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DETERMINATION OF OPTIMAL PROCESS PARAMETERS IN TURNING OF MEDIUM CARBON STEEL EN8

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ABSTRACT
The present work is to investigate the effect of cutting parameters, Speed, feed and depth of cut on the responses (Material Removal Rate and Surface Roughness) while turning of a medium carbon steel EN8. The machining has been done using a Tungsten carbide tool under dry environment. For conducting the experiments, Taguchi's standard L27 (3 factors X 3 levels) Orthogonal array has been selected and the optimization of responses was done using Single objective Taguchi method. Analysis of variance (ANOVA) was employed to find the relative importance of cutting parameters on the responses. From Taguchi results, the optimal combination is obtained at s3-f3-d3, 760 rpm, 0.3 mm/rev and 1.5 mm for material removal rate and at s3-f1-d3, 760 rpm, 0.1 mm/rev and 1.5 mm for surface roughness respectively. From ANOVA results, feed has high influence in affecting both material removal rate and surface roughness. Finally, Mathematical models for the responses were prepared using the MINITAB-16 software. The models prepared were following a normal distribution and best fit for the prediction of the responses.

INTRODUCTION
In any machining process, Material Removal Rate and Surface finish are the most significant characteristics according to manufacturer and customer point of view. High Material removal rate is required for increasing the production rate and a good surface finish is desired to improve the tribological properties, fatigue strength, corrosion resistance and aesthetic appeal of the product. [1-5] Quality of the surface plays a very important role in the performance of dry, turning because a good quality turned surface improves fatigue strength, corrosion resistance and creep life. Surface roughness also affects on some functional attributes of parts, such as, contact causing surface friction, wearing, light reflection, ability of distributing and holding a lubricant, load bearing capacity, coating and resisting fatigue. [6-10] In any machining process, it is difficult to achieve a good surface finish because it depends on many factors. In general Surface finish depends on cutting conditions (speed, feed and depth of cut), mechanical properties of the material (hardness, density, etc.) and tool nomenclature (nose radius, rake angles etc.). [11-15] In machining operations, it is customary to reduce the number of cutting parameters since with an increase in the number of cutting parameters the number of experiments to be conducted will be increased thereby experimentation cost as well as machining time will also be increased. Generally, the selection of cutting parameters will be done based on the operator's experience or by design data books, but which leads to decrease in productivity due to sub optimal use of machining capabilities this causes an increase in machining cost and decrease in quality. Hence statistical design of experiments and statistical/mathematical models are used for decreasing the machining cost and time. Statistical design of experiments refers to the process of planning the experiments so that the appropriate data can be analyzed by statistical methods, resulting in valid conclusions. [16-20] For optimization of single responses Taguchi has suggested a new design called robust design and uses orthogonal array. It offers a simple and systematic qualitative optimal design at a relatively low cost. An OA is a small set of all possibilities which help to determine the least number of experiments, which will further helps to conduct experiments to determine the optimum level for each process parameters and establish the relative importance of individual process parameters. Taguchi method used Signal to Noise ratio; this ratio considers both mean and variance. Taguchi has suggested three Signal to Noise ratio characteristics, namely Larger the better, Nominal the better and Smaller the better for the analysis of the responses. [21-25]

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In the present work, an attempt has been made to explore the effect of cutting parameters on material removal rate and surface roughness while machining of EN8 steel. EN8 is medium carbon steel has high industrial applications in tool, oil and gas industries. It is most commonly used where high tensile strength property is required and also used for axial shafts, propeller shafts, crank shafts, high tensile bolts and studs, connecting rods, riffle barrels and gears manufacturing etc. [26-30] The experiments were done as per Taguchi's L27 Orthogonal Array using a tungsten carbide tool. For the optimization of responses, the single objective Taguchi method has employed along with Analysis of variance (ANOVA). Optimal designs for both material removal rate and Surface roughness were predicted. Regression models for the responses were developed and the accuracy and adequacy of the models were checked with the help of residual plots.

EXPERIMENTAL DETAILS

The turning tests were conducted on EN8 steel having dimensions of 36 mm diameter (ϕ) and 300 mm Length (L). The chemical composition and mechanical properties of EN8 steel were given in the tables 1 and 2 respectively. The machining was done on a conventional lathe using a tungsten carbide insert having ISO designation DNMG 160404 (Tool holder ISO designation PDJNL2525M16) under dry environment. After machining, Surface roughness values were taken at three different places on the machined surfaces using handy surf shown in the figure 1 and the average was considered as final roughness value.

