Optimizing Surface Roughness and Material Removal Rate in SAE 8620 Steel via Grey Relational Analysis

Lina Maria Pérez [1], Andrea Castillo [2], Alejandro Martínez [3]
[1]Department of Biochemical Engineering, Universidad de los Andes, Bogotá, Colombia
[2]Department of Chemical Engineering, Universidad Nacional de Colombia, Medellín, Colombia
[3]Department of Environmental Engineering, Universidad Javeriana, Bogotá, Colombia

ABSTRACT
Low carbon Alloy steel has widespread applications in industries. In present work machining parameters for SAE 8620 have been optimized using Grey relational analysis (GRA) in view ofsurface roughness (SR) and material removal rate (MRR) as responses.Machining experiments were conducted on CNC lathe machine.L27 orthogonal array design has been used to develop relationships for predicting SR and MRR. MS EXCEL software has been used for analysis grey relational grade of each level of parameters. The optimum parameter values have been achieved for turning performance with respect toSR and MRR. Feed rate (FR)has shown significant role on turning performance with 95% confidence interval.

Keywords: Surface Roughness, MRR, GRA, Optimization, Low carbon Alloy

I. INTRODUCTION
Machining parameters plays imperative role in giving required shape under given tolerances to work piece. Turning is one of the machining process used to remove of material from the diameter of rotating cylindrical part. It is an important operation in several manufacturing processes in some industries, which gives more importance to variety and accuracy to the machining.To achieve efficient quality machining parameters are optimized as per the required variables of responses such as diameter accuracy, tool wear rate (TWR), SR, MRR and many others. From past decade design of experiment (DOE) has been applied by number of researchers for optimizing parameters for different processed.The aim of the DOEincludes determining variables that are most influential on the response, set the influential parameter so thatresponseis near the nominal requirement, set the parameter so that variability in responseis small.

In view of above discussion literature has been studies for SR and MRR optimization in turning process and different optimization technique. Many researchers investigated and formulated the effect of cutting variables for the optimization of SR and MRR.Grzesik [1, 2]tried to predict SR in turning with a single point tool by using brammertz formulation.[3, 4]Investigation has been carried out for study of the effect of cutting edge geometry and work piece hardness on SR in turning of AISI 52100.Also [5, 6] studied surface integrity in turning of hardened steel to see influence of FR, Cutting speed (CS) and TWR. Jiao et al. [7] and Sahin[8] predicted SR for turning operation using fuzzy adaptive networks (FAN) and response surface methodology (RSM) respectively. RSM has also been used for modeling response characteristics for controlling CS, DC, node radius and FR for AISI P-20 [9]. L27 orthogonal array has been applied on factors tomake knowledge base artificial neutral network (ANN) algorithm forSR [10, 11].Tzeng et. al.[12] proposed the grey relational analysis method to predict the optimized SR parameter for SKD 11 on computer numerical control (CNC) turningbased on orthogonal array of taguchi method. Gaitonde et al. [13] studied the effect of machinability in high precision and high hardened components during turning of AISI D2 cold work tool steel. The multi-response optimization of machining parameters has been done for hot turning SS (Type 316) [14], SS 316 [15] with Taguchi grey relational analysis (TGRA). TGRA has also been used for optimizing turning process parameters to get effective SR, chip thickness [16], machine force and tool wear [17]. For these responses Selvaraj et al.Optimization ofparameters has been done for nitrogen alloyed duplex stainless steel in turning [18].RSM and analysis of variance (ANOVA) have also been used to predict SRin turning of AISI 4140 with wiper and conventional ceramic tool [19].LakhdarBouzid et al. (2014) carried out Simultaneous optimization of SR and MRR for turning of X20Cr13 stainless steel. Many other researchers have optimizedmachining parameters with help of various techniques such as full factorial, taguchi, response surface methodology, fuzzy logic etc. Further, optimization of turning parameter for turning of SAE 8620 Low carbon alloy steel using Tin coated carbide cutting tool need to be studied.

In the present work is based on optimization of machining parameters using GRA for the machining of SAE 8620. The influence of parameter such as CS, FR and DC on the SR and MRRhave been studied by conducting various measurements and machining experiments. Further, the most significant factor among the different combinations of optimum turning parameters using analysis of variance (ANOVA) has been obtained.

