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Experimental Investigation of Effect of Process Parameters on Mrr and Surface Roughness In Turning Operation on Conventional Lathe Machine For Aluminum 6082 Grade Material Using Taguchi Method

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ABSTRACT

In this study, the effect of the machining parameters like spindle speed, feed, depth of cut and nose radius on material removal rate and surface roughness are investigated, also optimum process parameters are studied. An L_8 orthogonal array (mixed level design), analysis of variance (ANOVA) and the signal –to-noise (S/N) ratio are used in this study. Mixed levels of machining parameters are used and experiments are done on conventional lathe machine. Aluminum Alloy - Al 6082 grade material is used in high stress applications, Trusses, Bridges, Cranes, Transport applications, Ore skips, Beer barrels, Milk churns etc. The most significant parameters for material removal rate are speed, depth of cut and least significant factor for MRR is nose radius For surface roughness speed, nose radius are the most significant parameters and least significant factor for surface roughness is depth of cut. The mathematical model obtained as a result of regression analysis can be reliable to predict MRR and surface roughness Ra.

***Keywords* -** Analysis of Variance, Mixed Level Array, Optimization, Regression Analysis, Taguchi Method.

I. INTRODUCTION

In a global competitive environment every industries are trying to decrease the cutting cost and increased the quality of machined parts/components. So, it required to focus on material removal rate and surface roughness. The machining time reduces lead to reduce overall costs which depend on volume of material to be removed and machining parameters like speed, feed and depth of cut.

The quality of surface roughness is also important properties of machined parts, the good quality machined parts improved fatigue strength, corrosion resistance, creep life. The surface roughness also on some functional attributes like surface friction, wearing, light reflection, ability of holding and distributing a lubricant, load bearing capacity, etc. Increasing the productivity and the quality of the machined parts are the main challenges of the based industry [1].

Aluminum alloys are classified under two classes: cast alloys and wrought alloys. Moreover, they can be classified according to the specification of the alloying elements involved, such as strain-hardening alloys and heat-treatable alloys. Most wrought aluminum alloys have excellent machinability. While cast alloys containing copper, magnesium or zinc as the main alloying elements can cause some machining difficulties, the use of small tool rake angles can improve machinability [2]. Aluminum is widely used non-ferrous metal. Aluminum is almost always alloyed, which markedly improves its mechanical properties, especially when tempered. The main alloying agents are copper, zinc, magnesium, manganese, and silicon and the levels of these other metals are in the range of a few percent by weight [3].

The work material used for present study is Aluminum alloy 6082 is a medium strength alloy with excellent corrosion resistance and it has the highest strength of the 6000 series alloys. Alloy 6082 is known as a structural alloy. As a relatively new alloy, the higher strength of Aluminum alloy 6082 has seen it replace 6061 in many applications.

Many types of tool materials, ranging from high carbon steel to diamonds, are used as cutting tools in today’s metal working industry. It is important to be aware that differences do exist among tool materials, what these differences are, and the correct application for each type of material. In some particular applications, a premium or higher priced material will be justified. This does not mean that the most expensive tool is always the best tool [2]. The imports of tool damage leads to economic losses like work piece spoiling or poor surface quality. Selection of best process parameters using various optimization techniques will help to solve the problem of improper selection of process parameters. In order to select optimal cutting parameters, manufacturing to obtain optimal cutting parameters, manufacturing industries have depended on the use of handbook based information which leads to decrease in productivity. This causes high manufacturing cost and low product quality [4]

Many researcher have been carried experimental investigation to study the effect of cutting parameters, tool geometry using the Aluminum alloys. They have taken speed, feed and depth of cut as input parameters and surface roughness as responding parameter. They proved that feed, speed is the most significant factor. [2], [5]-[10]. Only few researcher have studied the interaction effect of nose radius. For surface roughness they found that nose radius is most significant factor [5].