Table 1: Chemical Composition of EN8 Steel

Element	C	Mn	Si	S	P	Cr	Ni	Mo
% Weight	0.36-0.44	0.6-1.0	0.10-0.40	0.05 max	0.05 max	-	-	-

Table 2: Mechanical Properties of EN8 Steel

Property	Maximum Stress (N/mm^2)	Yield Stress (N/mm^2)	Elongation (%)	Impact (J)	Hardness (BHN)
Value	700-850	465	16	28	201-255

Fig 1: Handysurf

DESIGN OF EXPERIMENTS

For conducting the experiments Taguchi's standard L27 Orthogonal Array has been selected. The selected cutting parameters with their levels and the standard L27 Orthogonal array were given in the tables 3 and 4 respectively.

Table 3: Cutting Process Parameters with their Levels

Level	Speed (rpm)	Feed (mm/rev)	Depth of Cut (mm)
1	360	0.1	0.5
2	560	0.2	1.0
3	760	0.3	1.5

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Table 4: L27 Orthogonal Array

Job No	Speed	Speed (rpm)	Feed	Feed (mm/rev)	Depth Of Cut	Depth Of Cut (mm)
1	1	360	1	0.1	1	0.5
2	1	360	1	0.1	2	1
3	1	360	1	0.1	3	1.5
4	1	360	2	0.2	1	0.5
5	1	360	2	0.2	2	1
6	1	360	2	0.2	3	1.5
7	1	360	3	0.3	1	0.5
8	1	360	3	0.3	2	1
9	1	360	3	0.3	3	1.5
10	2	560	1	0.1	1	0.5
11	2	560	1	0.1	2	1
12	2	560	1	0.1	3	1.5
13	2	560	2	0.2	1	0.5
14	2	560	2	0.2	2	1
15	2	560	2	0.2	3	1.5
16	2	560	3	0.3	1	0.5
17	2	560	3	0.3	2	1
18	2	560	3	0.3	3	1.5
19	3	760	1	0.1	1	0.5
20	3	760	1	0.1	2	1
21	3	760	1	0.1	3	1.5
22	3	760	2	0.2	1	0.5
23	3	760	2	0.2	2	1
24	3	760	2	0.2	3	1.5
25	3	760	3	0.3	1	0.5
26	3	760	3	0.3	2	1
27	3	760	3	0.3	3	1.5

RESULTS AND DISCUSSIONS

The experimental results of Material removal rate and the measured surface roughness values were given in the table 5.

Table 5: Experimental Results

Exp.No.	Speed (rpm)	Feed (mm/rev)	Doc (mm)	MRR	R_a
1	360	0.1	0.5	11.38	5.0
2	360	0.1	1	21.75	5.7
3	360	0.1	1.5	31.39	4.7
4	360	0.2	0.5	20.74	5.6
5	360	0.2	1	38.66	6.2
6	360	0.2	1.5	53.01	7.2
7	360	0.3	0.5	39.38	9.4
8	360	0.3	1	69.72	8.9
9	360	0.3	1.5	100.02	5.5
10	560	0.1	0.5	13.70	5.0
11	560	0.1	1	24.30	5.3
12	560	0.1	1.5	34.71	3.8
13	560	0.2	0.5	13.98	5.3
14	560	0.2	1	25.80	4.4
15	560	0.2	1.5	36.25	6.9
16	560	0.3	0.5	46.12	9.2

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17	560	0.3	1	78.50	7.0
18	560	0.3	1.5	92.03	4.4
19	760	0.1	0.5	25.52	2.5
20	760	0.1	1	46.32	3.7
21	760	0.1	1.5	66.26	7.4
22	760	0.2	0.5	42.86	5.1
23	760	0.2	1	78.53	4.0
24	760	0.2	1.5	102.46	6.7
25	760	0.3	0.5	63.72	8.0
26	760	0.3	1	117.80	6.9
27	760	0.3	1.5	119.60	3.5

The mean values for material removal rate and surface roughness were calculated and given in the tables 6 and 7. The Main effect plots for the means and S/N ratios of both the responses were drawn and shown in the figures 2 to 5.

