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Selection Of An Optimal Parametric Combination For Achieving A Better Surface Finish In Dry Turning Of SS 420 Materials

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Abstract

This paper studies the use of S/N ratio and Response surface methodologies for minimizing the surface roughness during turning of SS 420 material at dry machining conditions. Experiments are conducted to study the influence of tool geometry (nose radius) and cutting parameters (feed, speed and depth of cut) on machining performance in dry turning conditions based on Taguchi's orthogonal array method. The mathematical model in terms of machining parameters is developed for surface roughness prediction using response surface methodology. The Analysis of Variance (ANOVA) is employed to analyze the effect of these turning parameters. The analysis of the result shows that the optimal combination for good surface finish are medium cutting speed, low feed rate, low depth of cut and higher nose radius .Using Taguchi method for design of experiment (DOE), other significant effects such as the interaction among turning parameters are also investigated. The study shows that the Taguchi method is suitable to solve the stated problem with minimum number of trials as compared with a full factorial design.

Key words *Taguchi method. S/N ratio. Response surface methodology(RSM). Analysis of variance*

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1. Introduction

The significance of machining process has been increased through rapid development of manufacturing industry. In machining, cutting fluid may be considered as the prime factor. However the use of such cutting fluid may seriously degrade the environment. This gives rise to the serious problems of procurement, storage, disposal and maintenance and cost of the cutting process [1]. So getting the possible surface fluid through dry machining while considering the various tool positions has been one of the challenging works.

Turning is one of the most widely used metal removal operations in industry in view of its capability to yield a high metal removal rate and achieve a reasonably good surface quality. It has a large number of applications in industries such as the aerospace and automotive sectors, where quality is an important factor in the production of slots, pockets, precision moulds and dies.

Surface roughness is defined as the irregularities of any material resulting from machining operations. Average roughness Ra is theoretically derived as the arithmetic average value of departure of the profile from the mean line along a sampling length [2]. Surface roughness depends on process parameters (like cutting velocity, feed rate, depth of cut etc) tool geometry (like rake angle, nose radius etc) and machining irregularities such as chatter, wear, material properties and cutting fluid. In case of dry machining, greater amount of thermal stress is developed on tool and work piece material as they rub against each other. Thus to pursue dry machining such disadvantages should be compensated. The possible approach is to adjust the process parameters and tool geometry in order to get the optimum surface finish.

In order to get good surface quality and dimensional properties, it is necessary to employ optimization techniques to find optimal cutting parameters and theoretical models to do prediction. Taguchi and response surface methodologies can be conveniently used for these purposes. Kwak [3] has applied Taguchi and response surface methodologies for optimizing geometric errors in surface grinding process. The response surface method (RSM) is more practical, economical and relatively easy to use [4]. Chung [5] has also observed that the nose radius plays a significant role in the surface finish.

In this paper the influence of process parameter on surface roughness on the machining of SS420 material is investigated. Test results are analyzed to obtain optimal surface roughness Ra using signal to noise (S/N) ratio. Second order model is developed using response surface methodology for optimal selection of machining parameters for minimum surface roughness. The analysis of variance (ANOVA) is employed to analyze the effect of these turning parameters.

2. Methods

2.1 Taguchi method

Taguchi techniques have been used widely in engineering design [6,7]. The main trust of the Taguchi techniques is the use of parameter design, which is an engineering method for product or process design that focuses on determining the parameter (factor) settings producing the best levels of a quality characteristic (performance measure) with minimum variation. Taguchi designs provide a powerful and efficient method for designing processes that operate consistently and optimally over a variety of conditions. To determine the best design requires the use of a strategically designed experiment which exposes the process to various levels of design parameters. Taguchi used the signal-to-noise (S/N) ratio as the quality characteristic of choice [8,9]. S/N ratio is used as a measurable value instead of standard deviation due to the fact that as the mean decreases, the standard deviation also decreases and vice versa. In other words, the standard deviation cannot be minimized first and the mean brought to the target. Taguchi recommends the use of the loss function to measure the performance characteristic deviating from the desired value. The value of the loss function is further transformed into a signal-to-noise (S/N) ratio. Usually, there are three categories of performance characteristic in the analysis of the S/N ratio. The loss function for the lower –the – better performance characteristic can be expressed as

