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Optimization of Cutting Condition for Turning Operation Based On the Taguchi Method

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Abstract

Present dissertation work has attempted to optimize the various significant cutting conditions for turning process by Taguchi method and design of experiments. The response variable is surface roughness (Ra). The stainless steel AISI 316 SS has been used as a workpiece material. The various cutting conditions selected for the study were cutting speed, feed rate, depth of cut and nose radius. A standard L_{18} orthogonal array was selected for design of experiments. The results obtained from the experimental runs were analyzed using Minitab16 software. Analysis of Variance (ANOVA) for Signal-to-noise (S/N) ratio was done to find the most contributing cutting conditions affecting the Ra. The corresponding values of the response parameter were also calculated using mathematical formulae and confirmed by performing validation experimentation. From the present experimental study, it is observed that Ra in turning process is mainly affected by all input parameters. Feed rate was the most significant factor affecting the Ra followed by cutting speed, nose radius and depth of cut.

Keywords: AISI 316 SS, Turning, Taguchi Methodology and Surface Roughness.

1. Introduction

Austenitic stainless steel is one of the extreme significant engineering materials with a wide range of applications. This material is charming because of its characteristics like toughness, elevation hardness, excellent ductility, yield strength, superior resistance to oxidation and corrosion, compatibility in high vacuum and elevation temperature. But those materials are "difficult to machine" than carbon and low alloy steels because of their poor thermal conductivity, high strength and a higher grade of ductility and work hardenability [1], [2], [3], [4]. The problems such as high tool wear and poor surface finish are popular while machining those materials [1]. Therefore, efforts have been made to develop the machinability of austenitic stainless steel by insert free cutting elements such as tellurium, sulfur, selenium and lead [5]. In the machining operation, surface finish is one of the extreme noticeable mechanical requirements of the customer. The austenitic alloys utilized extreme frequently are those of the AISI three hundred series. Grade AISI 316 SS is the standard molybdenum-bearing score. Molybdenum give 316 better corrosion resistance characteristics over crevice corrosion in the chloride environments. It has excellent welding and forming characteristics. AISI 316 SS has a wide variety of uses like it is utilized in aerospace components; chemical processing equipment; for dairy, food and drink industries; for surgical embeds in the threatening environments of the body; in deck components for ships and boats in the marine environment; as well as heat exchangers [3], [6].

Nowadays, it is possible to come across many experimental studies studying the effects of cutting conditions on surface roughness, occurring during machining of various forms of stainless steel. In one of these studies, the machinability of AISI 316 SS with coated cemented carbide (CCC) cutting tools was studied and cutting speed was stated as the vital para.meter for surface roughness Ra [7]. In another investigation, the confirmation tests performed according to the optimal cutting conditions for Ra and machining force during turning of AISI 316 SS, resulted in approximately 23.4% betterment [8] developed a mathematical model for cutting conditions on turning of AISI 316 SS.

In the present study, Taguchi method has been employed to determine the best cutting conditions (nose radius, cutting speed, feed and depth of cut) to get the minimum Ra.

2. Experimental Set Up

The experimentation was carried out on a lathe machine type (Harrison / England) with a power of 2.2 KW, spindle speed of (40 - 2500 rpm) and feed rate of (0.03-1 mm/rev). Stainless steel AISI 316 SS material was used as a workpiece, the chemical composite listed in Table 1. The carbide insert of ISO geometry ‘CNMG 120416’ was used throughout the experiment.

Table 1: Chemical composition of AISI 316 SS.

Elements	C	Mn	Si	P	S	Cr	Mo	Ni	N
Weight %	0.08	2.00	0.75	0.045	0.03	18.00	3.00	14.00	0.10

The responses selected for experimentation were surface roughness Ra. Response characteristics are given in the Table 2.

Table 2: Response Characteristics

Response name	Response type	Unit
Surface Roughness Ra	Smaller the better	µm

2.1. Selection of the Cutting Conditions and their Levels

The cutting conditions and their levels given in Table 3 were selected based on extensive literature survey and the range limitation of lathe machine.

Table 3: Cutting condition and their levels.

Factors	Unit	Levels		
		Level 1	Level 2	Level 3
Nose radius r	mm	0.85	1.25	-----
Cutting speed	m/min.	200	500	800
Feed rate	mm/rev.	0.03	0.06	0.06
Depth of cut	mm	0.50	0.75	1.00

2.2 Selection of the Orthogonal Array

In the present experiment, the L18 orthogonal array meets the requirements of experiment as it is a smallest mixed 2-level and 3-level array. The experimentation was carried out as per the L18 orthogonal array given in Table 4.

