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Investigation Of Effect Of Cutting Parameters On Material Removal Rate Of AISI 304 Alloy Steel Using Taguchi

K.A Adedeji, O.A Adefuye, O.A. Ademolu
Lagos State University, Lagos State Polytechnic
Kaz6deji@gmail, connectcrossby@yahoo.com

***Abstract*—In the present study, an attempt is made to investigate the effects of cutting parameters (cutting speed, feed rate and depth of cut) on material removal rate (MRR) in orthogonal turning of AISI 304 Alloy steel using coated tool insert in dry and wet environments. This research is based and limited on Taguchi method which was employed using the L27 orthogonal array and the analysis of variance (ANOVA) for investigating effects of cutting parameters (cutting speed, feed rate and depth of cut) on the metal removal rate of the AISI 304 alloy steel material. The HIGHER THE BETTER signal to noise (S/N) ratio based on the Taguchi technique was applied for MRR**

Keywords—MRR, ANOVA, depth of cut, feed rate, cutting speed

1.0 INTRODUCTION

Steel is primarily composed of Iron and Carbon with other trace elements that give it unique properties from each other. One of the classes of Steels is known as Stainless Steel. It is alloyed with Chromium to reduce the usual corrosion experienced by most iron-based materials. This study will investigate the effects of cutting parameters on material removal rate while turning AISI 304 alloy steel.

According to Korkut and Donertas (2007), it was discovered that when cutting AISI 1020 and AISI 1040 steels, the cutting process is most influenced by increase in the cutting speed. In the optimization of MRR during hard turning of Austenitic 304L stainless steel, it was discovered that optimization of MRR is a function of proper selection of cutting parameters *Ojolo et al*, *(2016).*

The turning experiments would be conducted based on Design of Experiment using Taguchi via a Minitab 17 statistical software. Analysis of variance (ANOVA) shall be conducted to determine the significance of each of the input parameters on the response (MRR) and the optimum cutting parameters to enhance maximum MRR shall be determined by means of main effects plot. The analysis of the results will increase the existing knowledge base on the most suitable combination of parameters that will enhance rapid orthogonal turning of AISI 304 from the initial dimension to the predetermined finish dimension. According to Sahu *et al* (2014), the foundation of the engineering industry is metal cutting process. It is involved either directly or indirectly in the manufacture of almost every component of our modern civilization. Turning is a metal cutting process in which a cutting tool removes material from the surface of a less resistant workpiece by the application of force to produce a desired shape, dimension and surface finish (Anzalone, 2011). Orthogonal cutting is the type of cutting where the cutting tool's motion is perpendicular to the cutting edge. In this cutting, the chip flow is perpendicular to the cutting edge *Olaiya (2021)*

2.0 MATERIALS AND METHODS

2.1 Materials

2.1.1 Workpiece

The experimental work piece material for this research is AISI 304 alloy steel. This material was concluded for usage because of its importance in various engineering applications. AISI 304 alloy steel, finds useful applications in food industry, it is also widely used in marine and similar industries due to its excellence corrosion resisting property.

The Table 1 below shows the range of chemical composition of AISI 304 alloy steel as obtained from the literature

Table 1: Chemical composition of AISI 304 Alloy steel

Element C Cr Fe Mn Ni P S

Weight 0.08 max 18 66.35 2.0 max 8.00 0.045 max 0.03 max

(%) - - -

20 74.00 10.50

Source: NAS, 2016

2.1.2 Machine Tool

The machine tool used for this research is Colchester conventional center lathe located in Department of Mechanical Engineering, Lagos State Polytechnic, Ikorodu. It is shown in plate I

Plate I: Colchester Lathe Photo

2.1.3 Cutting Tool and Holder

The cutting tool used is CMMG 20408H Tungsten coated carbide tool used (indexable). The cutting tool holder is a right hand cutting tool insert (indexable) holder. The insert and holder are produced by Widia Tools, India.

