

Taguchi Optimization of Cutting Parameters in Turning AISI 1020 MS with M2 HSS Tool

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Abstract: In this paper the effect of three cutting parameters viz. Spindle speed, Feed and Depth of Cut on surface roughness of AISI 1020 mild steel bar in turning was investigated and optimized to obtain minimum surface roughness. All the experiments are conducted on HMT LB25 lathe machine using M2 HSS cutting tool. Ranges of parameters of interest have been decided through some preliminary experimentation (One Factor At a Time experiments). Finally a combined experiment has been carried out using Taguchi's L_{27} Orthogonal Array (OA) to study the main effect and interaction effect of the all three parameters. The experimental results were analyzed with raw data ANOVA (Analysis of Variance) and S/N data (Signal to Noise ratio) ANOVA. Results show that Spindle speed, Feed and Depth of Cut have significant effects on both mean and variation of surface roughness in turning AISI 1020 mild steel. Mild two factors interactions are observed among the aforesaid factors with significant effects only on the mean of the output variable. From the Taguchi parameter optimization the optimum factor combination is found to be 630 rpm spindle speed, 0.05 mm/rev feed and 1.25 mm depth of cut with estimated surface roughness $2.358 \pm 0.970 \mu\text{m}$. A confirmatory experiment was conducted with the optimum factor combination to verify the results. In the confirmatory experiment the average value of surface roughness is found to be $2.408 \mu\text{m}$ which is well within the range ($0.418 \mu\text{m}$ to $4.299 \mu\text{m}$) predicted for confirmatory experiment.

Keywords: AISI 1020 steel, ANOVA, Surface Roughness, Taguchi Method

1. INTRODUCTION

AISI (American Iron and Steel Institute) 1020 (0.18% - 0.23% carbon) is one of the most commonly used mild steel for simple structural applications for its excellent weldability and machinability. The action of cutting process in machining bears some traces of unevenness, roughness, notches, etc. both in the direction of cutting and direction of feed. Nucleation sites for cracks or corrosion may form due to irregularities in the surface. Surface finish influences functional properties of machined components such as corrosion resistance, wear rate,



coefficient of friction, and fatigue strength of the machined components [6, 9]. Surface finish is also characterized by surface roughness. It is the vertical deviations of the real form from the ideal form [1]. For a defined sampling length surface roughness is defined by arithmetic average of the deviations (R_a). Friction and wear increases with surface roughness, thus decreasing the life of machine elements such as bearings [1, 18]. Producing a high quality surface at low cost requires a trade-off between manufacturing cost of a component and its performance. Cutting parameters determined by experience or by use of handbook is an important task to obtain high cutting performance. Surface roughness, surface texture and dimensional deviations of a product are a result of cutting parameters [8]. A number of investigative studies [4, 5, 8, 10, 13, 14, 16, 17, 19] have been carried out by different researchers to optimize various cutting parameters for reducing surface roughness of various steel materials.

In turning AISI 1030 with Square-shaped inserts with enriched cobalt coating (CVD $TiN-TiCN-Al_2O_3-TiN$), feed rate is found to be the highest affecting factor in surface roughness among cutting speed, feed rate and depth of cut [4]. M. Nalbant et al [6] also found that insert radius along with feed rate as the main affecting factors among insert radius, feed rate, and depth of cut in AISI 1030 with TiN coated tools. When S45C steel bars are machined using tungsten carbide cutting tools for minimum surface roughness, feed rate is found to be the most contributing factor [19]. In turning mild steel using HSS (High Speed Steel) cutting tool, feed is also found to be the most influencing factor among speed, feed and depth of cut [10]. D.V.V. Krishan Prasad [5] also found feed as the most significant factor in turning mild steel with HSS cutting tool among speed, feed, depth of cut, side rake angle and back rake angle. Side rake angle is found to have least effect on surface roughness. Among depth of cut, Spindle speed and feed rate in AISI 1040, surface roughness decreases with increase in depth of cut and Spindle speed but increases with feed rate [14]. When mild steel is machined with TiN-coated carbide tools feed rate is also found to be the most influencing factor on surface roughness than cutting speed and depth of cut [13]. Among turning parameters like cooling conditions, cutting speed, feed rate and depth of cut in AISI 1050, feed rate is found as the most effective parameters [16]. M.T. Sijo and N. Biju [17] obtained that feed rate, cutting velocity and nose radius have significant contribution on the surface roughness, whereas depth of cut and hardness of work material have less significant contribution on the surface roughness.