MRR and surface roughness are the important parameters and it requires to optimize. The optimization of lathe turning process is often achieved by trial-and-error method based. But this does not give guarantee of quality as well as machining economics [11]. The traditional experimental design methods are very complicated and difficult to use and required a large number of experiments when process parameters are increase [12]. A general optimization plan is required to avoid cumbersome trial runs on machine and wastages. Taguchi method is widely adopted for the improvement of quality and machining economics. Taguchi parameter design uses the orthogonal array concept, used to estimate main effects using few experimental runs [13].

II. MRR AND SURFACE ROUGHNESS MEASUREMENT

The material removal rate has been calculated from the difference of weight of work before and after machining by using following formula.

$$MRR = \frac{W_i - W_f}{\rho_a t}$$

Where,
W_i = weight of work before machining
W_f = weight of work after machining
t = machining time in minute
ρ_a = density of Al 6082 (2.7 g/mm^3)

There are several ways to describe surface roughness such as average roughness (R_a), Root mean square (R_s), Maximum peak to valley roughness (R_t) and Ten point height method (R_z). One of the most often used average roughness which is often represented as Ra symbol. The average value (without considering the positive or negative sign) of the ordinates ($y_1, y_2, \ldots, y_n$) drawn on the mean line of the surface profile called as CLA number or Ra value.

$$Ra = \frac{y_1 + y_2 + y_3 + \ldots + y_n}{L} = \frac{\sum y}{L}$$

The above method finding CLA number is quite tedious. The easy method is as below
In this method the area ($A_1, A_2, \ldots, A_n$) generated from mean line and surface profile measured with help of planimeter and then Ra value is found as below

$$Ra = \frac{A_1 + A_2 + A_3 + \ldots + A_n}{L} = \frac{\sum A}{L}$$

Where, L = sampling length

There are many method is used to measure surface roughness , such as fingertip, microscopes, stylus type instruments, profile tracing instruments etc. The portable surface roughness tester Surftest SJ-301 used in present experimental work.

Fig. 1: Mitutoyo Surftest SJ-301

III. TAGUCHI METHOD

The Taguchi method involves reducing the variation in a process through robust design of experiments. The objective of method is to produce high quality of product with low cost to manufacturer. Taguchi developed method for designing experiments to investigate how different parameters affect the mean and variance of process performance characteristics. The selection of orthogonal array (OA) is the most important steps in Taguchi technique. An OA is small set of possibilities which helps to determine with least no. of experiments run. For example consider a system which has 4 parameters and each of them has 3 levels. To test all the possible combinations of these parameters, we will need a set of $3^4 = 81$ test cases. But instead of testing the system for each combination of parameters, we can use an orthogonal array to maximize the test coverage with the number of test equal to only 9. To obtain process parameter setting, Taguchi proposed statistical measure of performance called signal to noise ratio is also known as S/N Ratio. This ratio considers both mean as well as variability. In addition to S/N ratio, ANOVA is used to indicate the influence of process parameters on performance measures. Taguchi proposed three performance characteristics in analysis of the Signal to noise ratio (S/N ratio) that is the smaller the better, the higher the better and the nominal the better (Ross, 1996). In the present work the first selection the higher the better characteristic for material removal rate and the lower the better characteristics for the surface roughness.

The higher the better S/N ratio for MRR,

$$\text{S/N ratio} = -\log_{10}\left[\begin{array}{l}\text{mean of sum squares of reciprocal}\\ \text{of measured data}\end{array}\right]$$

The lower the better S/N ratio for surface roughness,

$$\text{S/N ratio} = -\log_{10}\left[\begin{array}{l}\text{reciprocal of mean of sum squares}\\ \text{of reciprocal of measured data}\end{array}\right]$$

IV. DESIGN OF EXPERIMENT

For the experimental design Taguchi method was employed to reach more comprehensive a result with lesser experiments. The objective of Design of experiment is to determine the variables in a process that are the critical parameters and their target values and so on the basis of selected parameters, experimental design is carried out. Taguchi method is a powerful tool for the design of high quality systems which provides simple, efficient and systematic approach to optimize designs for performance, quality and cost. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions. The Taguchi experimental design is done for L_8 Orthogonal array (OA) for mixed level design for four parameters which are spindle speed, feed, depth of cut and nose radius. Minitab16 software was used for analyze the data.