Table 6: Mean Values of Material Removal Rate (MRR)

Level	Speed	Feed	Depth of cut
1	42.89	30.59	30.82
2	40.60	45.81	55.71
3	73.67	80.77	70.64

Table 7: Mean Values of Surface Roughness (R_a)

Level	Speed	Feed	Depth of cut
1	6.467	4.781	6.107
2	5.689	5.696	5.774
3	5.293	6.970	5.567

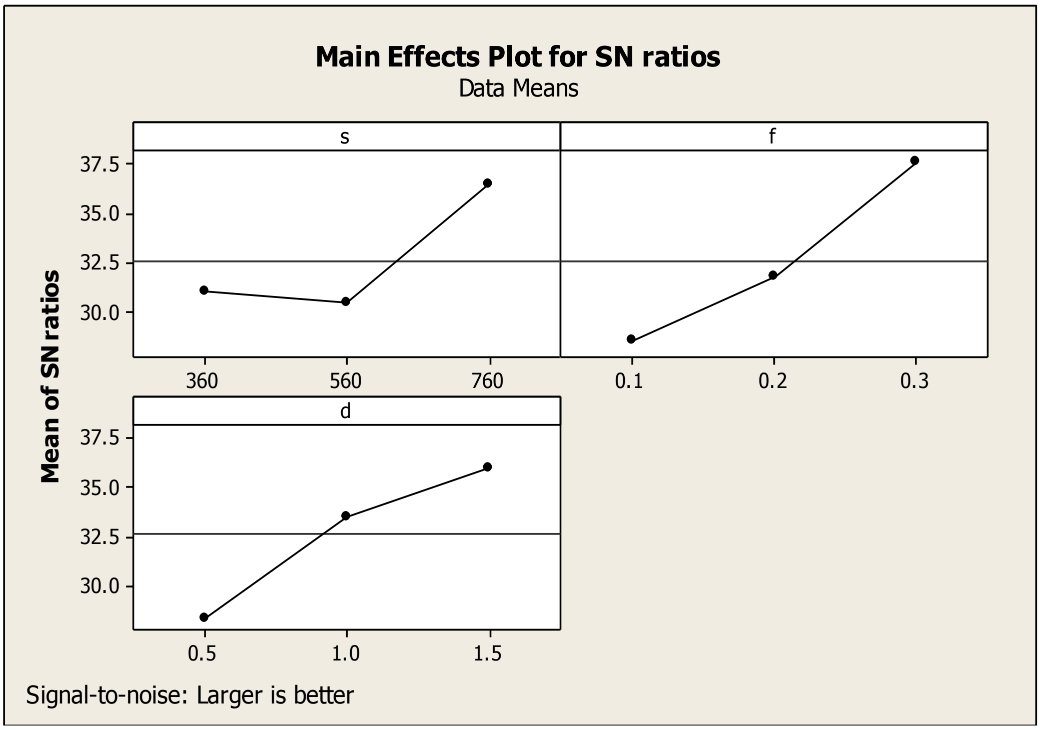

Fig 2: Main Effect Plot for S/N Ratios of Material Removal Rate (MRR)