II.EXPERIMENTATION

This section presents the machine toolused for machining along with composition and properties of the work pieceused in the study. It also includes information about the parameters chosen and their levels and at the end of the chapter it tells about how the output parameters such as material removal rate, surface roughness are obtained.

Turning operations has been performed on a computer numerical control (CNC) lathe machine (Stallion 100 HS) of Hindustan machine tools Ltd. Figure 1 shows the pictorial view of CNC lathe machine used for machining

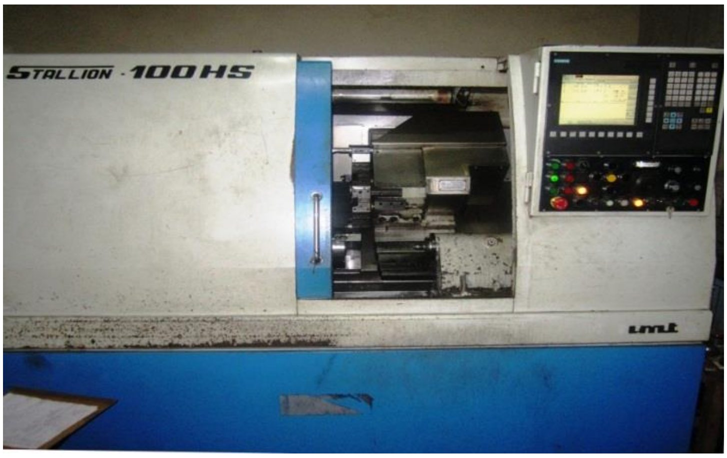


Figure 1: CNC Lathe machine (courtesy: R & D Centre for bicycle and sewing machine, Ludhiana)

Work Piece Material

The work material shown in Figure 2 has been selected for the study,which is SAE 8620 low carbon alloy steel having hardness 20-25 HRC and the ultimate tensile strength of 833 MPa. The density of the low carbon alloy steel is 7.87 g/cm^3 and the modulus of elasticity of work material is 205 GPa. It has various applications like manufacturing of camshafts, fasteners, gears, and chains/chain pins.The SAE 8620 is a low carbon alloy steel where major constituent is followed by manganese (Mn) 0.86 %, and Chromium 0.46 %. The composition of the work piece is given in Table 1.

Figure 2: Work piece material.

Table 1: Chemical composition for SAE 8620 low carbon alloy steel

Constituent	C	S	P	Si	Mn	Ni	Cr	Mo
% composition	0.22	0.025	0.032	0.24	0.86	0.42	0.46	0.19

Cutting Tool

In this study, TIN coated carbide tool single point insert is used[Korloy Inc. (1966)]. Insert and tool holder are of ISO coding CNMG 120408 and PDJNR 1616H07.Tool geometry of the insert CNMG 120408 VM (PVD coated) is Rhombic 80º, insert clearance, angle 0º (Negative), relief angle 3º, cutting edge length 12 mm, 4 mm thick and nose radius 0.8 mm. According to Taegutec catalog, ISO coding tool holder PDJNR 1616H07 is used for negative insert.

Parameters and their Levels

Each parameter has different effect on the turning performance. The various input parameters which have been used to investigate the effect on the response are CS, FR and DC etc.Parameters with their three levels as chosen for experimentation as per L27 orthogonal are given in Table 2.

Table 2: Parameters with Levels

Factors	Unit	Type	Levels		
			1	2	3
CS	m/min	Numeric	90	130	170
FR	mm/rev	numeric	0.07	0.14	0.21
DC	mm	numeric	0.4	0.8	1.2

Specimen Preparation

The specimens have been prepared on CNC Lathe machine. First, the raw rod of SAE 8620 low carbon alloy steelhas been cleaned to remove the undesirable particles such as dust, grease and foreign material etc.Then specimens of length 1134 mm have cut into 27 small pieces of length 42 mm and diameter 32 mm each. Further, machining has been performedon CNC lathe machine available at R&D Ludhiana to achieve final dimension of length 40 mm and diameter 30 mm as shown in Figure 3. The line diagram of specimen before and after turning is shown in Figure 4.