Table 1: Process Parameters

Factor	Process Parameters	Level 1	Level 2	Level 3	Level 4
A	Spindle speed (rpm)	110	400	575	1235
B	Feed (mm/rev)	0.142	0.21	-	-
C	Depth of cut (mm)	0.495	0.99	-	-
D	Nose Radius (mm)	1	1.5	-	-

The experimental layout was developed based on Taguchi's for mixed level design for four parameters L_8 OA experimental technique. An L_8 OA experimental setup was selected to satisfy the minimum number of experimental conditions for the factor and levels presented in table 2.

Table 2: Orthogonal Array

Spindle speed (A)	Feed (B)	DOC (C)	Nose Radius (D)
1	1	1	1
1	2	2	2
2	1	1	2
2	2	2	1
3	1	2	1
3	2	1	2
4	1	2	2
4	2	1	1

V. EXPERIMENTAL DETAILS

The process parameters that are affecting the characteristics of turned parts are

- Cutting Tool parameters e.g. tool geometry and tool material
- Work related parameters such as hardness, ductility, metallographic etc.
- Cutting parameters – Spindle speed, feed, and depth of cut.
- Environmental parameters- Dry cutting, wet cutting.

The following process parameters are (controllable) selected for present work : Spindle speed (A), Feed (B), Depth of Cut (C), Nose radius (D).

The work material used was Al 6082 corresponds to the following standard designations and specifications:

- AA6082
- HE30
- DIN 3.2315
- EN AW-6082
- ISO: Al Si1MgMn
- A96082

It is one of the largest used in different applications such as high stress applications, Trusses, Bridges, Cranes, Transport applications, Ore skips, Beer barrels, Milk churns etc. Al 6082 available in different form like square bar, square box section, Tee section, equal angle, unequal angle, flat bar, tube, sheet etc.

Table 3: The Chemical composition of Aluminum alloy 6082

Element	% Present
Si	0.7-1.3
Fe	0.5
Cu	0.1
Mn	0.4-1.0
Mg	0.6-1.2
Zn	0.2
Ti	0.1
Cr	0.25
Al	Remaining

The Tool material used HSS grade (AISI T-4). The characteristic properties HSS Grades are working hardness, high wear resistance, high red hardness and excellent toughness.

Table 4: The Chemical composition of AISI T-4

Element	% Present
C	0.7 – 0.8
Si	0.2 – 0.4
Mn	0.2 – 0.4
Cr	3.75 – 4.5
Mo	0.7 – 1.0
V	0.8 – 1.2
W	17.25 – 18.75
Co	4.25 – 5.75

Table 5: Experimental Details

Work piece Material	Aluminum alloy 6082
Length of work piece	40 mm
Diameter of work piece	20 mm
Tool used	AISI T-4
Lathe used	Nagmati All Geared Drive Lathe Machine
Environment	Dry

VI. RESULTS AND DISCUSSION

Table 6: Experimental Result and Corresponding S/N Ratio

Sr. No.	Speed (A) rpm	Feed (B) mm/rev	DOC (C) mm	Nose Rad. (D) mm	MRR mm^3/min	S/N for MRR	Ra	S/N for Ra
1	110	0.142	0.495	1	1149.43	61.14	9.45	-20.1716
2	110	0.21	0.99	1.5	3647.77	71.30	9.72	-19.0904
3	400	0.142	0.495	1.5	1904.76	65.66	4.01	-11.3999
4	400	0.21	0.99	1	6172.84	75.75	9.58	-20.2903
5	575	0.142	0.99	1	4444.44	73.02	7.44	-16.7685
6	575	0.21	0.495	1.5	3645.98	71.18	5.11	-14.8314
7	1235	0.142	0.99	1.5	8455.94	78.49	2.41	-8.3033
8	1235	0.21	0.495	1	6703.54	76.59	7.08	-16.3377

Table 7: ANOVA table for MRR

Variable factors	DF	SS	MS	F	p	Contribution (%)
Speed (A)	3	28638513	9546171	10.29	0.224	67.04
Feed (B)	1	2221354	2221354	2.40	0.365	5.12
Depth of Cut (C)	1	10851511	10851511	11.70	0.181	25.4
Nose Radius (D)	1	83190	83190	0.09	0.815	0.002
Error	1	927298	927298			
Total	7	42721866				