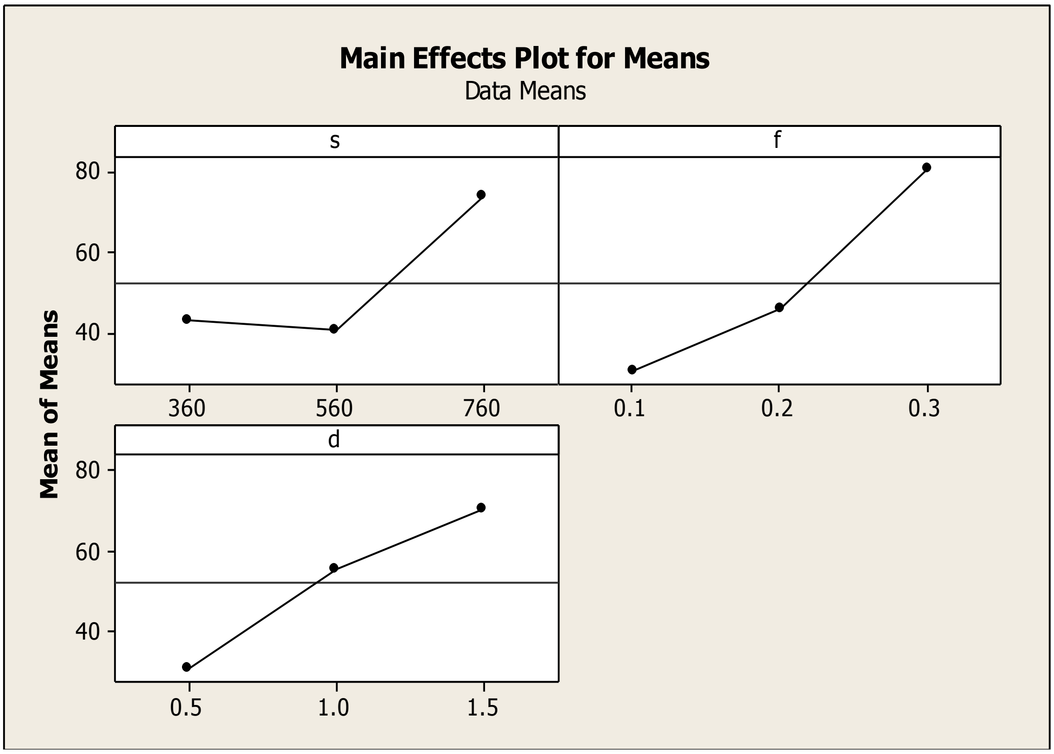

Fig 3: Main Effect Plot for Means of Material Removal Rate (MRR)

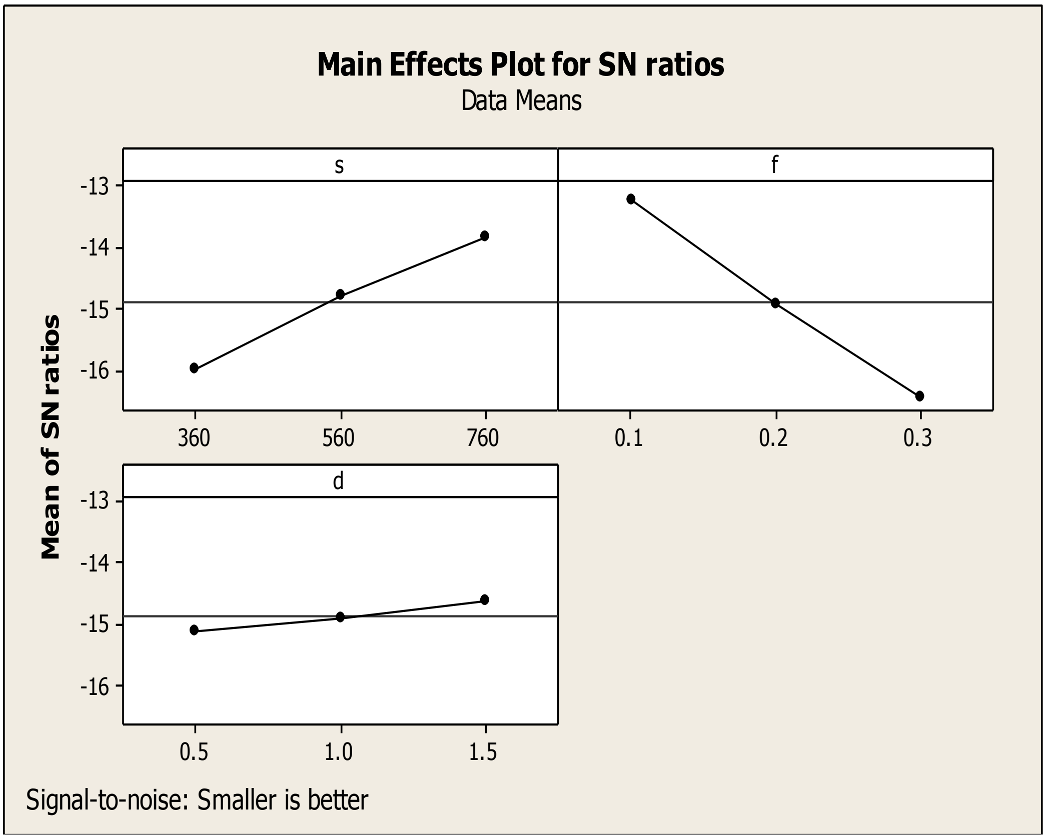

Fig 4: Main Effect Plot for S/N Ratios of Surface Roughness (R_a)

