THOMSON REUTERS ENDNOTE

[Rao* *et al.*, 5(9): September, 2016] **ISSN: 2277-9655**
IC™ Value: 3.00 **Impact Factor: 4.116**

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

EFFECT OF CUTTING PARAMETERS ON THE MULTIPLE RESPONSES

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DOI: 10.5281/zenodo.61505

ABSTRACT

The present work is to explore the effect of cutting parameters (speed, feed and depth of cut) on the responses in the machining of a medium carbon steel EN8. The experiments were conducted on a conventional lathe using a tungsten carbide tool under dry environment. Taguchi's standard L27 Orthogonal Array has been used for the experiment. Material Removal Rate (MRR) and Surface Roughness (R_a) were considered as the experimental responses. Taguchi based Grey Relational Grade method has been employed for the optimization of the multiple-responses. From the grey results, the optimal combination of the multiple-responses were found at v3-f3-d3, i.e. speed at 760 rpm, feed at 0.3 mm/rev and depth of cut at 1.5 mm respectively. Main effect plots for Grey Relational Grade (GRG) was drawn using MINITAB-16 software. From the main effect plots, it is found that the main effect is due to speed followed by the depth of cut and feed in affecting the multiple-responses.

KEYWORDS: Material Removal Rate (MRR), Surface Roughness (R_a), Taguchi method, Orthogonal Array (OA), Grey Relational Grade (GRG) method.

INTRODUCTION

Achieving a good surface quality and high productivity are the major challenges in machining processes. Surface quality is related to the surface roughness whereas productivity is related to the material removal rate. High Material Removal Rate can be achieved by increasing the cutting parameters. But, the Surface roughness depends on many conditions like cutting conditions (speed, feed and depth of cut), tool conditions (Tool nomenclature) and material properties (mechanical properties, hardness) etc. Surface Roughness affect many properties like corrosion resistance, wear resistance, fatigue resistance, initial tolerance, ability to hold the pressure, load carrying capacity, noise reduction in gears etc. Medium carbon steel EN8 has high industrial applications in tool, oil and gas industries. EN materials are commonly used for axial shafts, propeller shafts, crank shafts, high tensile bolts and studs, connecting rods, riffle barrels and gears manufacturing, etc.

In the present work, experimentation has been done to know the influence of cutting parameters on the Material Removal Rate (MRR) and Surface Roughness (R_a). The experiments were conducted on conventional lathe using Tungsten carbide tool as per the Taguchi's standard L27 Orthogonal Array. For the optimization of multiple-responses Taguchi based Grey method has been employed. Grey relational grade method converts the multiple-objective problem into a single objective problem. Main effect plots for the Grey Relational Grade (GRG) were drawn using the MINITAB-16 software.

EXPERIMENTAL DETAILS

Medium carbon steel EN8 is considered as the work piece having dimensions of 36 mm diameter and 300 mm of length. 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 (spindle speed: 875 rpm and power: 0.75 KW) using Tungsten carbide tool under dry environment. After machining, the surface roughness values were measured with talysurf.

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

METHODOLOGY

In the present work, for the analysis of multi-responses the Taguchi based Grey method has been employed. The Grey relational grade method was invented in 1982 by Deng. It is useful for dealing the problems with poor, insufficient and uncertain information. The theory does not attempt to find the best solution, but provides techniques for determining a good solution. In Grey analysis a multi-objective optimization problem can be converted into a single objective optimization problem. The experiments were conducted as per the standard Taguchi's L27 Orthogonal Array. The selected process parameters with their levels and the L27 Orthogonal Array with the actual experimental values were given in the tables 3 and 4.

