00829	1.86	0.202

Speed *DOC	1	0	0	0.000	0	0.978
Feed*DOC	1	0.00110	0.00110	0.0110	0.25	0.630
Residual error	10	0.04446	0.4446	0.00445		
Lack of fit	5	0.03187	0.03187	0.0067	2.53	0.166
Peru error	5	0.01259	0.01259	0.00252		
total	19	0.22424				

This ANOVA table describes that feed rate has maximum effect on the surface roughness as p value corresponding to it is 0. And interaction of cutting speed and depth of cut (at constant feed rate) has minimum effect on surface roughness on faced end as the p value is coming maximum.

In minitab surface and contour plots can be generated that shows how interactions of two factors affect the surface roughness in 3D graphs and 2D graphs. Surface graphs are 2D graphs and contour graphs are 3D graphs. Contour and surface plots for different interaction are discussed below.

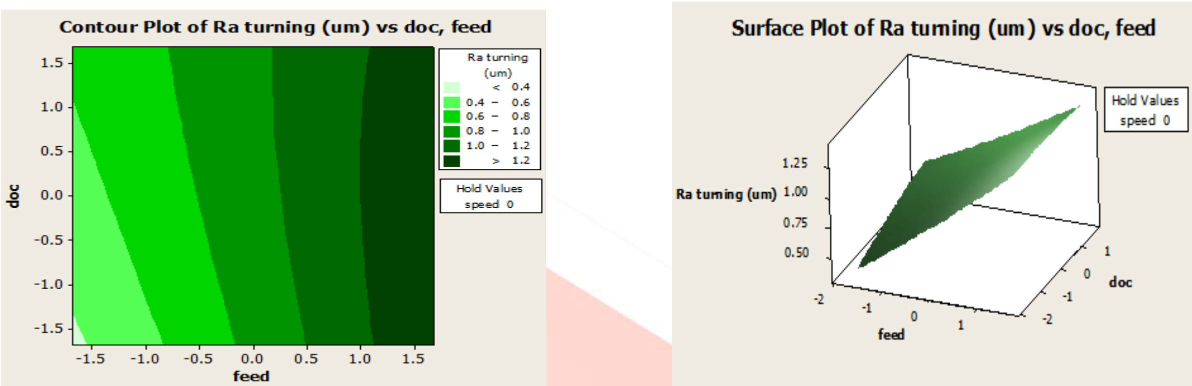

Figure 3: contour and surface plots of Ra turning (µm) vs DOC, feed

These graphs represents that surface roughness is minimum when both feed rate and depth of cut is minimum. Change indepth of cut has not significant role in the change of surface roughness but with change in the feed rate there is a significant change in the surface roughness. Surface roughness is maximum when feed rate and depth of cut is maximum.

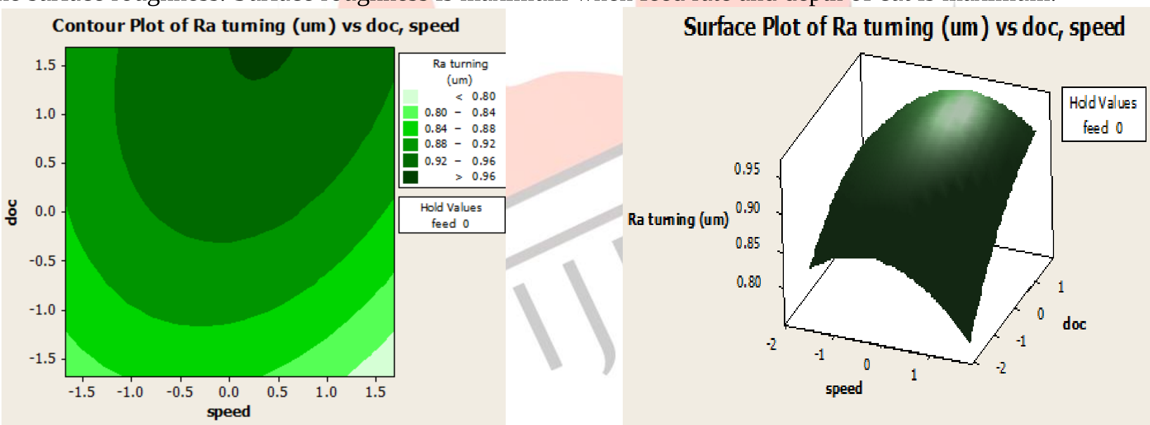

Figure 4: contour and surface plots of Ra turning (µm) vs DOC, speed

These graphs show that the surface roughness is minimum when cutting speed is maximum and depth of cut is minimum. The colors represents the surface roughness, lighter the color less surface roughness and darker the color represents more surface roughness. This represent that surface roughness is maximum when depth of cut is maximum and cutting speed is kept at middle of its range.