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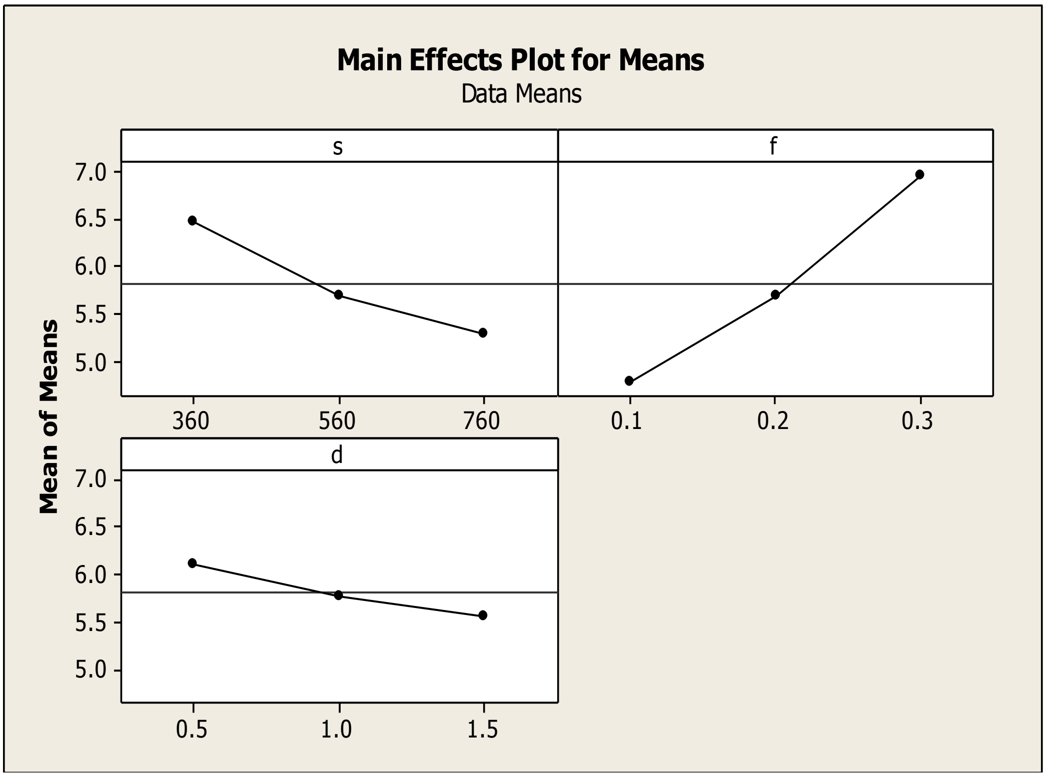

Fig 5: Main Effect Plot for Means of Surface Roughness (R_a)

From the figures 2 to 5 the optimal combination of cutting parameters for Material removal rate was found at: s3-f3-d3, 760 rpm, 0.3 mm/rev, 1.5 mm and for Surface roughness it is found at: s3-f1-d3, 760 rpm, 0.1 mm/rev, 1.5 mm.

ANALYSIS OF VARIANCE (ANOVA)

The Analysis of variance (ANOVA) is employed at 95% of confidence level, i.e. at $\alpha = 0.05$ to find the relative importance or significance of cutting parameters on responses. Anova results of Material removal rate and Surface roughness were given in the tables 8 and 9. From the results, it is observed that feed has the high influence in affecting both the responses.

Table 8: ANOVA Results of Material Removal Rate (MRR)

Source	Degree of freedom	Sum of squares	Mean squares	F value	P value	Significance
Speed	2	6140.0	3070.0	28.61	0.000	Significant
Feed	2	11912.5	5956.3	55.51	0.000	Significant
Depth of cut	2	7282.1	3641.1	33.93	0.000	Significant
Error	20	2146.0	107.3			
Total	26	27480.6				

Table 9: ANOVA Results of Surface Roughness (R_a)

Source	Degree of freedom	Sum of squares	Mean squares	F value	P value	Significance
Speed	2	6.421	3.211	1.17	0.330	-
Feed	2	21.754	10.877	3.98	0.035	Significant
Depth of cut	2	1.340	0.670	0.24	0.785	-
Error	20	54.695	2.735			
Total	26	84.210				

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PREDICTION OF OPTIMAL DESIGNS

Prediction of optimal design for material removal rate (MRR)

Performance of Material removal rate when the two most significant factors (feed and depth of cut) are at their better level (based on estimated average).

$\mu_{A3B3} = A_3 + B_3 - T$

$A_3 = 80.77$, $B_3 = 70.64$ (From Table 6)

$T = 52.38$ (From Table 5)

$\mu_{A3B3} = A_3 + B_3 - T$

$= 80.77 + 70.64 - 52.38 = 99.03$

$$CI = \sqrt{\frac{F_{95\%,1,dof\ error}\ V_{error}}{n_{efficiency}}}$$

Where, $\eta_{efficiency}$ = N/(1+dof) of all parameters associated to that level.