$$L_{ij} = \frac{1}{n}\sum_{k=1}^{n} y_{ijk}^{2}$$

where L_{ij} is the loss function of the i^{th} performance characteristic in the j^{th} experiment, y_{ijk} the experimental value of the i^{th} performance characteristic in the j^{th} experiment at the k^{th} trial, and n, the number of trials.

The loss function is further transformed into an S/N ratio. In the Taguchi method, the S/N ratio is used to determine the deviation of the performance characteristic from the desired value. The S/N ratio L_{ij} for the i^{th} performance characteristic in the j^{th} experiment can be expressed as

$$\eta_{ij} = -10\log(L_{ij})$$

2.2. Response surface methodology

The RSM is an empirical modeling approach for determining the relationship between various processing parameters and responses with the various desired criteria and searches for the significance of these process parameters in the coupled responses [10]. It is a sequential experimentation strategy for building and optimizing the empirical model. The objective of the response surface methodology is to develop the mathematical link between the responses and predominant machining parameters. The general second order polynomial response surface mathematical model can be considered to evaluate the parametric influences on the various machining criteria as follows:

$$Yu = \beta_0 + \sum_{i=1}^{k} \beta_i x_{iu} + \sum_{i=1}^{k} \beta_{ii} {x_{iu}}^2 + \sum_{i} \sum_{j} \beta_{ij} x_{iu} x_{ju}$$

where Yu represents the corresponding response of surface roughness Ra in the present research. The code values of ith machining parameters for uth experiment are represented by x_{iu}. The values of n indicate the number of machining parameters. The terms b_i, b_{ii} and b_{ij} are the second order regression co-efficient. The second term under the summation sign of this polynomial equation attributes to linear effects, whereas the third term of the above equation corresponds to the higher order effects and lastly the fourth term of the equation includes the interactive effects of the parameters.

3. Design of experiments and experimental details

3.1 Design of experiments

Properly designed experiment forms the basis of modeling process which ultimately results in formulation of reliable equations. So a well designed set of experiments is unavoidable. Therefore, Taguchi’s orthogonal array is utilized to substantially reduce the number of experiments.

In this process four factors at three levels are chosen which is given in the Table 1. The design of experiment used is a standard L_{27} (3^{13}) orthogonal array [11]. This orthogonal array is chosen due to its capability to check the interactions among factors. Each row of the matrix represents one trial. The code values of machining parameters and actual setting values are presented in Table 2.

3.2 Experimental details

The experiment is performed on SS 420 of size 25 mm diameter, which contains 12% of chromium sufficient enough to give corrosion resistance property and good ductility. Its chemical composition is given as minimum of 0.15% C, 12.0-14.0% Cr , < 1.0% Si , <0.04% P ,<1.0% Mn, <0.03% S remaining as Fe . The physical and mechanical properties of the SS420 are given in Table 3. Table 4 represents the details of cutting tool and tooling systems used for the experimentation. The different sets of experiments are performed using a Kirloskor centre lathe. The machined surface was measured at three different positions and the average value was taken using a RUGOSURF 10G surface texture measuring instrument whose specification is given in Table 5.

The objective of the experiment is to optimize the turning parameters to get better (i.e. low value) surface roughness, Ra value and to study the influence of different cutting parameters on surface finish criterion. The Taguchi design approach is utilized for experimental planning during the turning of SS420.Test results are analyzed to achieve optimal surface roughness height Ra. Mathematical model is developed by means of response surface methodology for optimal selection of machining parameters for minimum surface roughness heights Ra during SS420 turning.