Table 8: ANOVA table for Ra

Source	DF	SS	MS	F	P	% Contribution
Speed (A)	3	24.4898	8.1633	22.6	0.153	45.64
Feed (B)	1	8.3641	8.3641	23.15	0.130	15.59
DOC (C)	1	1.5313	1.5313	4.24	0.288	02.86
Nose Radius (D)	1	18.9113	18.9113	52.35	0.087	35.24
Error	1	0.3612	0.3612			
Total	7	53.6576				

MINITAB 16 statistical software has been used for the analysis of the experimental data and provides the calculated results of signal-to-noise ratio. The average value of Signal to noise (S/N) ratios has been calculated to find out the effects of different parameters as well as their levels. The ANOVA (Analysis Of Variance) technique is help to determine which parameter is most significant.

Where,

DF – Degree of freedom, SS – Sum of Square

MS – Mean of Square, F – Statistical parameter,

P- Percentage

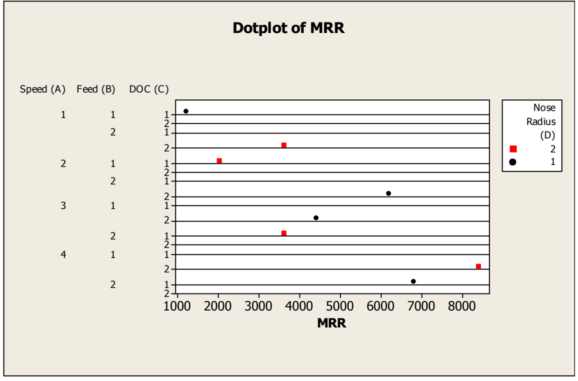

Fig. 2: Dot plot for MRR

From figure 2. The highest MRR obtained at $A_4B_1C_2D_2$ and lowest MRR obtained at $A_1B_1C_1D_1$.

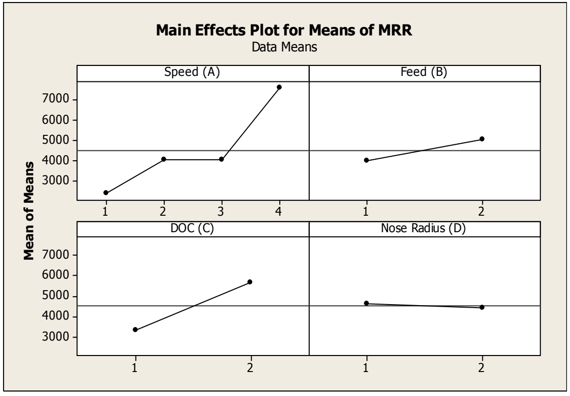

Fig. 3: Main effects plot for means of MRR

The main effect plot for MRR is shown in figure 3. These show the variation of individual response with speed, feed, depth of cut (DOC), and nose radius parameters separately. The mean effects plots are used to determine the optimal conditions for MRR. According to main effects plots the optimal conditions for material removal rate are

Cutting speed at level 4(1235 rpm)

Feed at level 2 (0.21 mm/rev.)

DOC at level 2 (0.99 mm)

Nose radius at level 1 (1 mm)