$\eta_{efficiency}$ = N/ (1+dof) = 27/(1+2+2) = 27/5 = 5.4

V_{error} = 107.3 (From Table 8)

$F_{95\%,\ 1,\ 20}$ = 4.3512 (From standard F-table)

CI = $\sqrt{(4.3512 \times 107.3) / 5.4} = \sqrt{86.46} = 9.2983$

The predicted optimal range of Material removal rate at 95% confidence level is obtained as,

$\mu_{A3B3} - CI \leq \mu_{A3B3} \leq \mu_{A3B3} + CI$

$99.03 - 9.2983 \leq \mu_{A3B3} \leq 99.03 + 9.2983$

$89.7317 \leq \mu_{A3B3} \leq 108.3283$

Prediction of optimal design for surface roughness (R_a)

Performance of Surface roughness when the two most significant factors (feed and speed) are at their better level (based on estimated average).

$\mu_{A3B1} = A_3 + B_1 - T$

$A_3 = 5.293$, $B_1 = 4.781$ (From Table 7)

$T = 5.8$ (From Table 5)

$\mu_{A3B1} = A_3 + B_1 - T$

$= 5.293 + 4.781 - 5.8 = 4.274$

$$CI = \sqrt{\frac{F_{95\%,1,dof\ error}\ V_{error}}{n_{efficiency}}}$$

Where, $\eta_{efficiency}$ = N/(1+dof) of all parameters associated to that level.

$\eta_{efficiency}$ = N/ (1+dof) = 27/(1+2+2) = 27/5 = 5.4

V_{error} = 2.735 (From Table 9)

$F_{95\%,\ 1,\ 20}$ = 4.3512 (From F-table)

CI = $\sqrt{(4.3512 \times 2.735) / 5.4} = \sqrt{2.2038} = 1.4845$

The predicted optimal range of Surface roughness at 95% confidence level is obtained as,

$\mu_{A3B1} - CI \leq \mu_{A3B1} \leq \mu_{A3B1} + CI$

$4.274 - 1.4845 \leq \mu_{A3B1} \leq 4.274 + 1.4845$

$2.7895 \leq \mu_{A3B1} \leq 5.7585$

REGRESSION ANALYSIS

The Linear relationship between cutting parameters and the responses can be analyzed by using regression analysis. Mathematical models for the Material removal rate and Surface roughness were prepared by using MINITAB-16 software. The accuracy and adequacy of the models prepared were checked graphically with Normal probability plot, Histogram plots drawn and shown in figures 6 to 9. From the figures it is observed that all the residuals are lying nearer to the straight line implying that the errors are following the normal distribution.

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The linear relation between MRR, R_a and cutting parameters were given as below

MRR = - 80.7 + 0.0769 s + 251 f + 39.8 d
R_a = 5.81 - 0.00294 s + 10.9 f - 0.541 d