4. Results and Discussion

The results of the turning tests allowed the evaluation of surface roughness using signal noise ratio and it can be validated by response surface methodology for machining SS 420 material.

4.1 Influence of the cutting parameters on the surface roughness (Ra)

The objective of using S/N ratio is a measure of performance to develop products and processes insensitive to noise factors [12]. The S/N ratio indicates the degree of the predictable performance of a product or process in the presence of noise factors. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance. The S/N ratio for each parameter level is calculated by averaging the S/N ratios obtained when the parameter is maintained at that level. The experimental results for surface roughness and its S/N ratio are shown in Table 6.

The average S/N ratios for smaller the better for arithmetic average roughness (Ra) and significant interactions are shown in Fig.1. Study of Fig.1 suggests that feed rate (F), nose radius (R) and interaction between depth of cut and feed rate (*DF*) are more significant. Cutting velocity (V) and depth of cut (D) are marginally significant. The lowest feed rate of level 1 (F_1=0.059) and highest nose radius of level 3 (R_3= 1.2 mm) appear to be the best choice to get low value of surface roughness or high value of surface finish and thus making the process robust to the feed rate in particular. The cutting velocity and depth of cut are insignificant on the average S/N response.

Table 7 shows the best level of process parameters to achieve high surface finish or low surface roughness. Therefore, the optimal combination to get low value of surface roughness (Ra) is 1-2-1-3 (F_1-V_2-D_1-R_3) within the tested range.

Fig.2 represents the percentage of contribution of process parameters and the interactions among them. It reveals that the feed factor (F = 54.863%) and the nose radius (R= 24.051%) have statistical and physical significance on the surface roughness, Ra. The interactions of feed/cutting velocity (FV= 15.62%) and depth of cut /feed (DF= 22.541%) have statistical and physical significance on arithmetic average roughness (Ra) in work piece. The interaction of velocity /nose radius (VR= 6.162%) presents percentage of marginal physical significance. The interactions of feed/nose radius (FR= -0.335%), depth of cut/cutting velocity (DV=1.421%) and depth of cut/nose radius (DR=0.917%) do not present percentages of physical significance of contribution on arithmetic average roughness (Ra) in work piece.

The main purpose of the analysis of variance (ANOVA) is the application of a statistical method to identify the effect of individual factors. Results from ANOVA can determine very clearly the impact of each factor on the process results [13].Table 8 shows the analysis of variance with arithmetic average roughness (Ra). This analysis is carried out for a 5% significance level, i.e. for a 95% confidence level. From table 8, it is clear that F calculated value for feed rate is 5.62, which is the most significant parameter and also nose radius have considerable influence on surface roughness. F calculated value is more than the table value; F0.05, 2, 20= 3.49) at 95% confidence level.

4.2 Response surface analysis for Ra

It also confirms that this model provides an excellent explanation of the relationship between the independent factors and the response arithmetic average roughness (Ra). The second order response surface representing the surface roughness, Ra can be expressed as a function of cutting parameters such as feed (F), cutting speed (V), depth of cut (D) and nose radius (R). The relationship between the surface roughness and machining parameters has been expressed as follows [14].

$$Ra = \beta_o + \beta_1(F) + \beta_2(D) + \beta_3(V) + \beta_4(R) + \beta_5(FD) + \beta_6(FV) + \beta_7(FR) + \beta_8(DV) + \beta_9(DR) + \beta_{10}(VR) + \beta_{11}(F^2) + \beta_{12}(D^2) + \beta_{13}(V^2) + \beta_{14}(R^2) \text{ ----------------}(1)$$

From the observed data for surface roughness, the response function has been determined in encoded units as:

$$Ra = - 4.89 + 2.49\,F - 38.0\,D + 0.599\,V + 3.27\,R - 5.38\,F{*}D + 0.0140\,F{*}V - 18.2\,F{*}R + 0.0097\,D{*}V + 15.8\,D{*}R - 0.232\,V{*}R + 80.5\,F^2 + 16.5\,D^2 - 0.00318\,V^2$$

S = 0.476727   R-Sq = 93.4%   R-Sq (adj) = 86.9%

Result of ANOVA for the response function i.e. surface roughness is represented in Table 9. This analysis is carried out for a level of significance of 5%, i.e., for a level of confidence of 95%. From the analysis of Table 9, it is apparent that, the F calculated value is greater than the F Table value ($F_{0.05,\ 13,\ 13}$=2.575) and hence the second order response function developed is quite adequate.