2.2 Method

2.2.1 Composition of workpiece material

The elemental composition of the workpiece material was ascertained via Optical Emission Spectrometer (OES). This is paramount in ensuring that the workpiece material being investigated is actually AISI 304 alloy steel. This result obtained is presented in Table 2

Table 2: Composition of AISI 304 Alloy steel workpiece

Element	C	Si	Mn	P	S	Cr	Mo	Ni	Al
Composition	0.0439	0.393	1.07	0.033	0.013	18.19	0.007	8.18	0.001

Co	Cu	Nb	Ti	V	W	Pb	Sn	As
0.268	0.165	0.004	0.001	0.113	0.007	0.002	0.0016	0.007

Ca	Sb	Se	Ta	B	N	Fe
0.0028	0.002	0.002	0.02	0.00069	0.04	71.4

2.2.2 Experimental Design

For improvement of scientific and engineering experimental process analysis, Design of Experiment (DOE) are very useful as it enhances experimental process planning, appropriate data collection and results analysis via statistical method, resulting in valid and objective conclusion (*Masounave et al, 1997)*

For this study, Taguchi experimental design was selected for the three variables – cutting speed, feed rate and depth of cut while the response studied was material removal rate (MRR). The variables and their levels are presented in Table 3 while Table 4 shows the 27 experiments conducted.

Table 3: Machining variables (factors) and their Levels

Factor	Unit	Level 1	Level 2	Level 3
		Low (-1)	Medium (0)	High (+1)
Cutting Speed	rev/min	625	840	1120
Feed Rate	mm/min	0.50	0.75	1.00
Depth of Cut	mm	0.25	0.35	0.50

Table 4: Experimental Layout of 27 experiments

Runs	Cutting speed (rev/min)	Feed Rate (mm/min)	Depth of cut (mm)
1	625	0.50	0.25
2	625	0.50	0.25
3	625	0.50	0.25
4	625	0.75	0.35
5	625	0.75	0.35
6	625	0.75	0.35
7	625	1.00	0.50
8	625	1.00	0.50
9	625	1.00	0.50
10	840	0.50	0.35
11	840	0.50	0.35
12	840	0.50	0.35
13	840	0.75	0.50
14	840	0.75	0.50
15	840	0.75	0.50
16	840	1.00	0.25
17	840	1.00	0.25
18	840	1.00	0.25
19	1120	0.50	0.50
20	1120	0.50	0.50
21	1120	0.50	0.50
22	1120	0.75	0.25
23	1120	0.75	0.25
24	1120	0.75	0.25
25	1120	1.00	0.35
26	1120	1.00	0.35
27	1120	1.00	0.35

2.2.3 Experimental Procedure

The workpiece used is cylindrical rods of AISI 304 alloy steel of dimension ø25 x 200mm length. The workpiece was fixed on the Lathe such that a length of 175mm was hung. Centre-drilling operation was carried out and the workpiece was then supported with tailstock. The support is consequent upon *Lawal et al (2011),* which reveals that when the ratio of overhang length, L to the diameter, d is greater than the workpiece must be supported. 27 orthogonal turning experiments were then conducted according to the des ign shown in Table 4.

2.2.4 Calculation of MRR

For every revolution of the workpiece, a layer of chip is removed. The MRR for each experiment was then calculated using equation I as proposed by *Ojolo et al (2006)*

$MRR = (W_1 - W_2)/ʃt$ (mm^3/min) 1

Where W_1 = Initial weight (g)

W_2 = Final weight (g)

ʃ = density of material (g/mm^3)

t = machining time (mins)

3.0 RESULTS AND DISCUSSION

3.1 Composition of workpiece material

The results of material composition conducted via Optical Emission Spectrometer (OES) is presented in Table 2. The composition compares favorably with what is available in the literatures reviewed

Element	C	Si	Mn	P	S	Cr	Mo	Ni	Al
Composition	0.0439	0.393	1.07	0.033	0.013	18.19	0.007	8.18	0.001
	Co	Cu	Nb	Ti	V	W	Pb	Sn	As
	0.268	0.165	0.004	0.001	0.113	0.007	0.002	0.0016	0.007
	Ca	Sb	Se	Ta	B	N	Fe		
	0.0028	0.002	0.002	0.02	0.00069	0.04	71.4		

3.2 Experimental Process Parameters and Results

The results of orthogonal turning experiment conducted based on the experimented design layout of Table 4 is presented in Tables 5 and 6 for dry and wet turning in experiments respectively