Table 3. Process parameters with their levels

Parameter	Level-1	Level-2	Level-3
Cutting speed (v), rpm	360	560	760
Feed (f), mm/rev	0.1	0.2	0.3
Depth of cut (d), mm	0.5	1.0	1.5

Table 4. L27 Orthogonal array

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

23	760	0.2	1
24	760	0.2	1.5
25	760	0.3	0.5
26	760	0.3	1
27	760	0.3	1.5

Calculation procedure of grey analysis

Step 1: Normalization of experimental results

$Z_{ij} = \frac{Y_{ij} - \min(Y_{ij}, i=1,2,3,\ldots n)}{\max(Y_{ij}, i=1,2,3,\ldots n) - \min(Y_{ij}, i=1,2,3,\ldots n)}$; for Higher-the-Better characteristic

$Z_{ij} = \frac{\max(Y_{ij}, i=1,2,3,\ldots n) - Y_{ij}}{\max(Y_{ij}, i=1,2,3,\ldots n) - \min(Y_{ij}, i=1,2,3,\ldots n)}$; for Lower-the-Better characteristic

Step2: Determination of quality loss function

Delta (Δ) = (Quality loss) = $|y_o - y_{ij}|$

Step3: Determination of Grey relational coefficient (GRC)

GRC = $\frac{\Delta_{\min} + \delta \Delta_{max}}{\Delta_{oi} + \delta \Delta_{\max}}$

Δ_{min}= minimum value of Δ_{oi}

Δ_{max}= maximum value of Δ_{oi}

δ = distinguishing coefficient which is in range of $0 \leq \delta \leq 1$ (for turning δ=0.5)

Step 4: Determination of the Grey Relational Grade (GRG) and corresponding Signal-to-Noise Ratios

GRG = $\frac{1}{m} \sum$ GRC; where m is the number of responses

Step5: Determination of the optimal combination of process parameters

RESULTS AND DISCUSSIONS

A series of experiments were done and the results of Material Removal Rate and Surface Roughness values were given in the table 5. The results obtained were analysed by taguchi based grey relational grade method.

Table 5. Experimental results

S.No.	Experimental results	
	MRR	R_a
1	11.38	5
2	21.75	5.7
3	31.39	4.7
4	20.74	5.6
5	38.66	6.2
6	53.01	7.2
7	39.38	9.4
8	69.72	8.9
9	100.02	5.5
10	13.7	5
11	24.3	5.3
12	34.71	3.8
13	13.98	5.3
14	25.8	4.4
15	36.25	6.9
16	46.12	9.2
17	78.5	7.0
18	92.03	4.4
19	25.52	2.5
20	46.32	3.7

21	66.26	7.4
22	42.86	5.1
23	78.53	4.0
24	102.46	6.7
25	63.72	8.0
26	117.8	6.9
27	119.6	3.5

The Signal-to-Noise ratios of the responses were calculated using Higher-the-better and Lower-the-better characteristics for Material removal rate and Surface roughness respectively, and the values were given in the table 6.

Table 6. S/N ratios of responses

S.No.	S/N Ratios of responses	
	MRR	R_a
1	21.1228	-13.9794
2	26.7492	-15.1175
3	29.9358	-13.4420
4	26.3362	-14.9638
5	31.7452	-15.8478
6	34.4872	-17.1466
7	31.9055	-19.4626
8	36.8671	-18.9878
9	40.0017	-14.8073
10	22.7344	-13.9794
11	27.7121	-14.4855
12	30.8091	-11.5957
13	22.9101	-14.4855
14	28.2324	-12.8691
15	31.1862	-16.7770
16	33.2778	-19.2758
17	37.8974	-16.9020
18	39.2786	-12.8691
19	28.1376	-7.9588
20	33.3154	-11.3640
21	36.4250	-17.3846
22	32.6410	-14.1514
23	37.9007	-12.0412
24	40.2111	-16.5215
25	36.0855	-18.0618
26	41.4229	-16.7770
27	41.5546	-10.8814

Normalization of the experimental results was done using the higher-the-better and lower-the-better characteristics and the values were given in the table 7. Similarly the loss function values were given in the table 8.

