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Optimization of Material Removal Rate & Surface Roughness in Dry Turning of Medium Carbon Steel En19 by Using Taguchi Method

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ABSTRACT
Optimization of machining parameters is valuable to maintain the accuracy of the components and to minimize the cost of machining. Surface finish is an important measure for the quality of the machined parts. The present work is an experimental investigation to study the effect of machining parameters on Material Removal Rate and Surface Roughness in dry turning of medium carbon steel EN19. Taguchi's single objective optimization method was used to find the effect of input parameters on the responses. The experiments were conducted as per Taguchi's L9 Orthogonal Array on CNC lathe under dry conditions. Cutting parameters of speed, feed and depth of cut were taken as inputs and machining was done by PVD TiAlN tool. Regression models for the responses were prepared by using MINITAB-16 software. Analysis of variance (ANOVA) was used to find the influence of machining parameters on the responses. From the ANOVA results, it is clear that speed has high influence followed by feed and depth of cut has very low influence in achieving the optimum values for both Material Removal Rate and Surface Roughness. Finally, experimental and Regression values of responses were compared. From the results, it is found that both the values are close to each other hence, the regression models prepared were more accurate and adequate. Percentage of errors between experimental and regression values were calculated and they found in the range of ±0.20.
Keywords-EN19 Steel, Taguchi, Regression Analysis, ANOVA, Surface Roughness.

I. INTRODUCTION

In present days, dry turning of steels is highly interested for industrial production & scientific research. Dry machining offers number of advantages over wet machining like lower equipment costs, shorter setup times, high accuracy, fewer process steps, good Surface finish, greater part geometry flexibility, no need of use cutting fluid hence reducing the Environmental pollution and health hazards. [1] Poor surface finish, tool wear rate, built-up-edge formation are the major problems encountered while machining of steels. Among all parameters surface quality has significant effect in estimating the productivity of machine tool and machined parts. The Surface Roughness also has a significant effect on surface friction, wearing, light reflection, ability of distributing and also holding a lubricant, load bearing capacity and resisting fatigue. Hence, to achieve a good surface quality the use of coated tools were introduced in the industrial application of modern coating technology. In the present study PVD coated carbide tool was used for machining of EN19 steel. The first PVD coating material on cutting tools was TiN in the early 1980s and since the 1990s most cutting tools are PVD coated, particularly in applications where sharp edges are required (threading, grooving, end-milling) and in cutting applications that have a high demand for a tough cutting edge (drilling). In solid carbide cutting tools PVD is the standard coating technology. The TiAlN PVD coating is currently the most widely deposited PVD coating for cutting tools. Advances in manufacturing technologies (increased cutting speeds, dry machining etc.) triggered the fast commercial growth of PVD coatings for cutting tools. PVD coatings on cutting tools have many applications like they can be run at high speeds hence reducing cycle times. They have resistant to all forms of wear hence, increasing the life of cutting tools and reduces tool-changing costs. PVD coatings are thin, typically 0.5 to 4 μm, thin feature in conjunction with close tolerances, means that the component retain its form, fit and dimensions after coating without the need of costly refinishing. PVD processes are environmentally benign and do not entail the use of emulsions or pollutants. The gases used in these processes are noble ones, as argon together with working gases such are hydrogen or acetylene, there will be no toxic reactions occurs while machining. Because of all these advantages, the PVD coated tools were used by many research scholars. [2]

Surface roughness most commonly refers to the variations in the height of the surface relative to reference plane. It is usually characterized by R_a- Centre-line-average (CLA) or Arithmetic average (AA), R_q- Standard deviation or variance (σ) or Root mean square (rms), Maximum peak-to-valley height (R_t or R_y or R_{max}), Average peak-to-valley height (R_z), Average peak-to-mean height (Rpm), Maximum valley depth (or) mean-to-lowest valley height (R_v), Skewness (S_k), kurtosis (K) etc. For complete characterization of a profile or a surface, none of the single parameter is sufficient. [3][4]