4.3. Determining the models accuracy

The error associated with the experimental and predicted values are very low, so the developed model is the most accurate and adequate for this particular experiment trial. The model accuracy percentage for all data sets can be found by [15]

$$\Delta = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{y_{i,\mathrm{expt}} - y_{i,pred}}{y_{i,pred}}\right| \text{------------------------} \quad (2)$$

where $y_{i,\mathrm{expt}}$ measured response corresponding to data set *i*, $y_{i,\mathrm{pred}}$ predicted response corresponding to data set *i* and *n* the number of data sets = 27. Equation (2) is used to test the accuracy of the predictive models using the experimental data results. This involves applying these equations to the factors and data for the individual runs in Table 6 and then calculating the accuracy. The average error rate of these models with the experimental data is within 4.7%. The comparison of the predicted and experimental values of surface roughness as per the Taguchi array is shown in Table 10 and graphically Fig. 3.

5. Conclusion

Based on this experiment**,** the following conclusions may be drawn for the turning conditions used and the characterization of the surface finish:

The feed rate has greater influence on the roughness followed by nose radius.

- Depth of cut has only meagre influence on the surface roughness and cutting velocity has no significance influence on the roughness.
- The interaction depth of cut /feed rate has greater influence on the roughness followed by the interaction feed rate / cutting velocity.

- The remaining parameters velocity/nose radius, depth of cut /velocity and depth of cut/ nose the radius have very low influence. The interaction feed/nose radius has no influence on surface roughness.

The proposed model for predicting the surface roughness is based on correlation obtained by response surface methodology between the cutting conditions (feed rate, cutting velocity, depth of cut and nose radius) and the surface roughness parameter. The results obtained prove that the predictions made by means of RSM are highly accurate and the average error rate of these models with the experimental data is within 4.7%.

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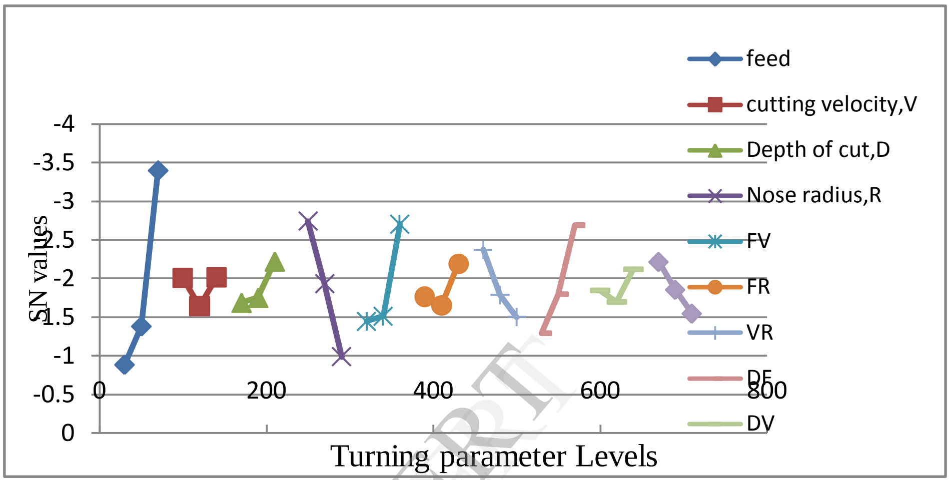

Fig.1. S/N ratio for surface roughness, Ra.