From the literature it was found that the surface roughness in turning operation is mostly affected by the following four cutting parameters: cutting speed, Spindle speed, feed rate and depth of cut. The surface roughness is also affected by work piece material, cutting tool material, tool geometry etc. [17]. Thus to obtain a desired output the correct combination of these factors is most vital. Therefore, the basic objective of this research work is to investigate the effect of the following three cutting parameter of turning operation: Spindle speed, feed and depth of cut on the surface roughness of an AISI 1020 mild steel bar and thus to optimize the aforesaid three parameters (factors) to obtain the minimum surface roughness. The cutting speed, being dependent on Spindle speed, is ignored.

2. METHODOLOGY

To investigate the effect of the selected factors on the surface roughness of AISI 1020 MS bar, Taguchi L_{27} OA (Orthogonal Array) has been selected. For the experimentations HMT (Hindustan Machine Tools) LB25 lathe machine with HSS M2 cutting tool has been used. The levels (settings) for the factors in the experiment have been selected from the recommended ranges provided in *Tool and Manufacturing Engineers Handbook*, published by Society of Manufacturing Engineers; USA, 1976 [2] and preliminary experimentation. The variable factors along with their levels are shown in Table 1.

Table 1 Variable factor for the Experiment

Factor A (Spindle speed)		Factor B (Feed)		Factor C (Depth of Cut)	
Level	Value (rpm)	Level	Value (mm/rev)	Level	Value (mm)
A ₁	400	B ₁	0.05	C ₁	0.5
A ₂	500	B ₂	0.081	C ₂	1.25
A ₃	630	B ₃	0.113	C ₃	2

It is found that optimum surface roughness can be obtained by higher values of Spindle speed [10]. The maximum Spindle speed provided by HMT LB25 lathe machine is 800 rpm, but due to vibration problem the maximum rpm selected for the experiments is 630 rpm. Within the recommended range of Spindle speed (485-647 rpm) [2], the following three Spindle speeds 400, 500 and 630 rpm are available in the HMT LB25 lathe machine and hence are selected as levels. Similarly from preliminary experimentations, the levels of depth of cut and feed are selected as shown in Table 1. For details of the preliminary experimentations and level selection, refer to Appendix A.

2.1 Selection of OA and Column Assignment

In this experiment the interaction among the selected factors are also studied. Taguchi L_{27} OA is used in this experiment because this is the smallest three level OA whose DOF (Degree of Freedom) is greater than the DOF of the experiment [7]. The column assignment of the factors (A, B, C) and their interactions (AxB, AxC, BxC) in the L_{27} OA is performed by referring to the three level Triangular Table [12, 15]. The column assignments of the L_{27} OA are shown in Table 2.

Table 2 Column assignments of L_{27} OA

Trial No.	Factors											
	A	B	AxB	AxB	C	AxC	AxC	BxC	-	-	BxC	-
1	400	0.05	1	1	0.5	1	1	1	1	1	1	1
2	400	0.05	1	1	1.25	2	2	2	2	2	2	2
3	400	0.05	1	1	2	3	3	3	3	3	3	3
4	400	0.081	2	2	0.5	1	1	2	2	2	3	3
5	400	0.081	2	2	1.25	2	2	3	3	3	1	1
6	400	0.081	2	2	2	3	3	1	1	1	2	2
7	400	0.113	3	3	0.5	1	1	3	3	3	2	2
8	400	0.113	3	3	1.25	2	2	1	1	1	3	3
9	400	0.113	3	3	2	3	3	2	2	2	1	1
10	500	0.05	2	3	0.5	2	3	1	2	3	1	2
11	500	0.05	2	3	1.25	3	1	2	3	1	2	3

12	500	0.05	2	3	2	1	2	3	1	2	3	1	2
13	500	0.081	3	1	0.5	2	3	2	3	1	3	1	2
14	500	0.081	3	1	1.25	3	1	3	1	2	1	2	3
15	500	0.081	3	1	2	1	2	1	2	3	2	3	1
16	500	0.113	1	2	0.5	2	3	3	1	2	2	3	1
17	500	0.113	1	2	1.25	3	1	1	2	3	3	1	2
18	500	0.113	1	2	2	1	2	2	3	1	1	2	3
19	630	0.05	3	2	0.5	3	2	1	3	2	1	3	2
20	630	0.05	3	2	1.25	1	3	2	1	3	2	1	3
21	630	0.05	3	2	2	2	1	3	2	1	3	2	1
22	630	0.081	1	3	0.5	3	2	2	1	3	3	2	1
23	630	0.081	1	3	1.25	1	3	3	2	1	1	3	2
24	630	0.081	1	3	2	2	1	1	3	2	2	1	3
25	630	0.113	2	1	0.5	3	2	3	2	1	2	1	3
26	630	0.113	2	1	1.25	1	3	1	3	2	3	2	1
27	630	0.113	2	1	2	2	1	2	1	3	1	3	2