Figure 3: Work piece specimen

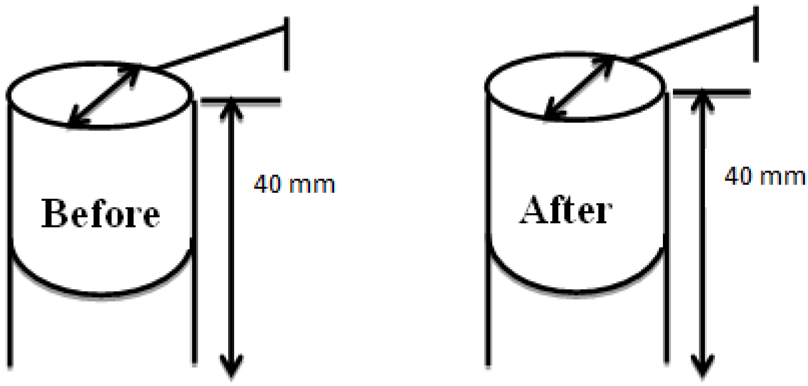


Figure 4: Dimensions of work piece

Testing

In present study, SR of finished turned work piece has been measured by making use of a portable surface tester (Surtronic 25) as shown in Figure 4 and the readings have been recorded three times for each specimen and average is considered. Cut-off length for roughness measurements was set to be 2.5 mm.

Figure 5: Surtronic 25 (Metrology lab, Mechanical department, SLIET)

MRR has been determined by using following relation:

$$\text{MRR} = \frac{V_b - V_a}{t}$$

Where, $V_b$is volume before machining (mm³), V_a is volume after machining (mm³) and t is machining time.

III.RESULT AND DISCUSSION

A total number of 27 turning experiments have beencompleted as per L27 orthogonal experimental plan given in Table 3 along with results. On, which further Grey Taguchi and analysis of variance (ANOVA) is done in MS EXCEL 2007. After the examination of ANOVA. SR and MRR values at different turning parameters are listed in Table 3 along with levels of parameters as design matrix based on L27 orthogonal array with interaction. In the turning, lower SR and higher MRR are indications of righteous performance.

Table 3: Experimental results for SR and MRR

Exp. no.	CS (m/min)	FR (mm/rev)	DC (mm)	SR (µm)	MRR (mm³/sec)
1	90	0.07	0.4	2.01	26
2	90	0.07	0.8	1.98	41
3	90	0.07	1.2	2.02	76
4	90	0.14	0.4	2.21	39
5	90	0.14	0.8	2.08	77.5
6	90	0.14	1.2	2.3	138.5
7	90	0.21	0.4	2.32	38
8	90	0.21	0.8	2.5	106
9	90	0.21	1.2	2.89	204
10	130	0.07	0.4	1.87	31.2
11	130	0.07	0.8	1.4	62
12	130	0.07	1.2	1.29	98
13	130	0.14	0.4	1.8	46.8
14	130	0.14	0.8	2.02	93
15	130	0.14	1.2	1.88	153
16	130	0.21	0.4	1.32	66
17	130	0.21	0.8	2.06	155
18	130	0.21	1.2	1.91	346.25
19	170	0.07	0.4	0.6	42
20	170	0.07	0.8	0.92	84
21	170	0.07	1.2	1.01	138.5
22	170	0.14	0.4	1.38	78
23	170	0.14	0.8	1.42	155
24	170	0.14	1.2	1.79	277
25	170	0.21	0.4	2.84	93.6
26	170	0.21	0.8	2.8	286
27	170	0.21	1.2	2.83	461

Data Analysis of Single Objective Optimization

Minimization of the surface roughness

Mean of SR value for each level of turning parameters has been obtained using average method presented.In Table 4, difference between the maximum and minimum value of parameters for SR value is: for CS is 0.52, FR is 0.95 and DC is 0.15. Here the maximum value if for FR, which indicates thatit has more effect on SRthan other parameters.

Table 4: Response table for surface roughness

	Level				
Factors	1	2	3	Max.-Min.(Δ)	Rank
CS	2.25	**1.72**	1.75	0.52	2
FR	**1.45**	1.73	2.40	0.95	1
DC	**1.83**	1.90	1.99	0.15	3