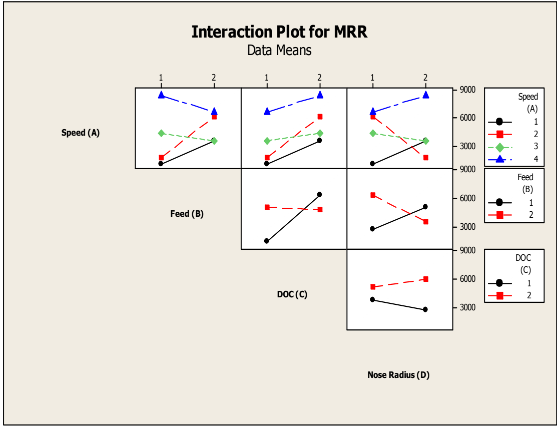

Fig. 4: Interaction plot for MRR

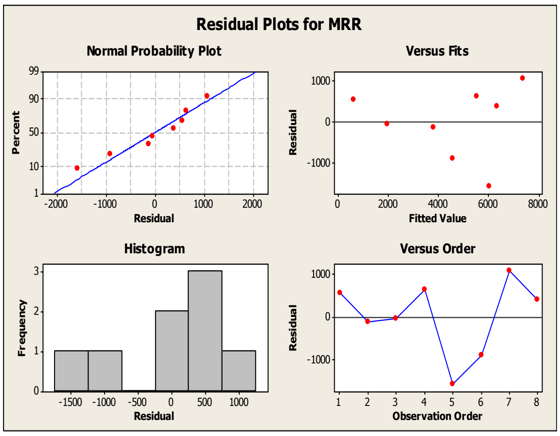

Fig. 5: Residual plot for MRR

From figure 5 the residual spread along straight line that suggest that the residual are distributed normally and it is clear that no obvious pattern and unusual structure. This implies that the model proposed is adequate.

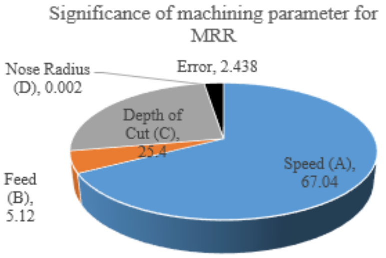

Fig. 6: Significance of machine parameter for MRR

From the ANOVA table 7, the most significant factor for the MRR is Speed (A) and its contribution is 67.04% . After that second significant factor for MRR is DOC (C) and its contributions is about 25.4%. Other factors are having less significant effects since 'p' value are more than 0.05 for the cofidence level 95%.

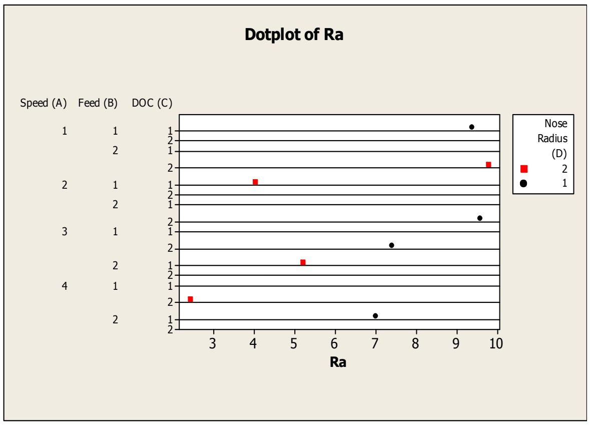

Fig. 7: Dot plot for Ra

From figure 7. The optimal Ra obtained at $A_4B_1C_2D_2$ and lowest MRR obtained at $A_1B_2C_2D_2$.

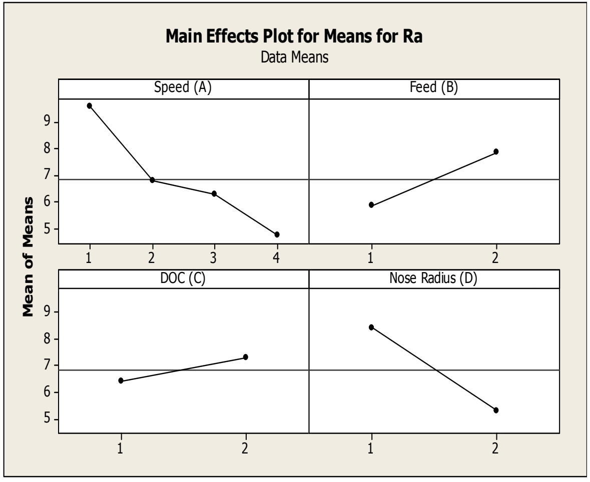

Fig. 8: Main effects plot for means of Ra

The main effect plot for Ra is shown in figure 8. According to main effects plots the optimal conditions for Ra are