Table 4: Design of Experiments L18 (2133) array.

Exp. No.	r mm	V m/min.	f mm/rev.	d mm
1	0.85	200	0.03	0.50
2	0.85	200	0.06	0.75
3	0.85	200	0.09	1.00
4	0.85	500	0.03	0.50
5	0.85	500	0.06	0.75
6	0.85	500	0.09	1.00
7	0.85	800	0.03	0.75
8	0.85	800	0.06	1.00
9	0.85	800	0.09	0.50
10	1.25	200	0.03	1.00
11	1.25	200	0.06	0.50
12	1.25	200	0.09	0.75
13	1.25	500	0.03	0.75
14	1.25	500	0.06	1.00
15	1.25	500	0.09	0.50
16	1.25	800	0.03	1.00
17	1.25	800	0.06	0.50
18	1.25	800	0.09	0.75

2.3 Measurement of Ra

Surface roughness was measured using tester type (TR 200 Roughness Tester, china). Surface roughness of each sample was measured at four different locations of machined surface and a mean is taken.

3. Results and Discussion

The experimental results for surface roughness by varying the selected cutting conditions as per L18 orthogonal array (OA). All observations are converted into S/N ratio. The S/N ratios worked out using MINITAB 16 software are tabulated in Table 5.

Table 5: Results for Ra and S/N Ratio.

Exp. No.	r mm	V m/min.	f mm/rev.	d mm	Ra µm	S/N Ratio
1	0.85	200	0.03	0.50	2.850	- 9.0969
2	0.85	200	0.06	0.75	3.270	- 10.2910
3	0.85	200	0.09	1.00	3.710	- 11.3875
4	0.85	500	0.03	0.50	2.710	- 8.6594
5	0.85	500	0.06	0.75	3.112	- 9.8608
6	0.85	500	0.09	1.00	3.520	- 10.9309
7	0.85	800	0.03	0.75	2.620	- 8.3660
8	0.85	800	0.06	1.00	3.115	- 9.8692
9	0.85	800	0.09	0.50	3.210	- 10.1301
10	1.25	200	0.03	1.00	2.760	- 8.8182
11	1.25	200	0.06	0.50	3.003	- 9.5511
12	1.25	200	0.09	0.75	3.373	- 10.5603
13	1.25	500	0.03	0.75	2.561	- 8.1682
14	1.25	500	0.06	1.00	2.952	- 9.4023
15	1.25	500	0.09	0.50	3.150	- 9.9662
16	1.25	800	0.03	1.00	2.490	- 7.9240
17	1.25	800	0.06	0.50	2.692	- 8.6015
18	1.25	800	0.09	0.75	3.053	- 9.6945

3.1 Analysis of Variance (ANOVA) for S/N ratios of Ra

The S/N ratio merges several recurrences into one value and is indication of the magnitude of variation existing. The S/N ratio has been evaluated to find the major contributing parameters which cause difference in the Ra. Ra is “Smaller is better” type output which specific by [9]:

$$(S/N)_{SB} = -\log(MSD)_{SB} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Where

$$(MSD)_{SB} = \frac{1}{n}\sum_{i=1}^{a} y^2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

$(MSD)_{SB}$ = Mean Square Deviation for smaller-the-better response.

Where, ‘y’ is value of output (Ra) variable and ‘n’ is number of observations in the experiments.

Table 6 shows the ANOVA results for S/N ratio of Ra at 95 % confidence interval. Feed rate was observed to be the most significant factor affecting the Ra, followed by cutting speed, nose radius and depth of cut according to F test.

Table 6: Analysis of Variance for SN ratios.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution %	Remark
r	1	1.9374	1.9374	1.93735	413.95	0.000	12.1307	S
V	2	2.1870	2.1870	1.09349	233.64	0.000	13.6935	S
f	2	11.3430	11.3430	5.67151	1211.83	0.000	71.022	S
d	2	0.4569	0.4569	0.22846	48.82	0.000	2.8608	S
Residual Error	10	0.0468	0.0468	0.00468			0. 293	
Total	17	15.9711						
R-Sq = 99.77% S: Significant factor								

The percentage contribution of each of the control parameters under study for Ra is shown by a pie chart in Figure (1). It can be seen that feed rate contributes significantly (71.022 %), followed by cutting speed (13.6935 %), nose radius (12.1307 %) and depth of cut (2.8608 %).