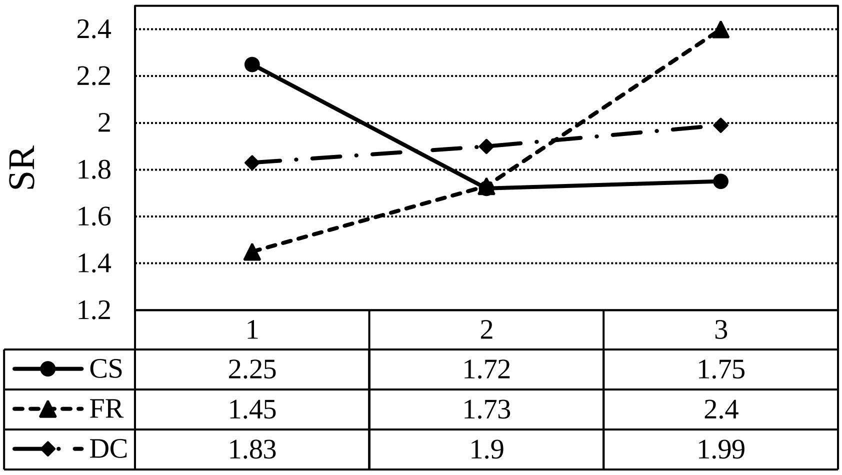


Figure 6: Effect of various turning parameters on surface roughness

Table 5: Analysis of variance for SR

Factors	DOF	Sum of square	Mean square	F Ratio	Percentage contribution
CS	2	2.291	1.145	37.355	0.2448
FR	2	4.852	2.426	79.106	0.5184
DC	2	0.794	0.397	12.954	0.0848
CS×FR	4	1.016	0.254	8.288	0.1086
FR×DC	4	0.128	0.032	1.044	0.0136
DC×CS	4	0.031	0.007	0.255	0.0033
Error	8	0.496	0.062		0.0262
Total	26	8.864			1

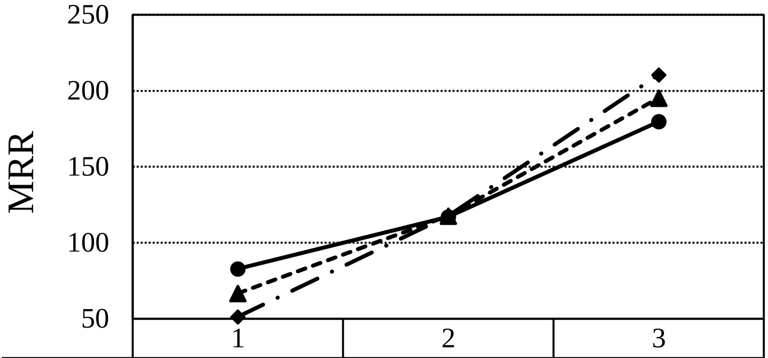
Figure 6 shows effect of turning parameters on SR value. It is observed that a smoother surface can be produced by CS (130 m/min), FR (0.07 mm/rev), and using DC (0.4 mm). Table 5 illustrates the results of ANOVA with SR in turning SAE 8620. The most significant variables affecting the SR are FR (51.84%), followed by CS (24.48%) and DC (8.48%).

Maximization of MRR

Table 6 presents difference of maximum and minimum value of parameters for MRR value is: for CS is 96.76, FR is 128.51 and DC is 159.19. The comparison of these all values gives level of importance for controllable factors with respect toMRR. Here the maximum value for DC, indicates that it effects more as compare to other parameters.Figure 7 shows the effect of turning parameters on MRR. MRR can be produced by CS (170 m/min), FR (0.21 mm/rev), and DC (1.2 mm). Table 7 illustrates related to result ANOVA with MRR in turning SAE 8620 low carbon alloy steel. The DC (39.28%), is the most significant factor, followed by FR (25.73%) and CS (14.79%).

Table 6: Response table for material removal rate

Factors	Level 1	2	3	Max.-Min.(Δ)	Rank
CS	82.88	117.10	**179.65**	96.76	3
FR	66.74	117.63	**195.26**	128.51	2
DC	51.33	117.78	**210.52**	159.19	1



	1	2	3
CS	82.88	117.1	179.65
FR	66.74	117.63	195.26
DC	51.33	117.78	210.52

Figure 7: Effect of various turning parameters on MRR

Table 7: Analysis of variance for maximum MRR

Factors	DOF	Sum of square	Mean square	F Ratio	Percentage contribution
CS	2	43337.18	21668.59	10.70	0.1479
FR	2	75397.99	37698.99	18.62	0.2573
DC	2	115077.03	57538.5	28.41	0.3928
CS×FR	4	9599.68	2399.92	1.18	0.0327
FR×DC	4	16357.15	4089.287	2.01	0.0558
DC×CS	4	16967.92	4241.98	2.09	0.0579
Error	8	16196.96	2024.620		0.0552
Total	26	276736.9			1

BI-objective optimization of optimal solution

The S/N ratio for "smaller the better" and "larger the better" quality characteristics have been computed for all 27 trials, and values have been given in Table 8. For data pre-processing in the GRA, the response values of SR are taken as "lower the better" and for MRR taken as "larger the better". Both have been computed values are reported in Table 8. Data pre-processing have been carried out for Grey relational coefficient (GRC) and Grey relational grade (GRG) represented in Table 8. As per the values of GRG rank has been assigned to each experiment as shown in Table 8.