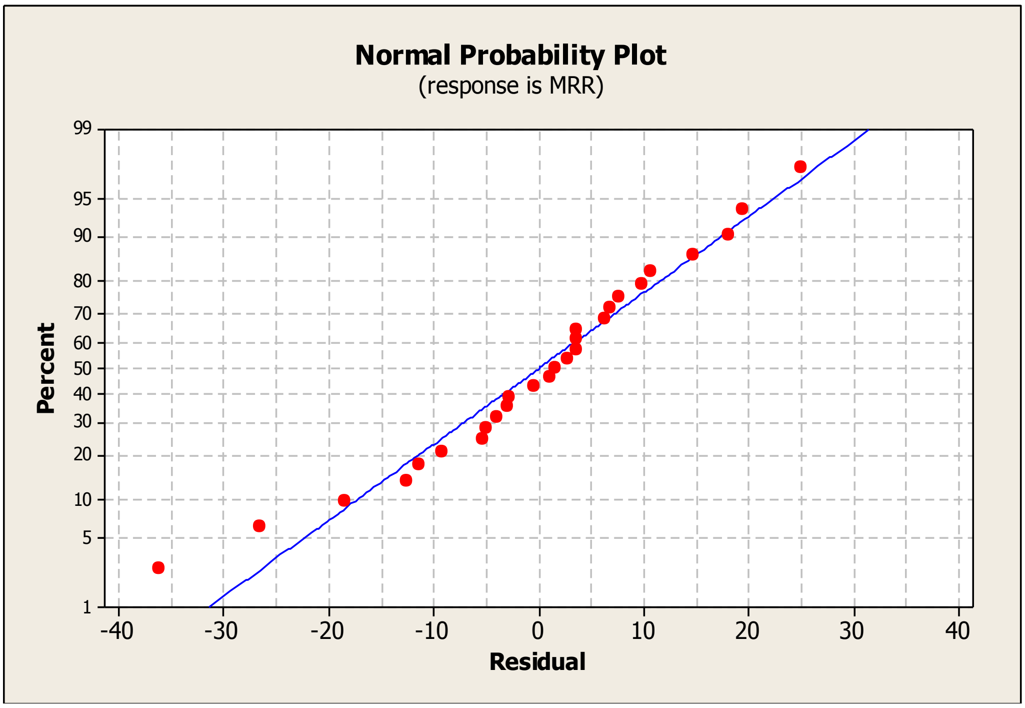

Fig 6: Normal Probability Plot of MRR

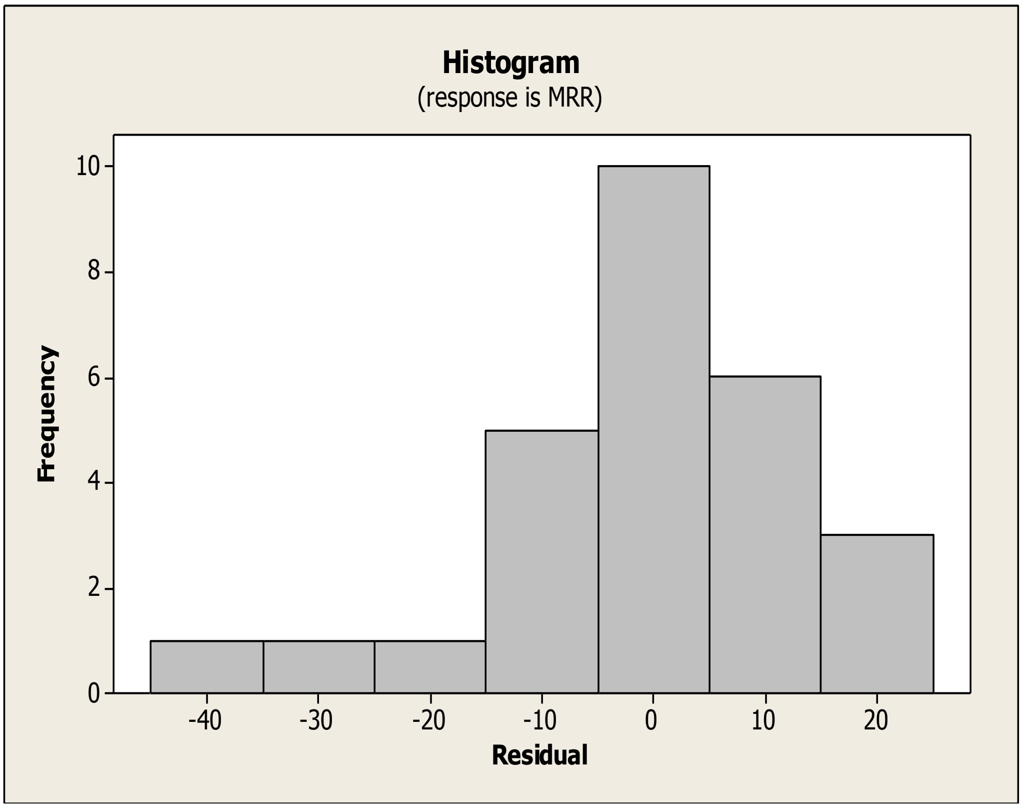

Fig 7: Histogram Plot of MRR

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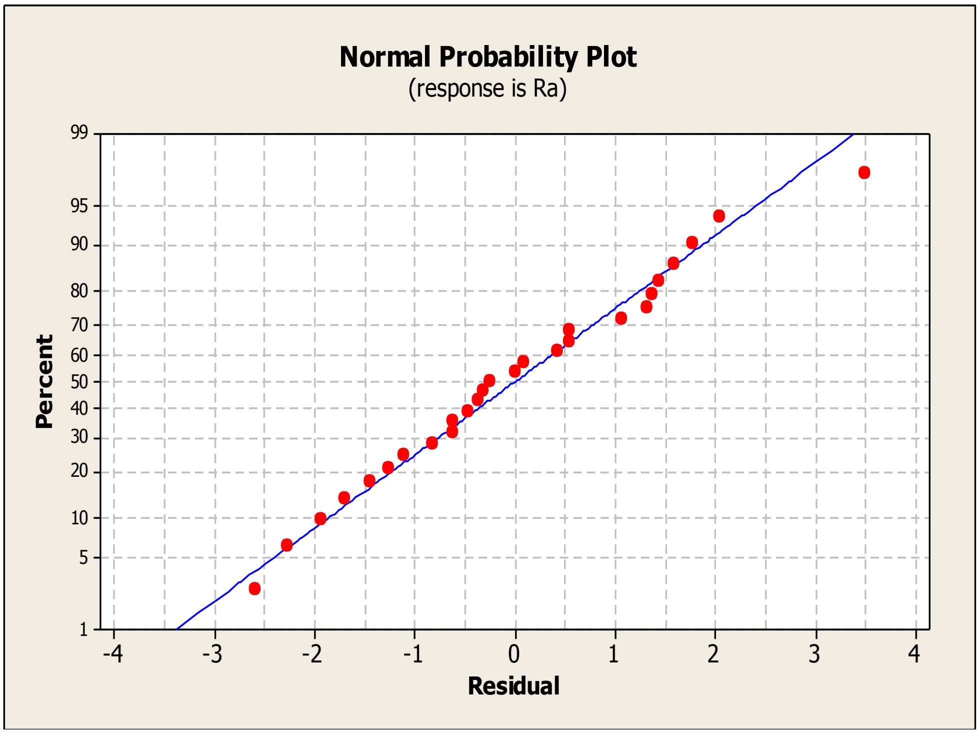