Table 5: Experimental Process Parameters and Results for Dry Turning

EXP NO	Cutting speed(rpm)	Feed rate(mm/min)	Depth of cut(mm)	MRR (mm^3/min)
1	625	0.50	0.25	34.25
2	625	0.50	0.25	34.56
3	625	0.50	0.25	34.09
4	625	0.75	0.35	57.29
5	625	0.75	0.35	57.13
6	625	0.75	0.35	57.29
7	625	1.00	0.50	42.54
8	625	1.00	0.50	43.00
9	625	1.00	0.50	42.24
10	840	0.50	0.35	0
11	840	0.50	0.35	0
12	840	0.50	0.35	0
13	840	0.75	0.50	42.70
14	840	0.75	0.50	42.70
15	840	0.75	0.50	42.70
16	840	1.00	0.25	31.80
17	840	1.00	0.25	31.80
18	840	1.00	0.25	31.80
19	1120	0.50	0.50	18.74
20	1120	0.50	0.50	18.74
21	1120	0.50	0.50	18.89
22	1120	0.75	0.25	31.80
23	1120	0.75	0.25	31.80
24	1120	0.75	0.25	31.49
25	1120	1.00	0.35	23.31
26	1120	1.00	0.35	23.81
27	1120	1.00	0.35	23.81

Table 6: Experimental Process Parameters and Results for Wet Turning

EXP NO	Cutting speed(rpm)	Feed rate(mm/min)	Depth of cut(mm)	MRR (mm^3/min)
1	625	0.50	0.25	34.10
2	625	0.50	0.25	34.10
3	625	0.50	0.25	34.10
4	625	0.75	0.35	57.14
5	625	0.75	0.35	57.14
6	625	0.75	0.35	56.83
7	625	1.00	0.50	43.47
8	625	1.00	0.50	43.32
9	625	1.00	0.50	42.32
10	840	0.50	0.35	25.65
11	840	0.50	0.35	25.65
12	840	0.50	0.35	25.80
13	840	0.75	0.50	43.01
14	840	0.75	0.50	43.01
15	840	0.75	0.50	42.70
16	840	1.00	0.25	31.80
17	840	1.00	0.25	31.95
18	840	1.00	0.25	31.95
19	1120	0.50	0.50	18.89
20	1120	0.50	0.50	18.89
21	1120	0.50	0.50	18.95
22	1120	0.75	0.25	31.95
23	1120	0.75	0.25	31.80
24	1120	0.75	0.25	31.95
25	1120	1.00	0.35	2.3.81
26	1120	1.00	0.35	24.12
27	1120	1.00	0.35	23.81

3.3 Analysis of Experimental Results

The Design of Experiment (DOE) in this research was Taguchi for the turning of AISI 304 alloy steel. 27 experiments each were conducted in dry and wet cutting environments respectively. The results obtained were analyzed using ANOVA and Signal to Noise (S/N) ratio optimization procedure to appraise the machining performance with respect to material removal rate (MRR).

Performance characteristics using S/N ratio are commonly applied as follows

Smaller the better, $S/N = 10log\left[\frac{1}{n}\sum_{i=1}^{n} y_2^2\right]$ 2

Nominal the better, $S/N = 10\log[\frac{y^2}{x^2}]$ 3

Larger the better, S/N = $-10\log[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_2^2}]$ 4

3.3.1 Analysis of Variance was conducted to determine the significant effects of the process parameters. The analysis was done for significant level of ∝= 0.05 and a confidence level of 95%. The Sum of Square (SS), Degree of Freedom (DOF), Mean Square (MS), F –values and Percentage contribution (P) are calculated in equations 5-10. Analysis of variance is presented in Table 6

$$The\ sum\ of\ Square\ SSy = \sum_{i=1}^{n} y_2^2 = \frac{1}{n}\sum_{i=1}^{n} y_2^2 \quad 5$$

$$DOF = number\ of\ level - 1 \quad 6$$

$$MS = \frac{SS\ (individual)}{DOF} \quad 7$$

$$F - Value = \frac{SS_{(individual)}}{MS_{(error)}} \quad 8$$

$$P - Value = \frac{SS(individual)}{SS_2} \quad 9$$

$$Error = Total - \sum DOF \quad 10$$

3.3.2 Analysis of Variance (ANOVA) for Material Removal Rate (MRR)

Analysis of variance (ANOVA) was conducted to determine the significant effects of each of the process parameters – cutting speed, Feed rate and depth of cut: - This analysis was done for a significance level of ∝= 0.05 and a confidence level of 95%.