Cutting speed at level 4(1235 rpm)
Feed at level 1 (0.142 mm/rev.)
DOC at level 1 (0.495 mm)
Nose radius at level 2 (1.5 mm)

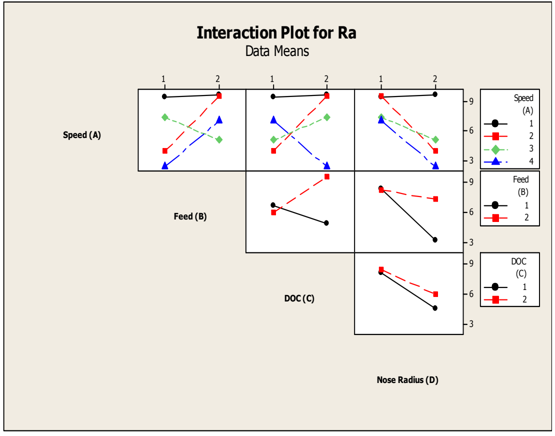

Fig. 9: Interaction plot for Ra

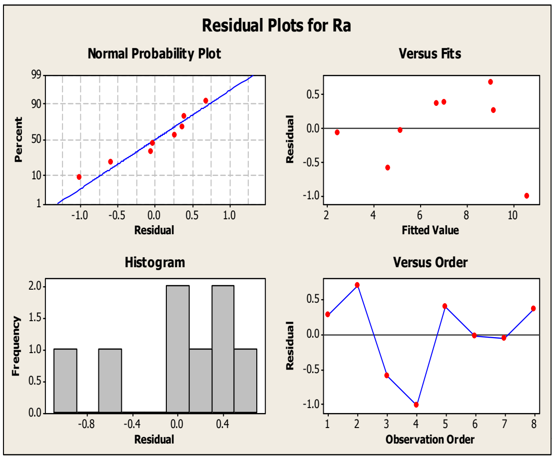

Fig. 10: Residual plot for Ra

From figure 10 the residual spread for Ra lie along straight line that suggest that the residual are distributed normally and it is clear that no obvious pattern and unusual structure that suggest the model proposed is adequate.

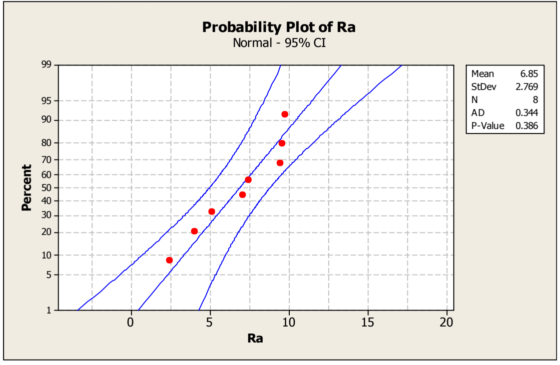

Fig. 11: Probability plot for Ra

Figure 11 shows that the all value are within the confidence interval of 95%. Two lines from the center line indicates the upper and lower limit of confidence interval. No, value out of the confidence interval. This tendency gives the better result for future predictions

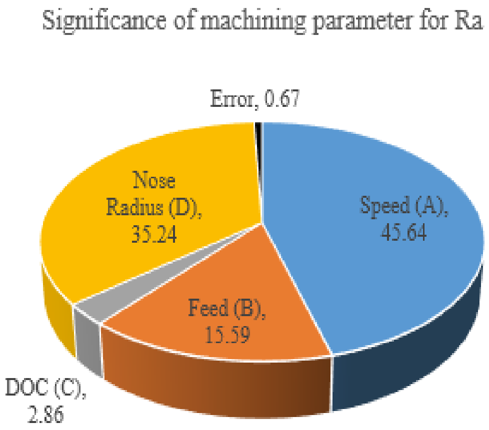

Fig. 12: Significance of machine parameter for Ra

From the ANOVA table 8, the most significant factor for the Ra is Speed (A) and its contribution is 45.64%. After that second significant factor for Ra is Nose radius (D) and its contributions is about 35.24%. Other factors are having less significant effects since ‘p’ value are more than 0.05 for the cofidence level 95%.