Table 7. Grey relational generation values

S.No.	Grey Relational Generation	
	MRR	R_a
1	0	0.63768
2	0.09582	0.53623
3	0.18490	0.68116

4	0.08649	0.55072
5	0.25208	0.46377
6	0.38468	0.31884
7	0.25873	0.00000
8	0.53909	0.07246
9	0.81907	0.56522
10	0.02144	0.63768
11	0.11939	0.59420
12	0.21558	0.81159
13	0.02403	0.59420
14	0.13325	0.72464
15	0.22981	0.36232
16	0.32101	0.02899
17	0.62022	0.34783
18	0.74524	0.72464
19	0.13066	1.00000
20	0.32286	0.82609
21	0.50712	0.28986
22	0.29089	0.62319
23	0.62050	0.78261
24	0.84162	0.39130
25	0.48364	0.20290
26	0.98337	0.36232
27	1.0	0.85507

Table 8. Loss function values

S.No.	Loss Function	
	MRR	R_a
1	1	0.36232
2	0.90418	0.46377
3	0.81510	0.31884
4	0.91351	0.44928
5	0.74792	0.53623
6	0.61532	0.68116
7	0.74127	1.00000
8	0.46091	0.92754
9	0.18093	0.43478
10	0.97856	0.36232
11	0.88061	0.40580
12	0.78442	0.18841
13	0.97597	0.40580
14	0.86675	0.27536
15	0.77019	0.63768
16	0.67899	0.97101
17	0.37978	0.65217
18	0.25476	0.27536
19	0.86934	0.00000
20	0.67714	0.17391
21	0.49288	0.71014
22	0.70911	0.37681
23	0.37950	0.21739

24	0.15838	0.60870
25	0.51636	0.79710
26	0.01663	0.63768
27	0.00000	0.14493

Grey relational coefficient values for the responses were calculated by assuming the distinguishing coefficient (δ) for turning as 0.5 and the values were given in the table 9.

Table 9. Grey relational coefficient values

S.No.	Grey Relational Coefficient (GRC)	
	MRR	R_a
1	0.33333	0.57983
2	0.35608	0.51880
3	0.38020	0.61062
4	0.35373	0.52672
5	0.40067	0.48252
6	0.44830	0.42331
7	0.40281	0.33333
8	0.52034	0.35025
9	0.73429	0.53488
10	0.33817	0.57983
11	0.36216	0.55200
12	0.38928	0.72632
13	0.33876	0.55200
14	0.36583	0.64486
15	0.39364	0.43949
16	0.42409	0.33990
17	0.56832	0.43396
18	0.66246	0.64486
19	0.36514	1.00000
20	0.42476	0.74194
21	0.50358	0.41317
22	0.41353	0.57025
23	0.56850	0.69697
24	0.75944	0.45098
25	0.49195	0.38547
26	0.96781	0.43949
27	1.00000	0.77528

From the grey relational coefficients of the responses, the Grey relational grade (GRG) values are calculated and given in the table 10. Signal-to-Noise ratios for the GRG are calculated using Higher-the-Better characteristic and the ranking is given in the descending order of the GRG values.

Table 10. Grey relational grade and their S/N ratios

S.No.	GRG	S/N GRG	Rank
1	0.45658	-6.80961	17
2	0.43744	-7.18165	22
3	0.49541	-6.10071	12
4	0.44022	-7.12654	20
5	0.44159	-7.09958	19

6	0.43581	-7.21411	23
7	0.36807	-8.68131	27
8	0.43530	-7.22430	24
9	0.63459	-3.95016	5
10	0.45900	-6.76376	14
11	0.45708	-6.80018	16
12	0.55780	-5.07046	9
13	0.44538	-7.02539	18
14	0.50535	-5.92824	10
15	0.41657	-7.60632	25
16	0.38200	-8.35880	26
17	0.50114	-6.0078	11
18	0.65366	-3.69294	4
19	0.68257	-3.31706	3
20	0.58335	-4.68146	8
21	0.45838	-6.77552	15
22	0.49189	-6.16269	13
23	0.63274	-3.97555	6
24	0.60521	-4.36189	7
25	0.43871	-7.15636	21
26	0.70365	-3.05289	2
27	0.88764	-1.03526	1

The graph is plotted by taking the experimental number on X-axis and Grey relational grade on Y-axis using EXCEL and shown in the figure 1. From the figure, it is observed that the optimal combination of the multiple responses was found at the twenty seventh experiment, i.e. speed at 760 rpm, feed at 0.3 mm/rev and the depth of cut at 1.5 mm respectively.