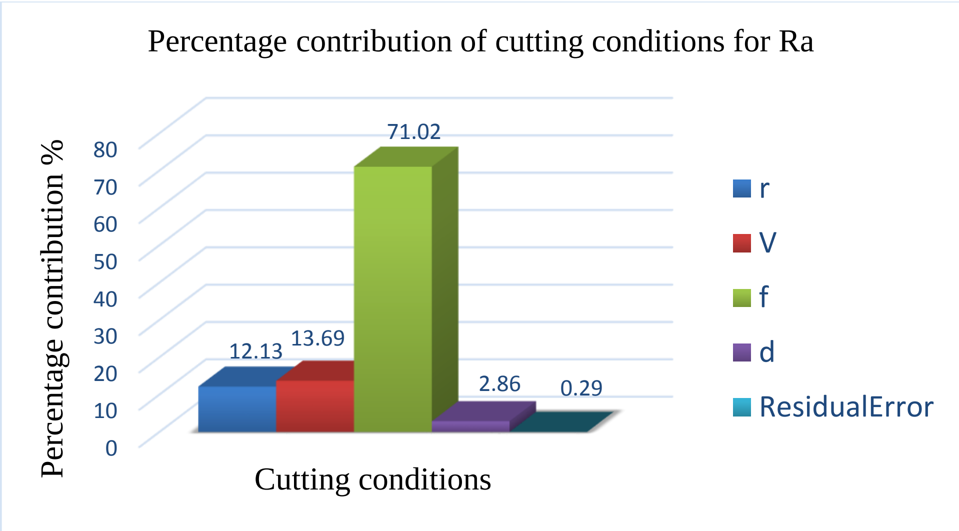

Figure 1: Percentage contribution of cutting conditions for Ra.

S/N ratio values of Ra are used to calculate mean of S/N ratios at three levels of all cutting conditions and set in Table (7). It gives us rank of all parameters in this investigation depending on the mean of S/N ratios for Ra at various levels in terms their relative significance.

Table 7: Response Table for Signal to Noise Ratios.

Level	r	V	f	d
1	-9.844	-9.951	**-8.505**	**-9.334**
2	**-9.187**	-9.498	-9.596	-9.490
3		**-9.098**	-10.445	-9.722
Delta	0.656	0.853	1.939	0.388
Rank	3	2	1	4

Feed rate has the highest rank signifying highest contribution to Ra, followed by discharge cutting speed, and nose radius. Depth of cut has the lowest rank.

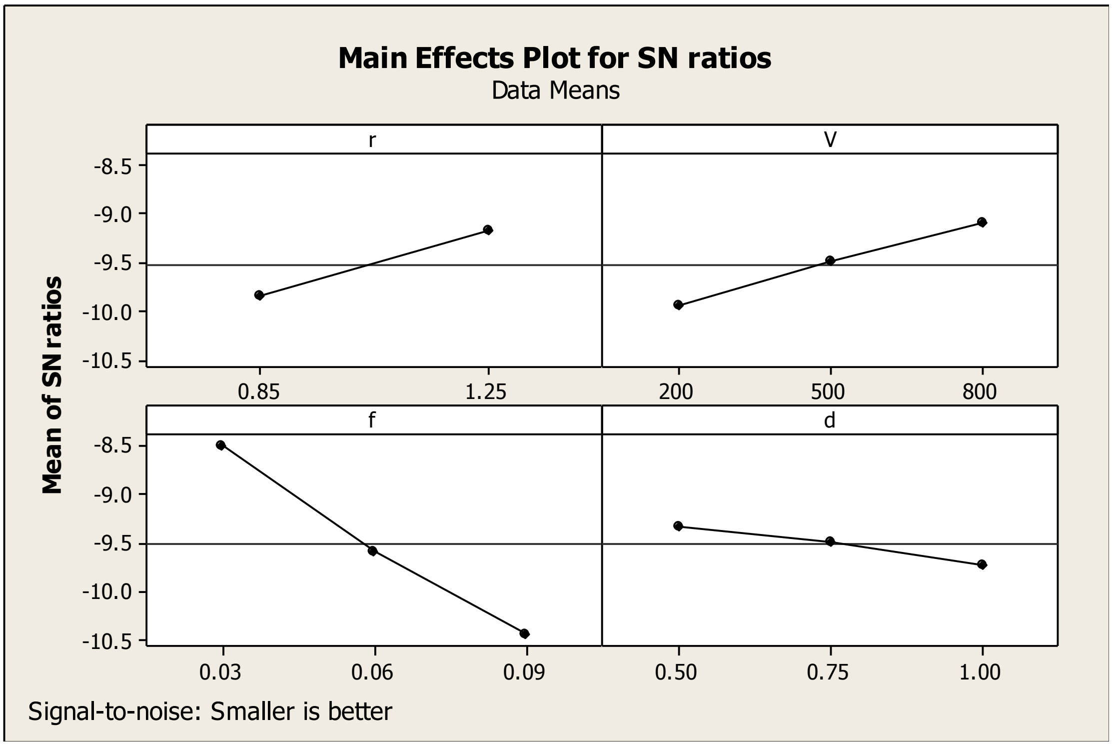

Figure 2: Main effects plot for S/N ratios of Ra.