Table 7: ANOVA for Material Removal Rate (MRR)

Dry Turning

Factor	DOF	SS	MS	F	P
Cutting speed (rpm)	2	2385	1192.5	38.16	37.24234853
Feed rate (mm/min)	2	3106	1553	49.696	48.50093691
Depth of cut (mm)	2	288	144	4.608	4.497189257
Error	20	625	31.25		9.759525297
Total	26	6404	246.3077		100

Table 8: ANOVA for Material Removal Rate (MRR)

Wet Turning

Factor	DOF	SS	MS	F	P
Cutting speed (rpm)	2	1778	889	518.518519	53.97692775
Feed rate (mm/min)	2	1439	719.5	419.655876	43.68548877
Depth of cut (mm)	2	42.71	21.355	12.4555264	1.296599879
Error	20	34.29	1.7145		1.040983607
Total	26	3294	126.6923		100

Table 8 shows that the most important for measuring material rate (MRR) is cutting speed with a contribution of 53.98%, with feed rate following with a contribution of 43.68%. The best significant is depth of cut with a contribution of 1.29%.

Table 10: S/N ratio for the experimental results

Wet Turning

EXP NO	Cutting speed(rpm)	Feed rate(mm/min)	Depth of cut(mm)	MRR (mm^3/min)	S/N Ratio for MRR
1	625	0.50	0.25	34.10	30.6551
2	625	0.50	0.25	34.10	30.6551
3	625	0.50	0.25	34.10	30.6551
4	625	0.75	0.35	57.14	35.1388
5	625	0.75	0.35	57.14	35.1388
6	625	0.75	0.35	56.83	35.0916

3.3.3 Signal to Noise (S/N) Ratio

It is very important to evaluate signal – noise ratio for the investigated response – material removal rate (MRR). This is consequent upon the fact that some unavoidable disturbances present in the experimental system which may include backlash on the machine slides, with vibrations from the base of machine tool, possible fluctuation of electric current and others which cannot be easily controlled. The S/N analysis is presented in Table 7. The bigger the better criterion was used to accomplish optimization for material removal rate (MRR).

$$\frac{S}{N} ratio = -10 \log \left[\frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_2^2}\right] \quad 11$$

Table 9: S/N ratio for the experimental results

Dry Turning

EXP NO	Cutting speed(rpm)	Feed rate(mm/min)	Depth of cut(mm)	MRR (mm^3/min)	S/N Ratio for MRR
1	625	0.50	0.25	34.25	30.6932
2	625	0.50	0.25	34.56	30.7715
3	625	0.50	0.25	34.09	30.6525
4	625	0.75	0.35	57.29	35.1616
5	625	0.75	0.35	57.13	35.1373
6	625	0.75	0.35	57.29	35.1616
7	625	1.00	0.50	42.54	32.5759
8	625	1.00	0.50	43.00	32.6694
9	625	1.00	0.50	42.24	32.5145
10	840	0.50	0.35	0	#DIV/0!
11	840	0.50	0.35	0	#DIV/0!
12	840	0.50	0.35	0	#DIV/0!
13	840	0.75	0.50	42.70	32.6086
14	840	0.75	0.50	42.70	32.6086
15	840	0.75	0.50	42.70	32.6086
16	840	1.00	0.25	31.80	30.0485
17	840	1.00	0.25	31.80	30.0485
18	840	1.00	0.25	31.8	30.0485
19	1120	0.50	0.50	18.74	25.4554
20	1120	0.50	0.50	18.74	25.4554
21	1120	0.50	0.50	18.89	25.5246
22	1120	0.75	0.25	31.80	30.0485
23	1120	0.75	0.25	31.80	30.0485
24	1120	0.75	0.25	31.49	29.9635
25	1120	1.00	0.35	23.31	27.3508
26	1120	1.00	0.35	23.81	27.5352
27	1120	1.00	0.35	23.81	27.5352

7	625	1.00	0.50	43.47	32.7638
8	625	1.00	0.50	43.32	32.7338
9	625	1.00	0.50	42.32	32.5309
10	840	0.50	0.35	25.65	28.1817
11	840	0.50	0.35	25.65	28.1817
12	840	0.50	0.35	25.80	28.2324
13	840	0.75	0.50	43.01	32.6714
14	840	0.75	0.50	43.01	32.6714
15	840	0.75	0.50	42.70	32.6086
16	840	1.00	0.25	31.80	30.0485
17	840	1.00	0.25	31.95	30.0894
18	840	1.00	0.25	31.95	30.0894
19	1120	0.50	0.50	18.89	25.5246
20	1120	0.50	0.50	18.89	25.5246
21	1120	0.50	0.50	18.95	25.5522
22	1120	0.75	0.25	31.95	30.0894
23	1120	0.75	0.25	31.80	30.0485
24	1120	0.75	0.25	31.95	30.0894
25	1120	1.00	0.35	23.81	27.5352
26	1120	1.00	0.35	24.12	27.6475
27	1120	1.00	0.35	23.81	27.5352