VII. MATHEMATICAL MODELING

The multiple linear regression model developed for material removal rate and surface roughness (Ra) using the MINITAB 16. The predictors are speed, feed, DOC and nose radius. The regression equation for
MRR = - 4141 + 1555 Speed (A) + 1054 Feed (B) + 2329 DOC (C) - 204 Nose Radius (D)

Table 9: Regression Table for MRR

Predictor	Coef	SE Coef	T	P
Constant	- 4141	2721	-1.52	0.225
A	1555.0	423.7	3.67	0.035
B	1053.9	947.5	1.11	0.347
C	2329.3	947.5	2.46	0.091
D	-203.9	947.5	-0.22	0.843

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	373335794	9333948	5.2	0.1023
Residual Error	3	5386073	1795358		
Total	7	42721866			

S = 1339.91 R-Sq = 87.4% R-Sq(adj) = 70.6%

The significance of each coefficient in the equation and the regression model were analyzed by ANOVA and tested by the p value and statistics and ANOVA results for regression models are reported in the table 9. Regression statistics indicate that coefficients for speed is statistically significant. ANOVA results of the regression shows that regression model for Ra is statistically significant at 95% confidence level ($p < 0.05$). The standard deviation of error is 1339.91. The value of R-Sq (87.4%) implies that 87.4% of variation in response values can be explained by the variations in the control factors considered. The value of R-Sq (adj) is 70.6 %. A high value of determination coefficient confirms model adequacy, goodness of fit and high significance of model. This indicates that the regression model for the response can be used for determining and estimating MRR.

The regression equation for surface roughness is
Ra = 10.8 - 1.50 Speed (A) + 2.05 Feed (B) + 0.875 DOC (C) - 3.07 Nose Radius (D)

Table 10: Regression Table for Ra

Predictor	Coef	SE Coef	T	P
Constant	10.842	1.751	6.19	0.008
A	-1.504	0.2727	-5.52	0.012
B	2.045	0.6098	3.35	0.044
C	0.875	0.6098	1.43	0.247
D	-3.075	0.6098	-5.04	0.015

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	51.427	12.857	17.29	0.021
Residual Error	3	2.231	0.744		
Total	7	53.658			

S = 0.862340 R-Sq = 95.8% R-Sq(adj) = 90.3%

ANOVA results for regression models are reported for Ra in the table 10. Regression statistics indicate that coefficients for speed, feed and nose radius are statistically significant. ANOVA results of the regression shows that regression model for Ra is statistically significant at 95% confidence level ($p < 0.05$). The standard deviation of error is 0.862340. The smaller the value of S indicate stronger the linear relationship. The value of R-Sq (95.8%) implies that 95.8% of variation in response values can be explained by the variations in the control factors considered. The value of R-Sq (adj) is 90.3 %. A high value of determination coefficient confirms model adequacy, goodness of fit and high significance of model. This indicates that the regression model for the response can be used for determining and estimating Ra.

VIII. CONCLUSION

The present study was carried out to study the effect of input parameters on the material removal rate and surface roughness. The following conclusions have been drawn from the study:

1. The Material removal rate is mainly affected by spindle speed and depth of cut and for surface roughness the most significant factors are cutting speed and nose radius.
2. The least significant factor for MRR is nose radius and for surface roughness is DOC.
3. Linear regression model constructed is used to predict MRR and surface roughness Ra.
4. The parameters considered in the experiments are optimized to attain maximum material removal rate. The best setting of input process parameters for turning (maximum material removal rate) within the selected range is as follows:
   i) Spindle speed i.e. 1235 rpm.
   ii) Feed rate i.e. 0.142mm/rev.
   iii) Depth of cut should be 0.99
   iv) Nose radius 1.5 mm.
5. The best setting of input process parameters for surface roughness in turning within the selected range is as follows:
   i) Spindle speed i.e. 1235 rpm.
   ii) Feed rate i.e. 0.142mm/rev.
   iii) Depth of cut should be 0.495
   iv) Nose radius 1.5 mm.

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