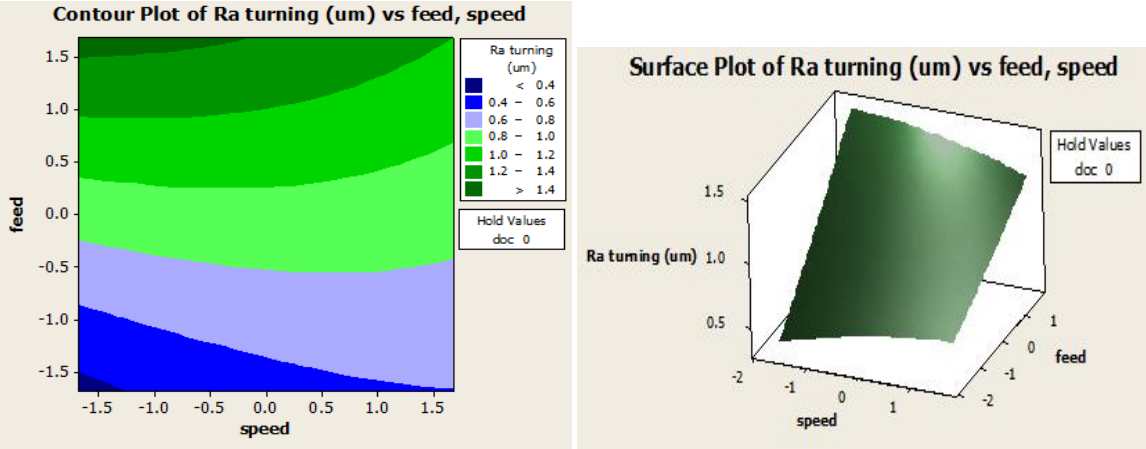

Figure 5: contour and surface plots of Ra turning (µm) vs feed, speed

These graphs show that surface roughness is minimum when both cutting speed and feed rate are minimum. In this graph dark blue color represents the minimum surface roughness. When cutting speed is minimum and feed rate is maximum then surface roughness is maximum as the dark green region represents maximum surface roughness. This graphs represent that feed rate shows greater effect on the surface roughness than cutting speed.

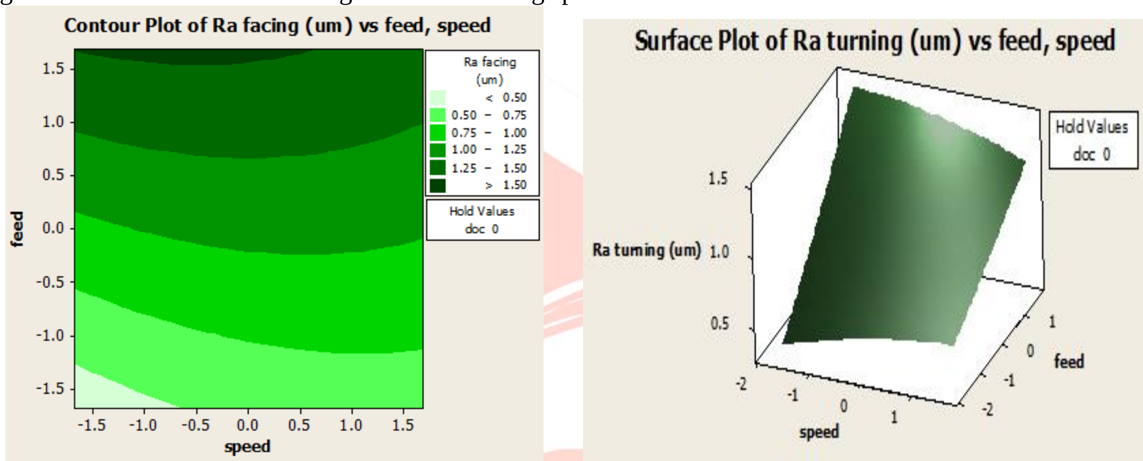

Figure 6: contour and surface plots of Raa facing (µm) vs feed, speed

In these graphs the effect of interaction ofcutting speed and feed rate is shown. Surface roughness is minimum when cutting speed and feed rate are minimum and maximum when feed rate is maximum and cutting speed ranges from minimum to middle range. These graphs show that feed rate has more effect on surface roughness than cutting speed during the facing operation.

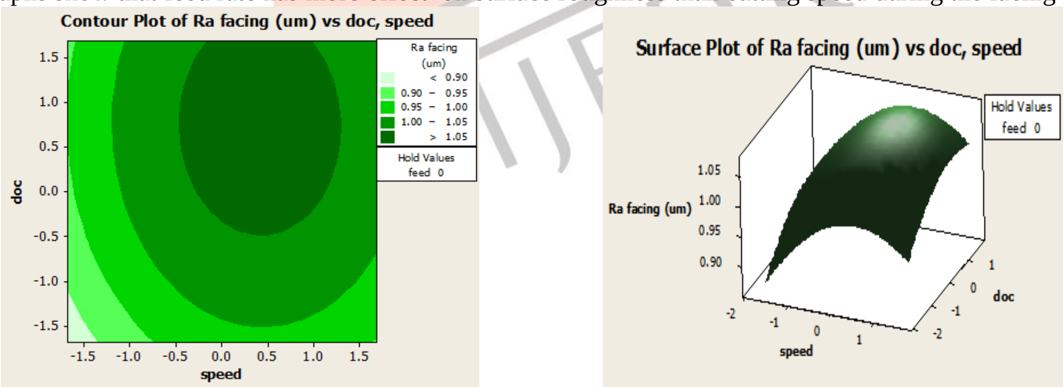

Figure 7: contour and surface plots of Ra facing (µm) vs DOC, speed

In these graphs contour plot shows prominent area. These graphs represent that surface finish is minimum when both the parameters are their lowest levels. Dark green color represents maximum surface roughness during the facing operation.