3.3.4 Main Effects Plots

The main effects plots of the Signal to Noise ratio is presented in Figures 1 and 2

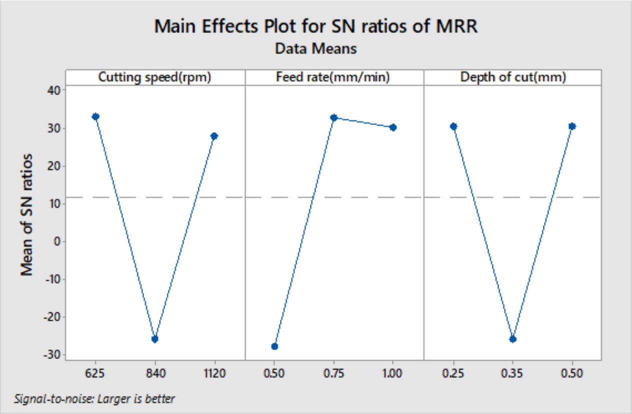


Figure 1: Main effects plot for S/N ratio of MRR (Dry Turning)

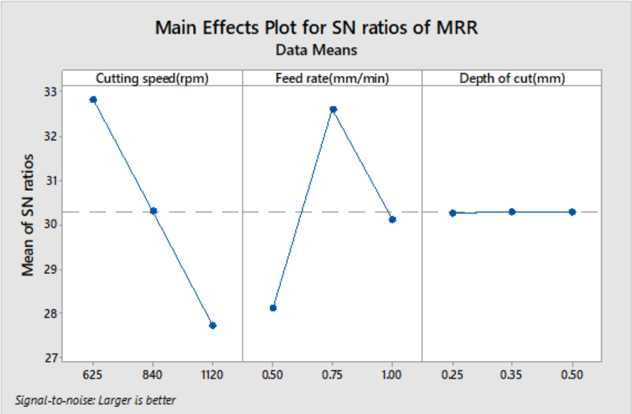
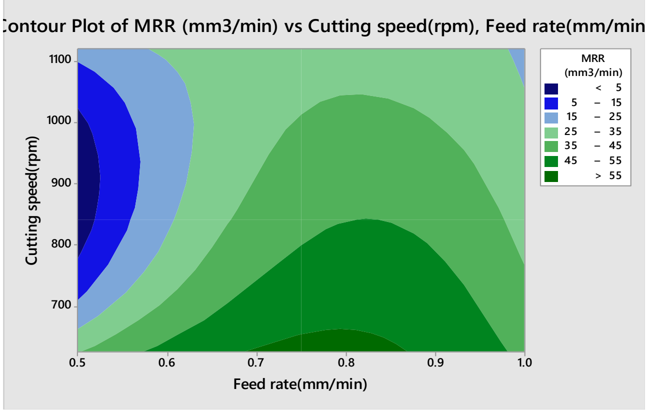
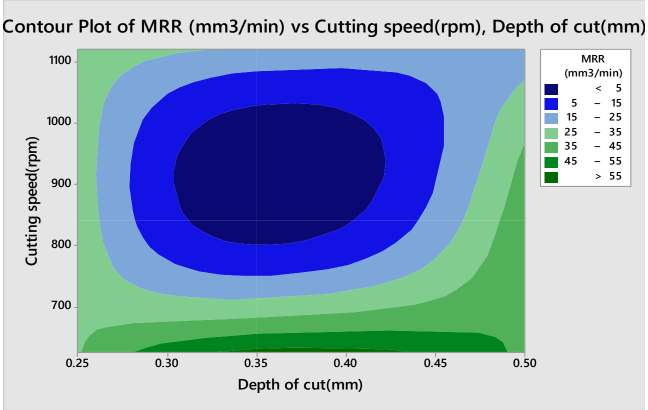