2.2 Data Analysis and Optimal setting

The optimal setting of factors is obtained by drawing main effect and interaction effect curves. The data obtained are analyzed by raw data ANOVA (Analysis of Variance) and S/N data (Signal to Noise Ratio) ANOVA. For S/N data analysis, the conversion of raw data to S/N data is based on lower the better type of quality characteristic as Surface roughness for intended use is lower the better type of characteristic. Depending on the effect of the factors on mean and variation of the response, the factors are segregated. Finally, the predicted mean and the range of the response variable for the population (POP) and sample group (CE) at the optimal settings are found out. All calculations are done as described by some of the earlier literature [11, 12]. For ANOVA calculations, refer to “ANOVA calculation.xlsx” excel file uploaded as supplementary material and for the equations of S/N data calculation, prediction of mean and range, refer to Appendix B.

2.3 Confirmatory Experiment (C.E)

Taguchi suggested that if the optimal setting is not among the trials of the experiments, then confirmatory experiment should be done to verify the results [11]. In the current project even though optimal setting is one of the trial conditions, a confirmatory experiment is done considering the predicted optimal setting of the factors to verify the results.

3. EXPERIMENTAL SETUP

All the experiments are carried out on HMT LB25 lathe machine. The specification of the lathe machine is about 500mm swing and 2000mm between centres with 18 speed variations (16 - 800 rpm), 52mm Spindle bore with 4 jaw chucks, face plate and multi-fix quick change tool post.

For this research work HSS M2 cutting tool has been used. M2 grade is recommended for carbon steels having a hardness range of 85 – 275 HB [3]. The nominal chemical composition of M2 HSS cutting tool is [2]:

Carbon, C = 0.85 – 1 %

Tungsten, W = 6 %

Molybdenum, Mo = 5 %

Chromium, Cr = 4 %

Vanadium, V = 2 %

The tool used is having side relief angle, front relief angle, back rake angle and side rake angle as: 8° , 8° , 0° and 8° [2].

3.1 Test Specimen preparation

To perform the experiments, an AISI 1020 MS solid round bar was cut into 270 mm long pieces (test specimen). To keep uniformity in diameter, diameter of each test specimen is reduced to 30 mm by turning. The process of reducing the diameter is shown in Fig. 1.

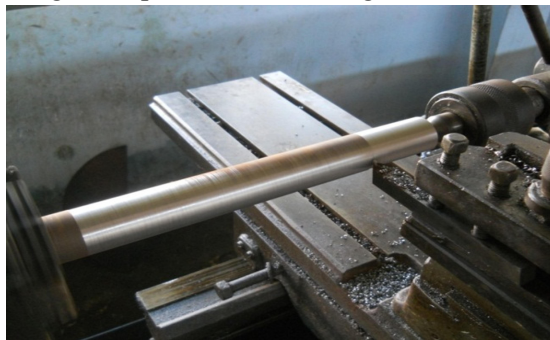


Fig. 1 Reduction of the initial diameter to 30 mm

Before performing the experimental trials, each test specimen was divided into nine sections of 15 mm length, keeping a gap of 10 mm in between two sections. The details of the test specimen are shown in Fig. 2 below:

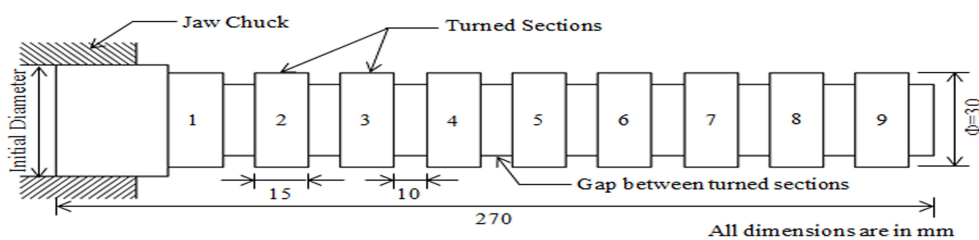


Fig. 2 Diagrammatic view of the test specimen

The sectional divisions of the test specimen for carrying out different trials are shown in Fig. 3.