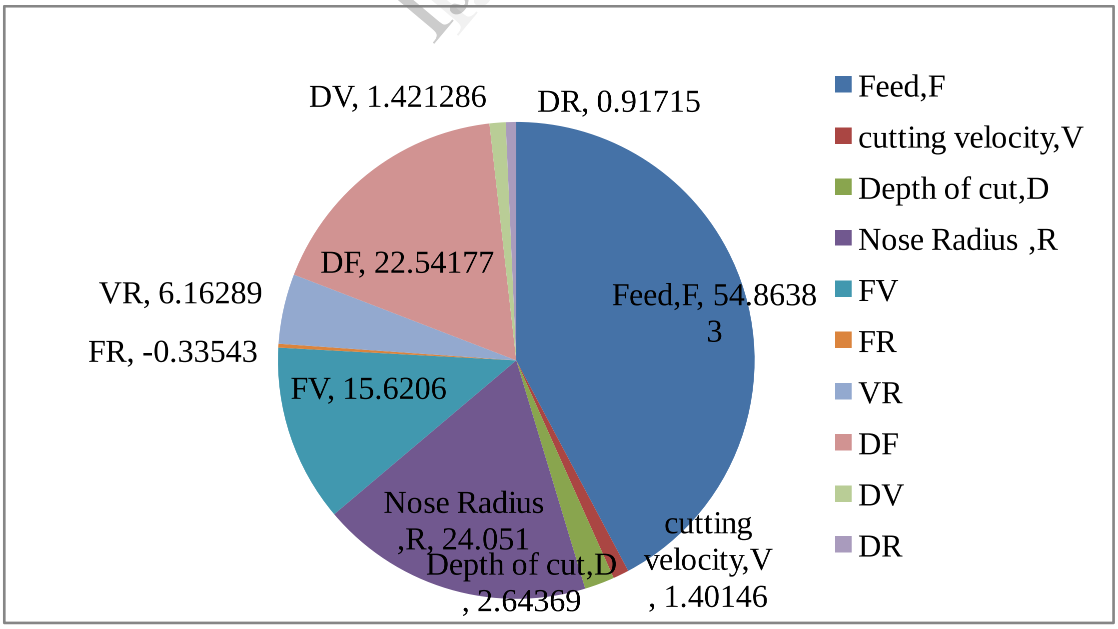

Figure 2 Pie- chart showing percentage contribution of surface roughness, Ra

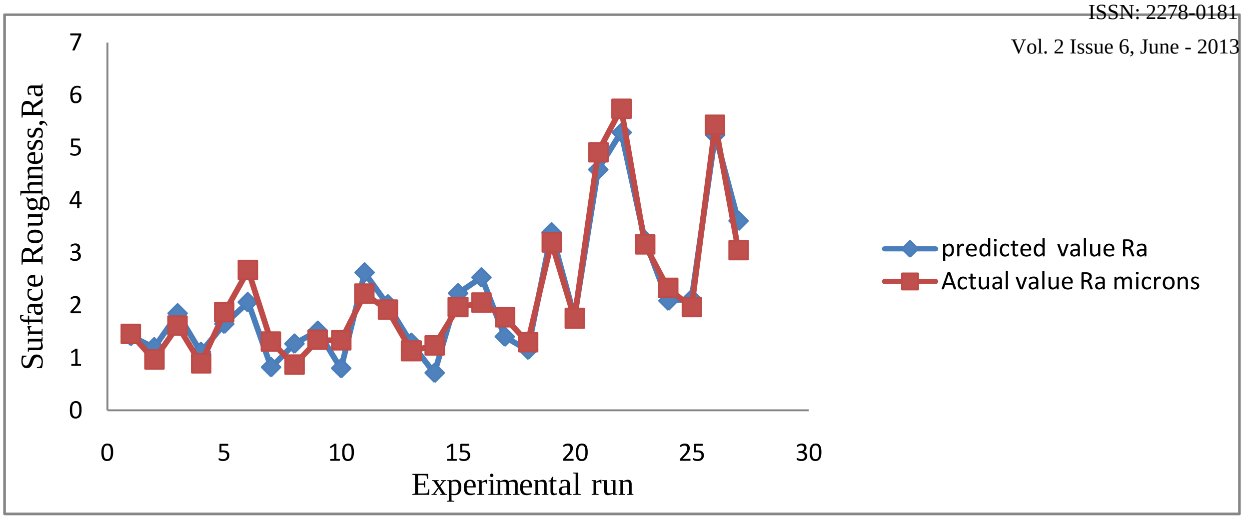

Fig 3 RSM Predicted and Experimental values of Ra

Table 1 – Three level tables with four factors

Levels	Feed F in mm/rev	cutting velocity V in m/min	Depth of cut D in mm	Nose radius R in mm
1	0.059	39.269	0.4	0.4
2	0.159	60.475	0.8	0.8
3	0.26	94.247	1.2	1.2

Table 2 – L_{27} (3^{13})Orthogonal Array Table

Runs	F		D*F		DOC	F*V	F*R	V*R	V	D*V		D*R	R
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	1	2	2	3	1
17	2	3	1	2	2	3	1	1	2	3	3	1	2
18	2	3	1	2	3	1	2	2	3	1	1	2	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2

Table 3 Physical and mechanical properties of SS 420

Grade	**Density (kg/m^3)**	**Elastic Modulus (GPa)**	**Mean Coefficient of Thermal Expansion (µm/m/°C)**			**Thermal Conductivity (W/m.K)**		**Specific Heat 0-100°C (J/kg.K)**	**Electrical Resistance (nΩ.m)**
			0 to 100°C	**0 to 315°C**	**0 to 538°C**	**At 100°C**	**At 500°C**		
420	**7750**	**200**	**10.3**	**10.8**	**11.7**	**24.9**	**-**	**460**	**550**

Table 4 – Cutting tool specification

Cutting tool Specification	Tooling System	Condition of Machining	Tool material and grade	Rake angle	Clearance angle	Nose radius	Cutting edge angle
DCMT 11 T3 04 F1 TP2500	Rhombic	Turning	Uncoated Tungsten Carbide(WC)	0^o	7^o	0.4 mm	55^o
DCMT 11 T3 08 F1 TP2500	Rhombic	Turning	Uncoated Tungsten Carbide(WC)	0^o	7^o	0.8 mm	55^o
DCMT 11 T3 12 F1 TP2500	Rhombic	Turning	Uncoated Tungsten Carbide (WC)	0^o	7^o	1.2 mm	55^o

Table 5 – Specification of surface texture measuring device.

Model no	**Make**	**Accuracy**	**Resolution**	**Measuring range**	**Stylus tip**
RUGOSURF 10G	TESA	0.05µm	0.005µm	0-300µm	Diamond