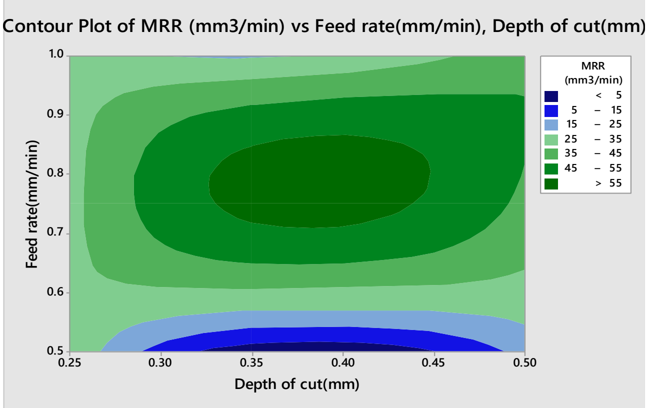
Figure 2: Main effects plot for S/N ratio of MRR (Wet Turning)

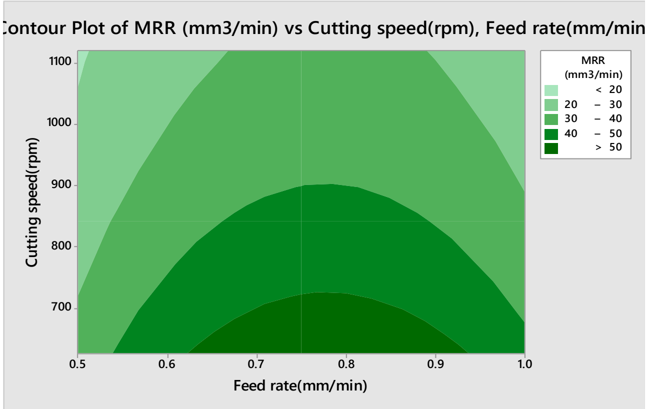
3.3.5 Contour Plots

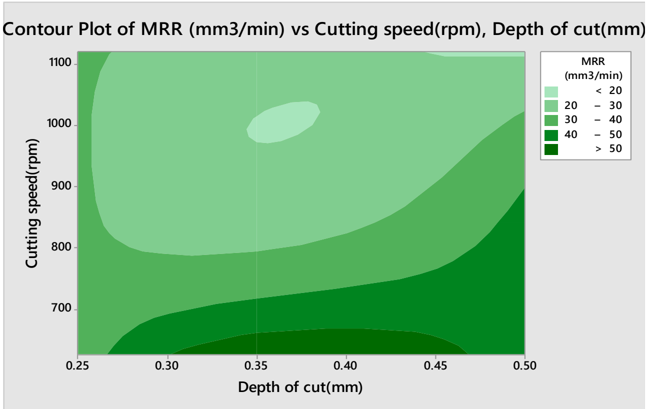
By means of Minitab 17 Statistical software, contour plots were developed. The plots were used in evaluating how change in two variables affect the response when the third (3^{rd}) variable is kept constant. Contour plots for material removal rate in dry turning are presented in Figure 3 to Figure 5 while Figure 6 to figure 8 show the contour plots for material removal rate in wet turning environment.



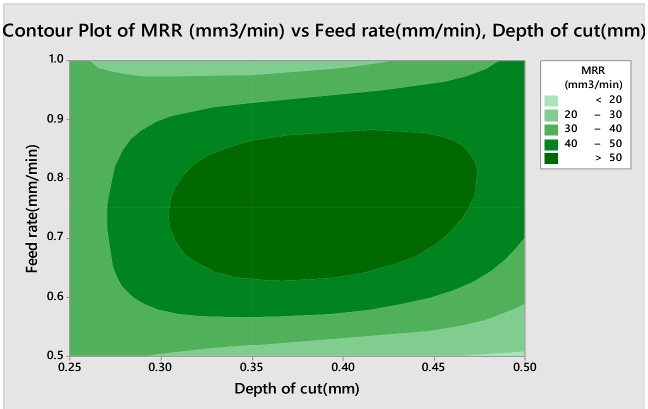








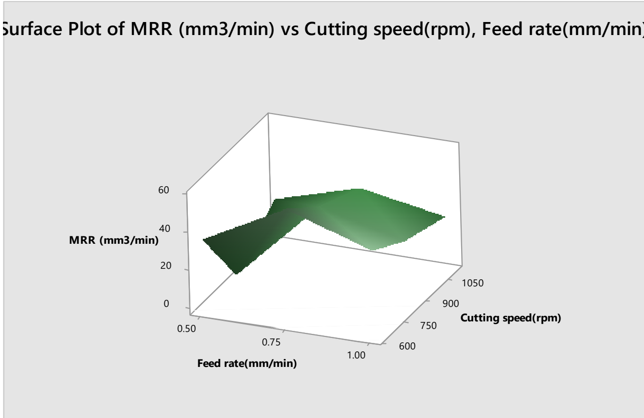
Figures 3 – 5: Contour plots for MRR (Dry Turning)