Fig 8: Normal Probability Plot of R_a

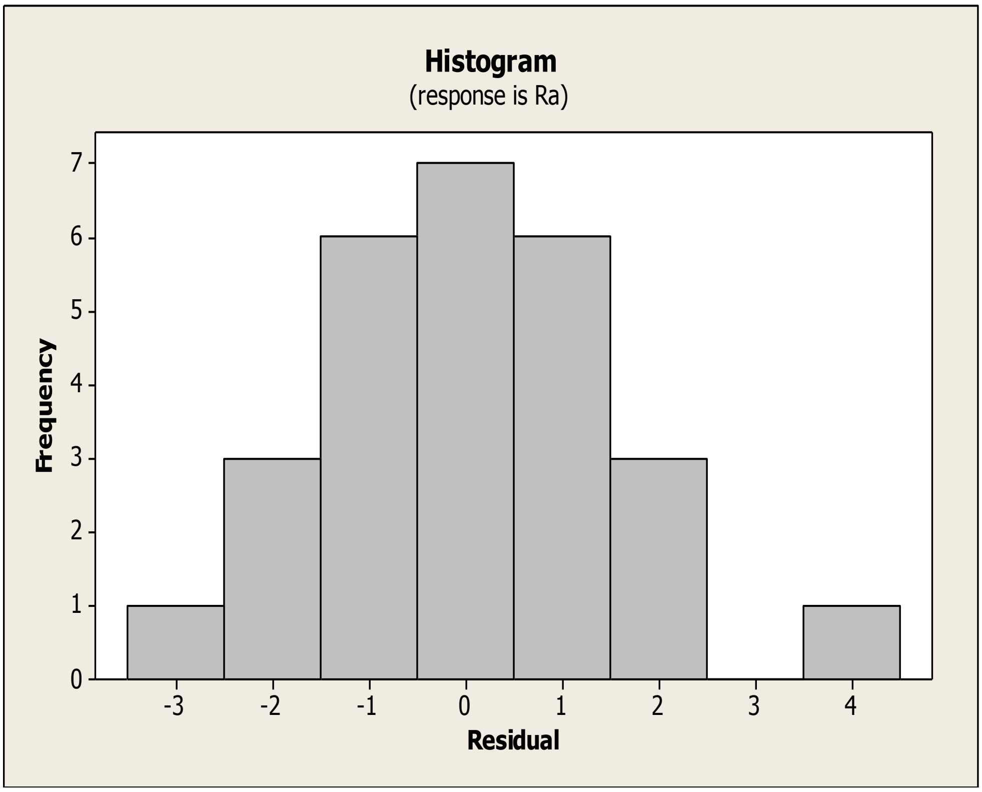

Fig 9: Histogram Plot of R_a

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CONCLUSIONS

- From Taguchi results, the optimal combination of cutting parameters for Material removal rate is found at s3-f3-d3: Cutting speed at 760 rpm (level 3), Feed at 0.3 mm/rev (level 3) and Depth of cut at 1.5 mm (level 3).
- The optimal combination of cutting parameters for Surface roughness is found at s3-f1-d3: Cutting speed at 760 rpm (level 3), Feed at 0.1 mm/rev (level 1) and Depth of cut at 1.5 mm (level 3).
- From ANOVA results, it is observed that feed has high influence (F = 55.51), speed has low influence (F = 28.61) for Material removal rate and feed has high influence (F = 3.98), depth of cut (F = 0.24) has low influence for Surface roughness.
- Mathematical models for the Material removal rate and Surface roughness were prepared and are more accurate and adequate

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