Main effects plot for S/N ratios of Ra is shown in figure (2). The graph shows that with increasing in nose radius from 0.85 mm to 1.25 mm, S/N ratio increases. The S/N ratio increases with an increase in cutting speed from 300 m/min. to 800 m/min. The feed rate is increased S/N ratio decreases. Further as the depth of cut is increased S/N ratio decreases.

To conclude the discussion, for minimum Ra, the level value with higher a S/N ratio of each of the control parameter under study should be selected at this stage. Thus, a high nose radius of 1.25 mm, high cutting speed of 800 m/min., low feed rate of 0.03 mm/rev., low depth of cut of 0.5 mm should be selected. Thus, it can be concluded that the optimum combination for Ra is r2 V3 f1 d1. This optimal parametric combination is not available in L18 array under study. Hence, the theoretical optimum value of Ra has to be calculated.

After assessing the optimum cutting conditions settings, the sequent step of the Taguchi method is to predict and verify the enhancement of quality characteristics using the optimal parametric combination, which is not available in L18 array under study. Hence, the theoretical optimum value of Ra has to be calculated.

The optimal value of S/N ratio is given by the formula [10].

$$n_{opt} = n_m + \sum_{i=1}^{a}(n_i - n_m) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where nm is the overall mean S/N ratios, ni is the mean S/N ratio at optimal level and' a' is the number of major design cutting conditions that affect quality properties. Based on the above equations the estimated multi-response signal to noise ratio can be obtained.

$n_{opt} = -\ 9.51545 + (-\ 9.187 + 9.51545) + (-\ 9.098 + 9.51545) + (-\ 8.505 + 9.51545) + (-\ 9.334 + 9.51545)$

n_{opt} = Optimal value of S/N ratio = – 7.57765

The corresponding value of Ra is given by the formula [Mane and Hargude, 2015]

$$y^2 = 10^{\frac{-n_{opy}}{10}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$y^2 = 10^{\frac{7.57765}{10}}$

$y^2 = 5.7248$

y= 2.392

4. Confirmation Experiment

A confirmation experiment is performed by setting the control parameters as per the optimum levels achieved. The experimental result obtained for the Ra is 2.477 µm. Thus, the experimental value agrees fairly well with the prediction. The utmost deviation of the predicted result from experimental result is around 3.43 %. Therefore, the experimental result confirms the optimization of Ra by Taguchi method and the resulting appears to be susceptible of predicting Ra.

5. Conclusions

1. The Surface roughness are mainly affected by the all input parameters.
2. An increasing in the nose radius leads to a decreasing in the Ra.
3. An increasing in the cutting speed leads to a decreasing in the Ra.
4. An increasing in the feed rate, deteriorating the surface finish.

Low surface roughness (Ra) values (Better surface finish) can be achieved with high nose radius, high cutting speed, low feed rate, and low depth of cut.

CONFLICT OF INTERESTS.

- There are no conflicts of interest.

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أمثليية ظروف القطع لعملية الخراطة أعتمادا على طريقة تاكوشي

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الخلاصة

البحث الحالي هو محاولة لنمذجة ظروف القطع في عملية الخراطة باستخدام طريقة تاكوشي وتصميم التجارب. المخرجات (الاستجابة) كانت فقط خشونة السطح. استخدم الفولاذ المقاوم للصدأ AISI 316 SS كمادة مشغلة واختيرت سرعة القطع، معدل التغذية، عمق القطع ونصف قطر رأس العدة كظروف للقطع. استخدمت المصفوفة العمودية القياسية L_{18} لتصميم التجارب. حللت النتائج التي تم الحصول عليها باسخدام البرنامج Minitab16. نفذ تحليل التباين ANOVA لايجاد العوامل المؤثرة على خشونة السطح. حسبت القيم المستحصلة كاستجابة باستخدام صيغ رياضية وتم تاكيدها بواسطة اختبار التاكيد. من النتائج العملية نلاحظ ان معدل التغذية له التاثير الاكبر على قيم الخشونة متبوعا بسرعة القطع ونصف قطر رأس العدة وعمق القطع.

الكلمات الدالة: الفولاذ المقاوم للصدأ نوع 316، الخراطة، طريقة تاكوشي وخشونة السطح.