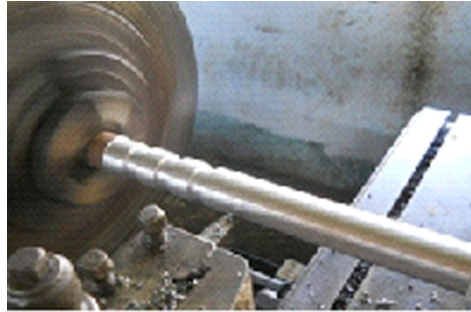


Fig. 3 Sectional division of the test specimen

3.2 Experimentation

On each of the 15 mm sections of the test specimen, turning operation was performed for a length of 12 mm with the factor settings as indicated by the trial condition. All the trials were carried out randomly during the experimentation. Surface roughness, the output variable was measured at the central section for 4.8mm of the turned surface by Mitutoyo Surface Roughness Measuring Tester SJ410 using ISO (International Organization of Standardization) 1997 standard. The diagrammatic view of the test specimen after experimentation is shown in Fig.4 below:

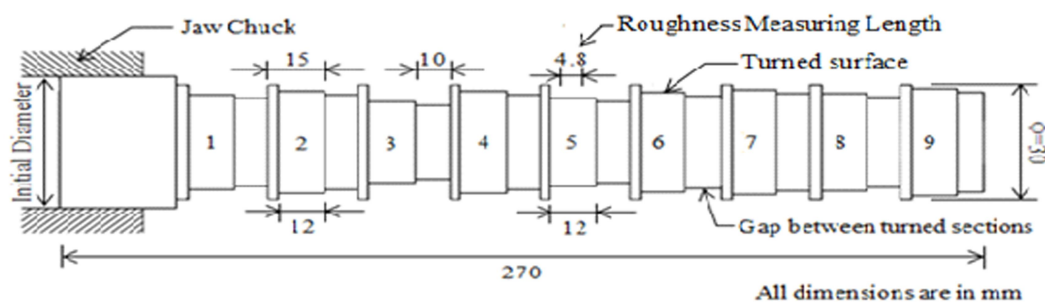


Fig. 4 Diagrammatic view of the test specimen after experimentation

A pictorial view of the measurement being performed on the test specimen after performing the turning operation is shown in Fig. 5.



Fig. 5 Pictorial view of the measurement being performed on the test specimen

4. RESULTS AND DISCUSSION

The data obtained from the experiment are shown in Table 3. The main effect plots for factor A, B and C are shown in Fig. 6 and Interaction effect plots of factor A & B (AxB), A & C (AxC) and B & C (BxC) are shown in Fig. 7 respectively.

Table 3 Experimental data

Trial No.	Surface Roughness (μm)			Average (μm)	S/N ratio dB
	R ₁	R ₂	R ₃		
1	4.375	4.445	4.561	4.460	-12.989
2	3.942	3.656	3.290	3.629	-11.220
3	3.826	3.756	3.642	3.741	-11.462
4	6.957	6.809	6.515	6.760	-16.603
5	5.386	5.158	5.204	5.249	-14.404
6	4.371	4.444	4.377	4.397	-12.864
7	11.972	11.806	11.727	11.835	-21.464
8	6.162	6.304	6.490	6.319	-16.014
9	5.359	5.423	5.515	5.432	-14.700
10	2.749	3.221	3.301	3.090	-9.827
11	3.004	2.973	3.209	3.062	-9.725
12	4.133	3.875	3.968	3.992	-12.027
13	5.053	4.931	5.282	5.089	-14.136
14	4.268	4.090	4.353	4.237	-12.544
15	5.345	5.220	5.464	5.343	-14.557
16	6.400	6.583	6.625	6.536	-16.307
17	5.752	5.526	5.779	5.686	-15.097
18	5.952	6.288	6.342	6.194	-15.843
19	2.675	2.904	3.163	2.914	-9.310
20	2.445	2.422	2.208	2.358	-7.461
21	3.238	3.197	3.455	3.297	-10.367
22	5.251	5.277	5.707	5.412	-14.673
23	5.804	5.608	5.931	5.781	-15.242
24	4.110	3.834	3.923	3.956	-11.948
25	6.914	6.866	6.569	6.783	-16.631
26	4.526	4.657	4.930	4.704	-13.456
27	5.675	5.806	5.504	5.662	-15.061

Where, R₁, R₂ and R₃ are the repetitions of trial conditions.