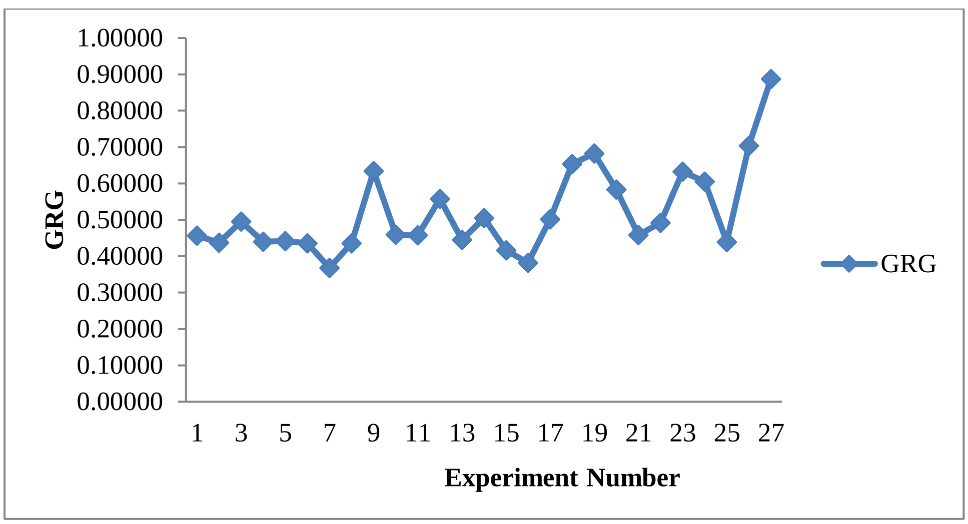

Figure 1. Experiment number Vs GRG

The main effect plots were drawn by taking Cutting parameter levels on X-axis and Grey Relational Grade on Y-axis using the MINITAB-16 software and shown in the figures 2 and 3. From the figures, it is clear that the main effect is due to speed followed by the depth of cut and feed in affecting the multi- responses.