The selection of optimal process parameters using various optimization techniques helps to solve the problems of improper selection of process parameters. In general experimental design procedures are too complex and not easy to use. A large number of experimental works have to be carried out when the number of process parameters increases with their levels. To solve this problem, Taguchi has used a special design of orthogonal array to study the entire parameter space with a small number of experiments only. Taguchi method was universally accepted optimization technique and used by the scholars for their research works. [5] [6] the advantage of Taguchi method is to save the effort in performing experiments and experimentation time also to reduce the cost. To obtain optimum process parameters Taguchi suggested signal to noise (S/N) ratio, this ratio considers both the mean and variance. Taguchi has proposed three performance characteristics; they are Larger-the-better, lower-the-better and nominal-the-better. In the present work larger the better and lower the better characteristics were used for Material Removal Rate and Surface Roughness respectively.

Larger-the-better: S/N ratio = $-10 \log [1/ (MRR^2)]$

Lower-the-better: S/N ratio = $-10 \log [R_a^2]$

In the present work, EN19 medium carbon steel was turned on CNC lathe with PVD coated carbide tool. The work has been done to explore the effect of cutting parameters on Material Removal Rate and Surface Roughness. EN19 is a medium carbon steel, which has high industrial applications such as in tool, oil and gas industries. It is used for axial shafts, propeller shafts, crank shafts, high tensile bolts and studs, connecting rods, riffle barrels and gears manufacturing etc. A Number of research works has been done by many scholars on EN grade materials. [7][8] Surface Roughness parameters are very significant from contact stiffness, fatigue strength and surface wear. Taguchi's single objective method was used to find the optimum combination of machining parameters to achieve optimum output characteristics. Regression models were prepared for the prediction of responses. [9][10] The accuracy and adequacy of the regression models were checked by using Regression analysis and Analysis of variance (ANOVA). Finally, experimental and predicted values were compared and % errors between them were calculated. % Errors for predicted and experimental values are found in the range of 0.20.

II. EXPERIMENTAL DETAILS

For the experimentation EN19 (medium carbon steel) work pieces, each of 25 mm diameter and 75 mm length has been chosen. Before conducting the experimentation, 0.5mm of outer surface was removed from each work piece to eliminate surface defects if any. The experiments were performed on CNC lathe under dry environment using coated carbide tool. For the finished products Surface Roughness values are taken at three different locations by using SJ-301 (Mututoyo) gauge and the average value was taken. The chemical composition and mechanical properties of EN19 steel was given in tables 1 and 2.

Experimental conditions
Medium carbon steel EN19 (100mm L x 25mm Ø)
Machine used : CNC lathe (DX-200 turning centre)
Power : 20Kw, Spindle speed: 4000 rpm
Cutting tool : PVD TiAlN
Insert : CNMG 120408
Tool holder : PCLNR2525M12
Surface Roughness gauge: SJ-301 (Mututoyo)
Environment : Dry

Figure 2.1 Test specimen

Table 1 Chemical composition of Medium carbon steel (EN19)

Element	% weight
C	0.36-0.44
Si	0.1-0.35
Mn	0.7-1
Cr	0.9-1.2
Mo	0.25-0.35
S	0.035
P	0.040

Table 2 Mechanical properties of Medium carbon steel (EN19)

Property	Value
Density (g/cm3)	7.7
Tensile strength (N/mm2)	850-1000
Yield strength (N/mm2)	680
Elongation (%)	13
Hardness (BHN)	50
IZOD (J)	248-302

III. METHODOLOGY

In general, Material Removal Rate and Surface Roughness are mainly depends on cutting variables, tool variables and work piece variables. Among these, cutting variables includes speed, feed and depth of cut which can be manually adjustable. In present study, cutting variables are taken as inputs and tool variables and work piece variables are fixed. The selected cutting parameters and their levels were given in the table 3. The experiments were conducted as per Taguchi's L9 array given in the table 4. Taguchi single objective method was used to find the optimum parameters and their levels for the responses. Regression analysis was used for prediction of responses with the development of mathematical models. First order polynomials for the responses were prepared by using MINITAB-16 software. Regression analysis was done for finding the accuracy and adequacy of mathematical models. ANOVA was used to find the significance of parameters on the responses. Finally, experimental and regression values were compared.