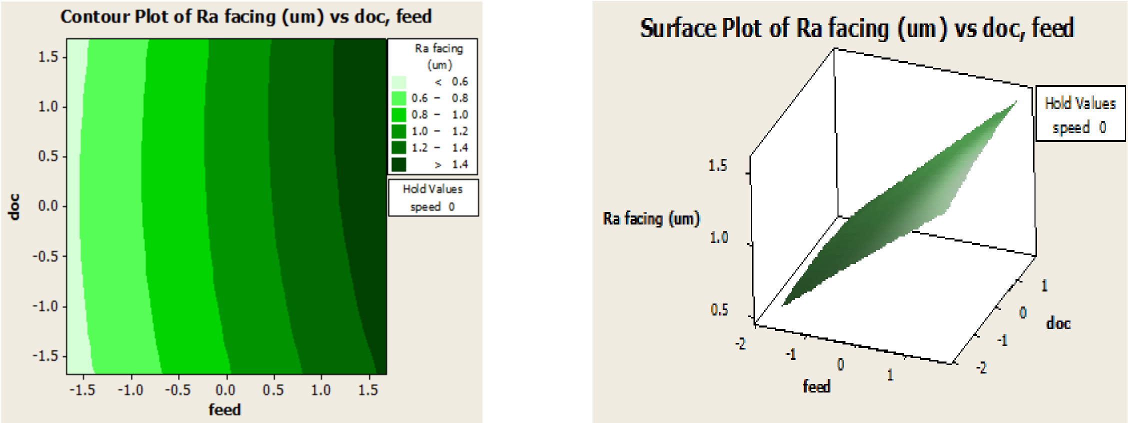

Figure 8: contour and surface plots of Ra facing (μm) vs DOC, feed

These graphs show that feed rate has more effect than depth of cut on surface roughness during the facing operation. Surface roughness is minimum when feed rate is minimum for the entire range of depth of cut and maximum when feed rate is maximum.

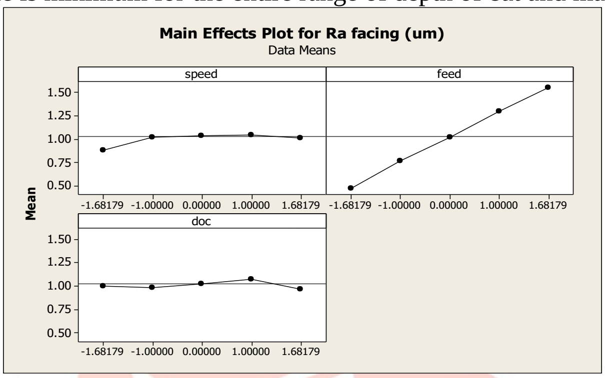

Figure 9: Main effect plots for Ra facing (μm)

This represents that feed rate shows maximum effect on surface roughness during facing as the line shows maximum deviation from the center line. Line representing the cutting speed is straight are nearly overlaps the mean line this shows that speed has minimum effect on surface roughness. Similarly depth of cut also has minimum effect on surface roughness during facing operation.

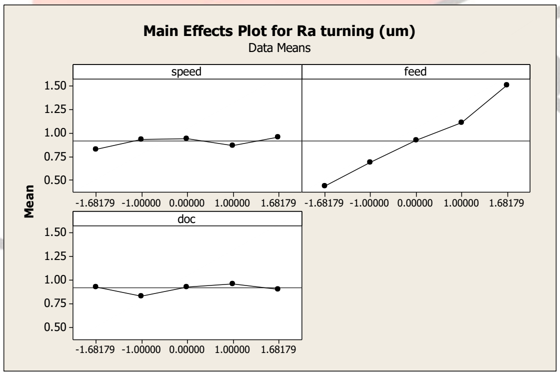

Figure 10: Main effect plots for Ra turning (μm)

This main effect plot for Ra turning shows that cutting speed and depth of cut has minimum effect of surface roughness during turning operation. And feed rate has maximum effect on surface roughness.

V.CONCLUSIONS

In this paper Response Surface Methodology was used to see the influence of the input parameters on the surface roughness of the aluminium 6061 alloy during turning and facing operation& to optimize the process. A mathematical quadratic equation is developed for surface roughness. The results are as bellow:

1. Feed rate is the main significant factorfor surface roughness. Depth of cut and cutting speed has no significant effect on surface roughness.
2. Contour and surface plots was used for determining the optimal conditions to obtain required surface roughness.
3. Response Surface Methodology shows that optimal values for the lowest surface roughness are 165.5 m/min, 0.1mm/rev, 0.85 mm for cutting speed, feed rate and depth of cut respectively.

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