Table 6 Experimental Results and S/N ratio for surface roughness Ra

Experiment runs	Feed F mm/rev	Depth of cut DOC mm	Cutting velocity V m/min	Nose radius R mm	Test result of Ra(µm)			Average Surface roughness Ra microns	Calculated S/N ratio for Ra (db)
					y_1	y_2	y_3		
1	1	1	1	1	1.38	1.545	1.455	1.46	-1.0956
2	1	2	2	2	0.971	0.908	1.039	0.972667	0.0802
3	1	3	3	3	1.706	1.787	1.365	1.619333	-1.3955
4	1	1	2	3	0.893	0.971	0.81	0.891333	0.3330
5	1	2	3	1	1.921	1.762	1.933	1.872	-1.815
6	1	3	1	2	2.617	2.692	2.72	2.676333	-2.850
7	1	1	3	2	1.334	1.243	1.347	1.308	-0.777
8	1	2	1	3	0.88	0.876	0.861	0.872333	0.3954
9	1	3	2	1	1.148	1.273	1.621	1.347333	-0.8631
10	2	1	2	3	1.465	1.281	1.248	1.331333	-0.82857
11	2	2	3	1	2.273	2.169	2.232	2.224667	-2.3150
12	2	3	1	2	1.512	1.869	2.365	1.915333	-1.881
13	2	1	3	2	1.201	1.11	1.09	1.133667	-0.3632
14	2	2	1	3	1.353	1.211	1.137	1.233667	-0.6079
15	2	3	2	1	2.046	1.959	1.894	1.966333	-1.9577
16	2	1	1	1	2.133	1.908	2.11	2.050333	-2.0788
17	2	2	2	2	1.785	1.988	1.537	1.77	-1.6531
18	2	3	3	3	1.13	1.41	1.36	1.3	-0.7596
19	3	1	3	2	2.637	3.475	3.491	3.201	-3.3685
20	3	2	1	3	1.746	1.763	1.753	1.754	-1.6268
21	3	3	2	1	5	4.566	4.817	4.913667	-4.6093
22	3	1	1	1	5.832	5.743	5.657	5.744	-5.0614
23	3	2	2	2	3.163	3.116	3.2	3.159667	-3.3309
24	3	3	3	3	2.358	2.23	2.399	2.329	-2.4477
25	3	1	2	3	1.941	2.107	1.853	1.967	-1.9586
26	3	2	3	1	4.99	5.957	5.358	5.435	-4.9013
27	3	3	1	2	3.186	2.944	3.042	3.057333	-3.2356

Table 7.The optimum level for the surface roughness Ra

Parameters	**Optimum Level of Ra**	**S/N Response value for Ra**
Feed- mm/rev	1	-0.88763
cutting velocity-m/min	2	-1.64315
Depth of cut-mm	1	-1.68882
Nose radius	3	-0.98851

Table 8 – Results of ANOVA for S/N ratio of Ra

Parameters	**Sum of squares**	**Degrees of freedom**	**Variance**	**F-Test**	**F,5%**	**% Contribution**
Feed, F	31.69	2	15.849	5.620	3.36	54.86
cutting velocity, V	0.809	2	0.4048	0.144	3.36	1.40
Depth of cut, D	1.527	2	0.7637	0.271	3.36	2.643
Nose Radius ,R	13.89	2	6.9482	2.464	3.36	24.05
FV	9.0252	4	2.2563	0.800	2.74	15.62
FR	-0.1938	4	-0.0484	-0.017	2.74	-0.335
VR	3.560783	4	0.8901	0.316	2.74	6.162
DF	13.02414	4	3.2560	1.154	2.74	22.54
DV	0.821188	4	0.2052	0.072	2.74	1.421
DR	0.529911	4	0.1324	0.046	2.74	0.917
Error	-16.9225	-6	2.8204			-29.28
total	57.77779	26				100

Table 9 Results of ANOVA for response function of Ra

Source	DF	SS	Variance	F
Regression	13	42.0678	3.2360	14.24
Residual Error	13	2.9545	0.2273	
Total	26	45.0223		

Table 10 Experimental and Predicted values of Ra

Experimental Run	Actual value,Ra	Predicted value,Ra
1	1.460	1.415914
2	0.973	1.201805
3	1.619	1.847592
4	0.891	1.112467
5	1.872	1.648305
6	2.676	2.060945
7	1.308	0.821878
8	0.872	1.269779
9	1.347	1.515143
10	1.331	0.801833
11	2.225	2.625752
12	1.915	2.018223
13	1.134	1.286525
14	1.234	0.714256
15	1.966	2.230109
16	2.050	2.531592
17	1.770	1.403971
18	1.300	1.153839
19	3.201	3.390049
20	1.754	1.78741
21	4.914	4.586455
22	5.744	5.292657
23	3.160	3.242389
24	2.329	2.087378
25	1.967	2.122323
26	5.435	5.247204
27	3.057	3.609304