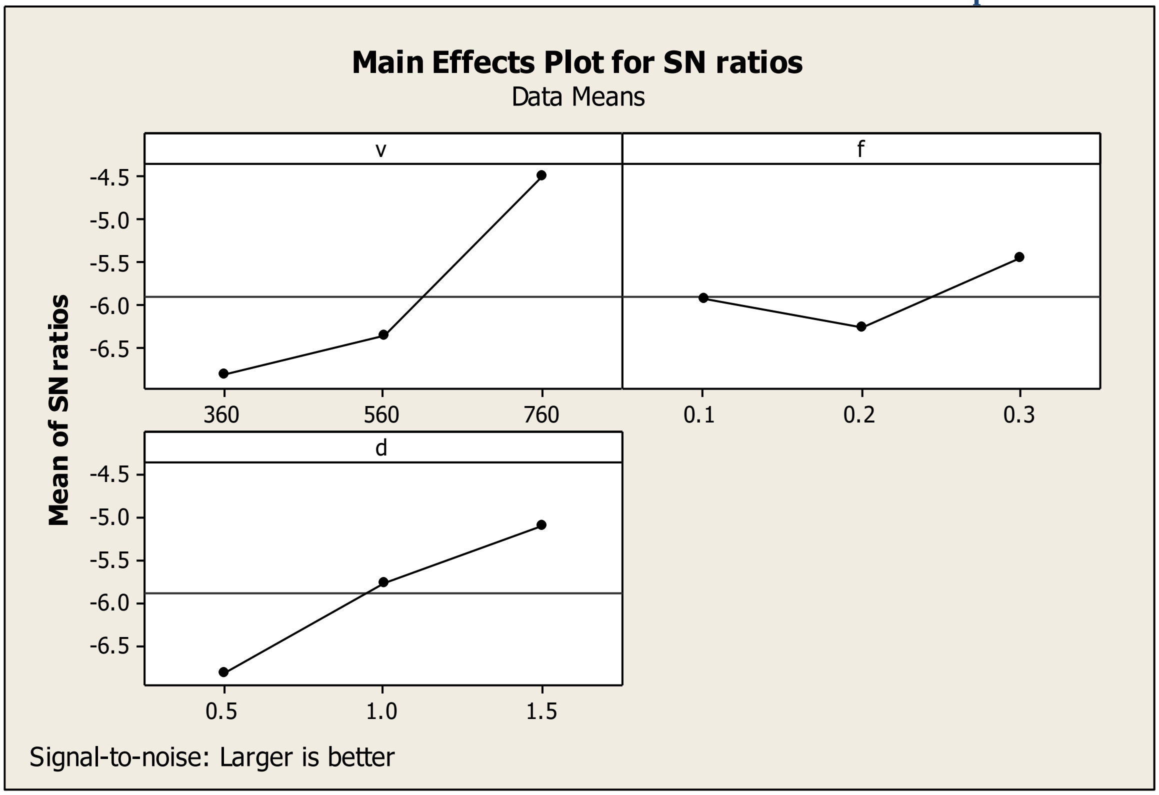

Figure 2. Main effects plots for S/N ratios of GRG

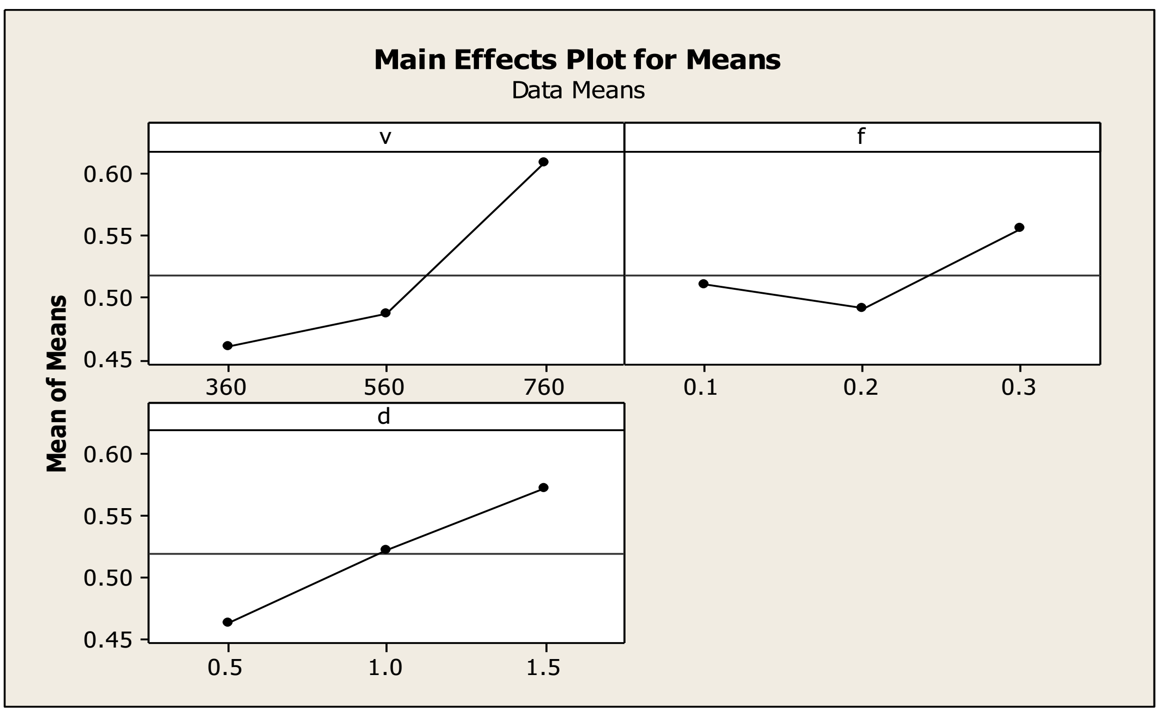

Figure 3. Main effects plots for means of GRG

CONCLUSIONS

[1] From the grey results, the optimal combination of process parameters was found at Speed: 760 rpm, Feed: 0.3 mm/rev and depth of cut: 1.5 mm.

[2] From the main effect plots for the Grey Relational Grade, it is observed that the main effect is due to the speed followed by depth of cut and feed in affecting the multiple responses.

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