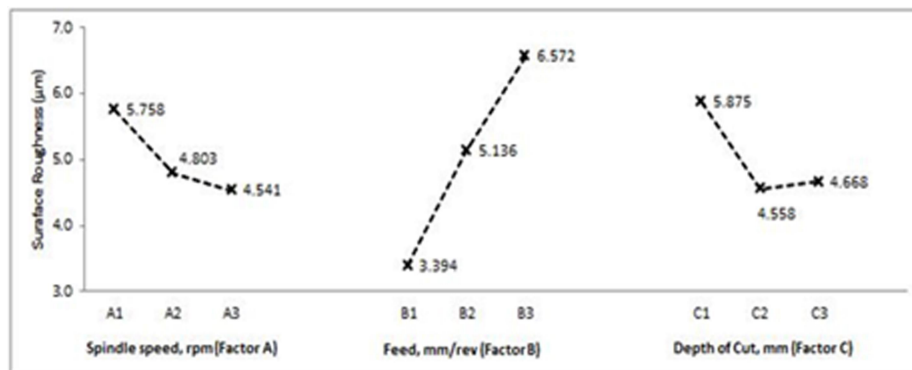


Fig. 6 Main effect plots for factor A, B and C

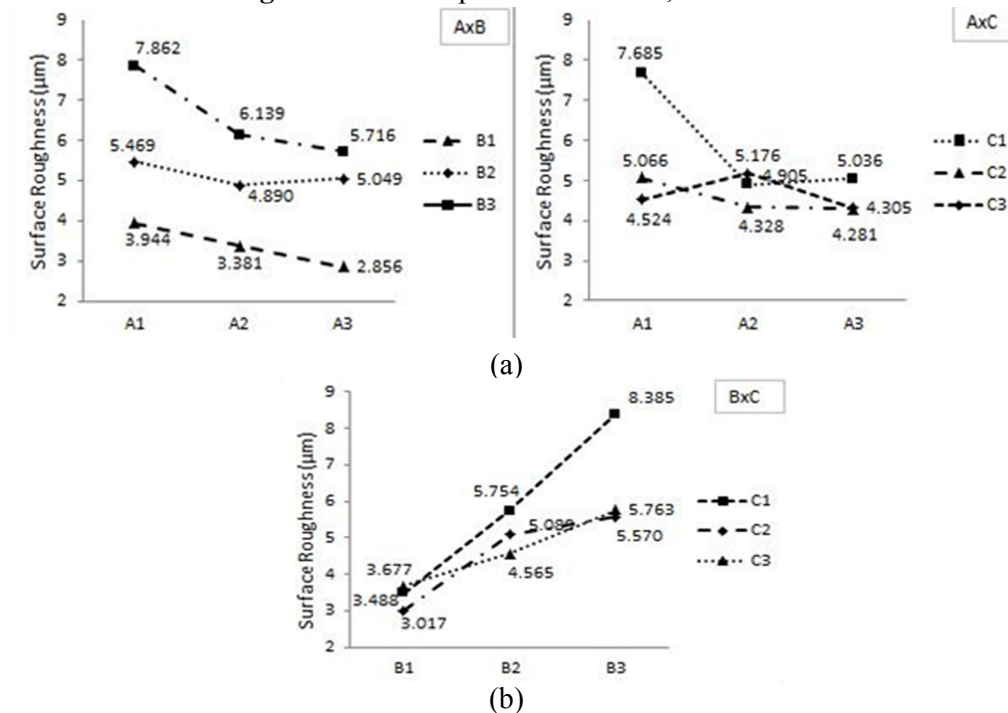


Fig. 7(a) & (b) Interaction effect plots factor A & B (AxB), A & C (AxC) and B & C (BxC)

The raw data and S/N data ANOVA are shown in Table 4 and Table 5 respectively.