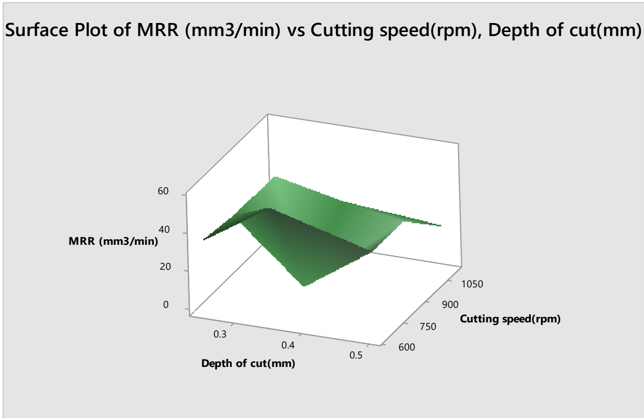


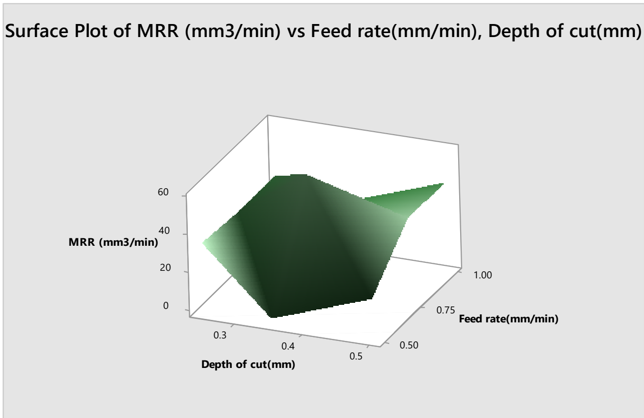
Figures 6 – 8: Contour plots for MRR (Wet Turning)

3.3.6 3D Surface Plots

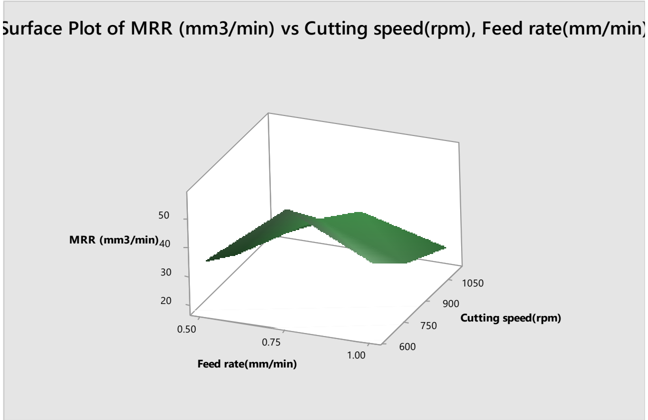
The Contour plots reveal the interaction of input variables and response in two dimensions, but the 3D Surface plots show the interactions in three dimensions. The 3D Surface plots of input variables and the response in dry turning are shown in Figure 9 to 11 while that of wet turning environment are presented in Figure 12 to 14.