Table 8: S/N ratio, Grey Relational coefficient, Grey Relational Grade and Rank

Exp. No.	S/N ratio values		Grey Relational coefficient		GRG	Rank
	SR	MRR	SR	MRR		
1	-6.0639	28.2994	0.6840	0.3333	0.5086	18
2	-5.9333	32.2556	0.6751	0.3726	0.5239	17
3	-6.1070	37.6162	0.6869	0.4436	0.5652	14
4	-6.8878	31.8212	0.7455	0.3679	0.5567	15
5	-6.3612	37.7860	0.7050	0.4462	0.5756	12
6	-7.2345	42.8289	0.7748	0.5443	0.6596	8
7	-7.3097	31.5956	0.7815	0.3654	0.5735	13
8	-7.9588	40.5061	0.8442	0.4943	0.6693	7

9	-9.2179	46.1926	1	0.6378	0.8189	3
10	-5.4368	29.8830	0.6435	0.3480	0.4958	20
11	-2.9225	35.8478	0.5202	0.4173	0.4688	24
12	-2.2117	39.8245	0.4935	0.4813	0.4882	21
13	-5.1054	33.4049	0.6240	0.3858	0.5049	19
14	-6.1070	39.3696	0.6869	0.4730	0.5800	11
15	-5.4831	43.6938	0.6464	0.5656	0.6066	10
16	-2.4114	36.3908	0.5007	0.4251	0.4637	25
17	-6.2773	43.8066	0.6989	0.5685	0.6337	9
18	-5.6206	50.7877	0.6549	0.8333	0.7441	4
19	4.4369	32.4649	0.3333	0.3750	0.3548	27
20	0.7242	38.4855	0.4071	0.4577	0.4329	26
21	-0.0864	42.8289	0.4278	0.5443	0.4860	22
22	-2.7975	37.8418	0.5153	0.4471	0.4812	23
23	-3.0457	43.8066	0.5252	0.5685	0.5468	16
24	-5.0570	48.8495	0.6213	0.7379	0.6796	6
25	-9.0663	39.4255	0.9782	0.4740	0.7261	5
26	-8.9431	49.1273	0.9613	0.7502	0.8557	2
27	-9.0357	53.2740	0.9740	0.9989	**0.9871**	1