Table 4 Raw data ANOVA

Source	f	S	V	F	S'	P	F(0.05) critical	Comment
Factor A	2	22.170	11.085	35.110	21.539	8.011	3.145	Significant
Factor B	2	136.808	68.404	216.660	136.177	50.650	3.145	Significant
Factor C	2	28.838	14.419	45.670	28.207	10.491	3.145	Significant
AxB	4	8.022	2.005	6.352	6.759	2.514	2.520	Significant
AxC	4	29.308	7.327	23.208	28.046	10.431	2.520	Significant
BxC	4	24.137	6.034	19.113	22.875	8.508	2.520	Significant
error	62	19.575	0.316	1		9.394		
Total	80	268.858	109.591			100		

Table 5 S/N data ANOVA

Source	f	S	V	F	S'	P	F(0.05) critical	Comment
Factor A	2	17.763	8.882	4.073	13.402	6.017	3.493	Significant
Factor B	2	144.076	72.038	33.036	139.715	62.727	3.493	Significant
Factor C	2	17.285	8.642	3.963	12.924	5.802	3.493	Significant
AxB	[4]	[4.326]	Pooled					
AxC	[4]	[17.235]	Pooled					
BxC	[4]	[13.443]	Pooled					
Error	20	43.612	2.181	1		25.454		
Total	26	222.737	91.743			100		

From the ANOVA results it can be seen that Factor A, Factor B and Factor C have significant effects (at 95% Confidence Level, CL) on both the mean and variation of the response variable (surface roughness), whereas their interactions have a significant effect on mean only. Among the three factors, Factor B has maximum effect on the surface roughness having 50.65% contribution to the mean and 62.727% contribution to the variation (with 95% confidence level). From the main effect plots (Fig. 6), the optimum factor combination is $A_3B_1C_2$. Interaction effect plots (Fig. 7) also show that the combination A_3B_1 , A_3C_2 and B_1C_2 produces the minimum surface roughness. Hence the optimal factor combination is $A_3B_1C_2$ i.e. Spindle speed = 630 rpm, Feed = 0.05 mm/rev and Depth of Cut = 1.25 mm.

The obtained optimal factor combination is one of the trial conditions (Trial 20) of the experiment. Thus the mean is calculated by averaging the response values of that trial [15]. From Table 3, the average value of the response variable (surface roughness) for Trial 20 is 2.358 μm . Thus, the mean surface roughness at optimum setting is, $R_a = 2.358 \mu\text{m}$.

Confidence interval (C.I.) at 95% confidence level (CL) [15],

C.I. POP = ± 0.970 (for Population)

C.I. CE = ± 1.941 (for Confirmatory Experiment)

Range of surface roughness with 95% confidence level [15],

$1.388 \leq R_a \text{ (POP)} \leq 3.329$ (for Population)

$0.418 \leq R_a \text{ (CE)} \leq 4.299$ (for Confirmatory Experiment)

4.1 Confirmatory experiment

Though the obtained optimal factor combination ($A_3B_1C_2$) is one of the trial conditions (Trial 20) of the experiment, a confirmatory experiment is conducted with three repetitions to ascertain the obtained results. The result of the confirmatory experiment is shown in Table 6.

Table 6 Result of the Confirmatory Experiment

Variable Factors			Surface roughness, (μm)	Average, (μm)	Range with 95% CL
Spindle Speed, rpm (Factor A)	Feed, mm/rev (Factor B)	Depth of Cut, mm (Factor C)			

630	0.05	1.25	R₁	R₂	R₃	2.408	1.388 ≤ R _a (POP) ≤ 3.329 0.418 ≤ R _a (CE) ≤ 4.299
			2.567	2.379	2.280		

Where, R₁, R₂ and R₃ are the repetitions of trial conditions.

5. CONCLUSION

In the present investigation, the effect of Spindle speed (A), Feed (B) and Depth of Cut (C) are found significant both on the mean and variation of the surface roughness of AISI1020 mild steel in turning operation. Among the three variable factors feed has the maximum effect both on mean (50.650%) and variation (62.727%) of the output variable. However mild two factor interactions are observed among the three factors (Spindle speed x feed, Spindle speed x depth of cut and feed x depth of cut) which have a significant effect on mean only. Within the range of experiment, the optimum factor combination for the minimum surface roughness is found to be 630 rpm Spindle speed, 0.05 mm/rev feed and 1.25 mm depth of cut with estimated surface roughness $2.358 \pm 0.970 \mu\text{m}$. A confirmatory experiment has been conducted to verify the results predicted from Taguchi optimization. In the confirmatory experiment the average value of surface roughness is found to be $2.408 \mu\text{m}$ which is well within the range ($0.418 \leq R_a \text{ (CE)} \leq 4.299$) predicted for confirmatory experiment.

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