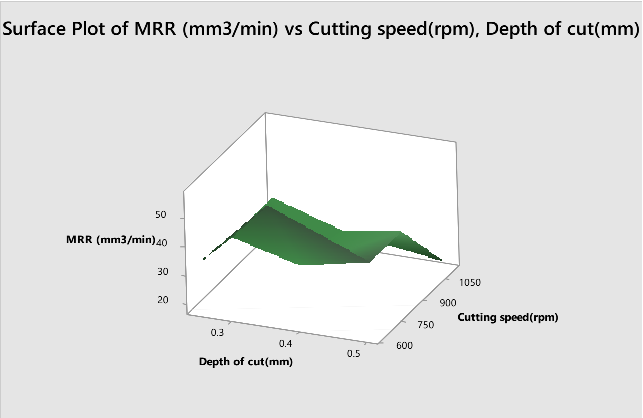


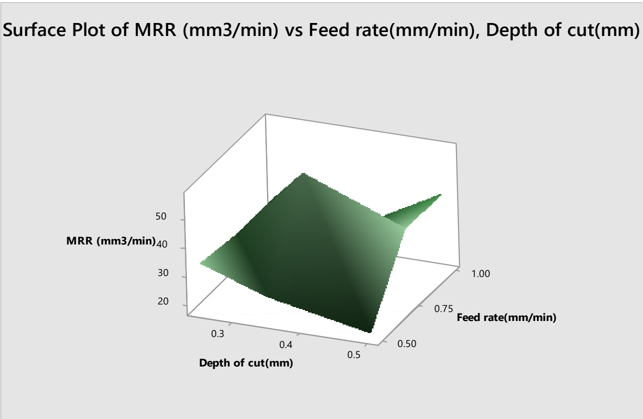




Figures 9 – 11:3D Surface plots for MRR (Dry Turning)







Figures 12 – 14:3D Surface plots for MRR (Wet Turning)

3.3.7 Interaction Plots

The Interaction plots for material removal rate (MRR) in dry turning is presented in Figure 15 while the one for wet turning is presented in Figure 16

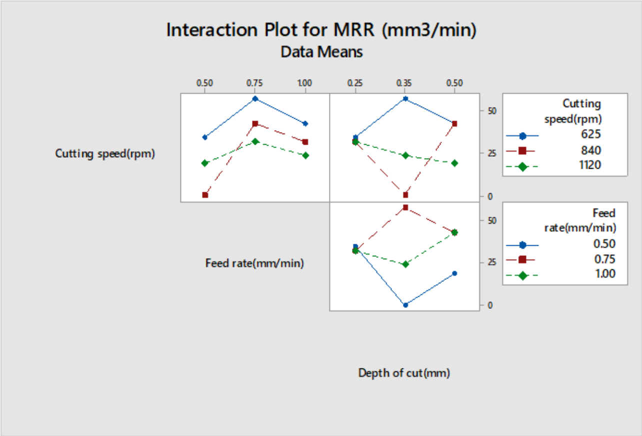


Figure 15: Interaction plot for MRR (Dry turning)

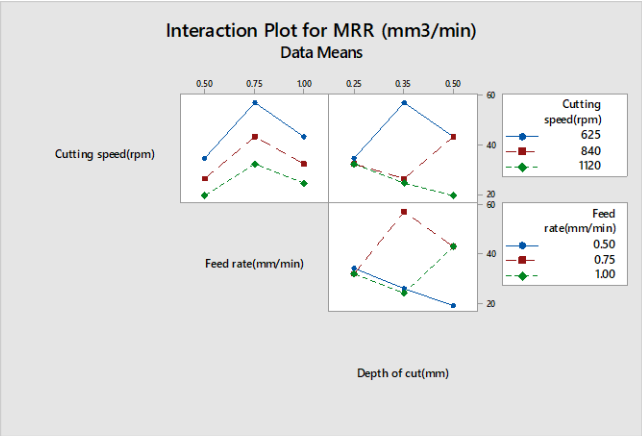


Figure 16: Interaction plot for MRR (Wet turning)

3.3.8 Regression Equation

The Regression equations for material removal rate (MRR) in dry and wet turnings are generated and are shown as equations 12 and 13 respectively

$$MRR\ (mm^3/min) = 121.08 - 0.48307CS + 615.85FR - 594.82DOC + 0.000186CS\times CS - 375.26FR\times FR + 427.13DOC\times DOC - 0.00241CS\times FR + 0.32760CS\times DOC$$

R-sq = 99.99% and R-sq (adj) = 99.98%.. 12

$$MRR\ (mm^3/min) = -63.79 - 0.11849CS + 409.86FR + 86.92DOC + 0.000043CS\times CS - 244.93FR\times FR - 188.70DOC\times DOC - 0.02879CS\times FR + 0.06628CS\times DOC$$

R-sq = 99.97% and R-sq (adj) = 99.95%..13

4.0 CONCLUSION

The effects of cutting parameters on material removal rate in dry and wet condition has been researched. From the analysis of the experimental results, the following conditions are hereby drawn

- Cutting environment has no significant effect on MRR. This is in agreement with the findings of *Lathe et al, (2017)*
- Cutting speed is discovered to be the most significant parameter in optimization of MRR. This finding is in agreement with most other Researchers.
- Optimum level of MRR can be obtained using a cutting speed of 625rpm, feed rate of 0.75mm/min and depth of cut of 0.5mm

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