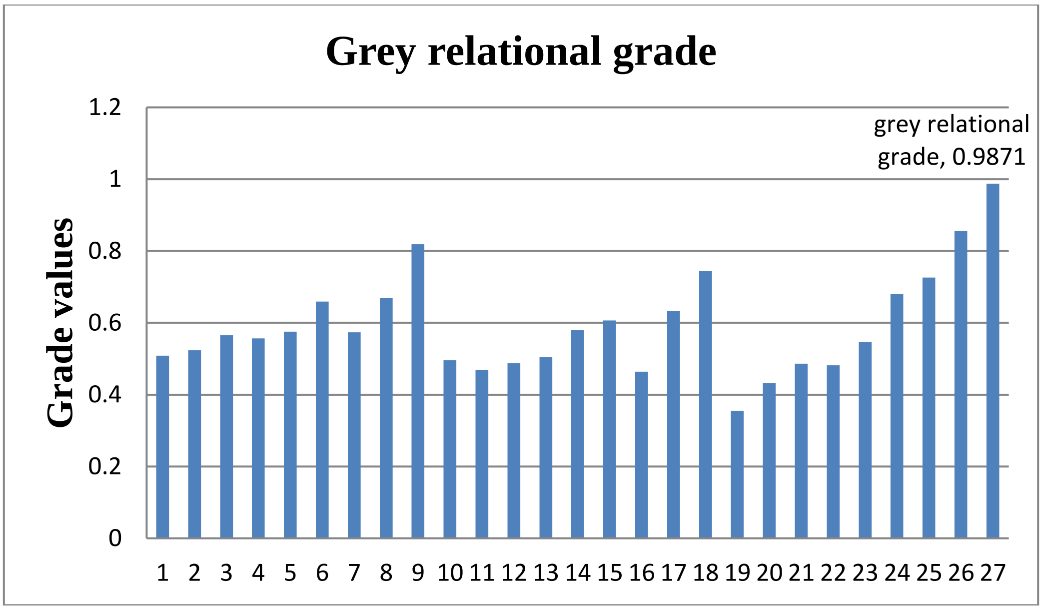


Figure 8: GRG for the minimum SR and maximum MRR

The value of average GRG is 0.5921 calculated from Table 8. The higher grey relational grade represents the optimum performance. Experiment 27 has achieved best multi-performance characteristics as it has the highest GRG as shown in Table 8 and Figure 8. The mean of GRG values for respective level of parameters is determined using the average method. Mean of GRG of each level of the turning parameters is sum up and shown in the multi-response performance index (Table 9). It also shows the response table for average GRG by factor level. Thick face values indicate the different levels of the factors corresponding to the best result and lead to an optimal design.

Table 9: Response table for grey relational grade; Main effects on Grey grade

	Level				
Factors	1	2	3	Max.-Min.(Δ)	Rank
CS	0.60	0.55	**0.61**	0.0627	3
FR	0.48	0.57	**0.71**	0.2386	1
DC	0.51	0.58	**0.67**	0.1522	2

The optimal parameters setting for effective SR and MRR is **(S3, F3, and D3)** as given in Table 9. Based on GRG values shown in Table 5.13, optimal performance for combined SR and MRR have been obtained for CS 170 m/min (level 3), FR 0.21 mm/rev (level 3) and DC 1.2 mm (level 3) combination. Table 10 shows the results of ANOVA on GRG. Main contribution percentages for CS, FR and DC to multiple performance characteristics in turning SAE 8620 low carbon allow steel are 3.8 %, 49.9 % and 20.1 % respectively. The interaction between CS and FR is 7.6 % which is more effective than other interactions. The predicted value of GRG at optimum level is calculated as 0.8221 and 95% confidence interval forGRG and confirmation experiment is between 0.7070 and 0.9372

Table 10: Result of ANOVA on GRG

Factors	DOF	Sum of square	Mean square	F Ratio	Percentage contribution
CS	2	0.020	0.010	1.052	0.038
FR	2	0.259	0.129	13.52	0.499
DC	2	0.104	0.052	5.451	0.201
CS×FR	4	0.039	0.009	1.040	0.076
FR×DC	4	0.017	0.004	0.460	0.034
DC×CS	4	0.001	0.001	0.014	0.001
Error	8	0.076	0.009		
Total	26	0.442			

Confirmative test has been performed as last step of GRA so, that optimum level of selected parameterscan verify enhancement of multi performance characteristics. Combinations for above turning parameters has been set, and two trials have beenperformed. Confidence interval (CI) value at 95% confidence level has been determined and the corresponding value of SR, MRR and GRG have been measured and reported in Table 11. GRG has improved by 2.1% which revels efficacy of GRA in enhancement of turning process with improved SR and MRR.

Table 11: Optimal values of machining and response parameters

Setting level	Optimal turning parameters		Final gain	% improvement	Confidence interval
	Prediction	Confirmation test			
	S3, F3, D3	S3, F3, D3			
GRG	0.8344	0.8347	0.021	2.1 %	0.7070 ≤ μ ≤ 0.9372

IV. CONCLUSION

Turning experiments have been conducted on CNC lathe machine using carbide cutting tool on SAE 8620 low carbon alloy steel as work material. L27 orthogonal array was used for different combinations of turning experiments. The SR and MRR were selected as responses different combinations of turning parameters. FR is the main significant parameter for SR followed by DC and CS with 6.27%, 23.86% and 15.22% respectively.The increase in CS produces better SR and it decreases from level one to level two and then increases from level two, where increase in feed rate the surface roughness increases.The value of GRG is within 95% confidence interval of the predicted optimum condition andGRG value in confirmation experiment has been improved by 2.1 %.The optimal level of parameters for improved SR and MRR is S3(170 m/min), F3(0.21 mm/rev) and D3(1.2 mm).

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