First order polynomial model

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + \cdots + b_nx_n$$

Second order polynomial model

$$y = b_0 + \sum_{i=1}^{i=k} b_i x_i + \sum_{i\neq j=1}^{i\neq j=k} b_{ij}\, x_i x_j + \sum_{ii=1}^{ii=k} b_{ii} x_{ii}^2$$

Table 3 Selected process parameters and their levels

Process parameters	Unit	Levels		
		I	II	III
Speed (v)	m/min	75	150	225
Feed (f)	mm/rev	0.05	0.1	0.15
DOC (d)	Mm	0.2	0.3	0.4

Table 4 L9 Orthogonal array design

Run no.	Speed (v)	Feed (f)	Depth of cut (d)
1	75	0.05	0.2
2	75	0.1	0.3
3	75	0.15	0.4
4	150	0.05	0.3
5	150	0.1	0.4
6	150	0.15	0.2
7	225	0.05	0.4
8	225	0.1	0.2
9	225	0.15	0.3

IV. RESULTS AND DISCUSIONS

Taguchi method was widely used optimization technique. It is used to find the optimum parametric combination for the responses. To obtain optimum parametric combination, Taguchi has proposed a statistical measure of performance called Signal-to-Noise (S/N Ratio). S/N Ratio considers both mean and variance. Taguchi proposed three S/N ratio characteristics, Larger-the-better, Nominal-the-better and Lower-the-better. In the present work, Larger-the-better and Lower-the-better characteristics were used for Material Removal Rate and Surface Roughness analysis respectively. The experimental results of Material Removal Rate (MRR) and Surface Roughness (R_a) of each experiment and the corresponding S/N ratios were given in the tables 5 and 6.

Table 5 Experimental results of responses

Run no:	Experimental results of responses	
	MRR (cm^3/min)	R_a (μm)
1	0.75	2.8
2	2.25	3.4
3	4.5	4.2
4	2.25	1.8
5	6	2.2
6	4.5	2.9
7	4.5	0.6
8	4.5	0.8
9	10.125	1.6

Table 6 S/N ratios of responses

Run No:	S/N ratios of responses	
	MRR	R_a
1	-2.4988	-8.9432
2	7.0437	-10.6296
3	13.0643	-12.4650
4	7.0437	-5.1055
5	15.5630	-6.8485
6	13.0643	-9.2480
7	13.0643	4.4370
8	13.0643	1.9382
9	20.1079	-4.0824

4.1 Taguchi Analysis

In Taguchi's S/N ratio, the term signal represents desirable value and noise being undesirable and response considering highest S/N ratio is close to optimal. The mean S/N ratio values of Material Removal Rate were given in the table 7.

Table 7 Mean S/N ratio values of Material Removal Rate (MRR)

Process parameter	Mean S/N ratio				Rank
	Level -1	Level-2	Level-3	Max-min	
Cutting speed(v)	5.87	11.89	15.412	9.542	1
Feed(f)	5.87	11.89	15.412	9.542	2
Depth of cut(d)	7.877	11.398	13.897	6.021	3

Total mean S/N ratio= 11.057

From the mean S/N ratio values of Material Removal Rate main effect plot was drawn and shown in fig. 4.1.1. From the plot, it is clear that the main effect on the Material Removal Rate which is primarily due to cutting speed followed by feed as with an increase in the speeds and feed levels we can observe a significant change in response. The depth of cut is found to be least significant as the change in response with the increasing levels is comparatively less when compared to cutting speed and feed effects.

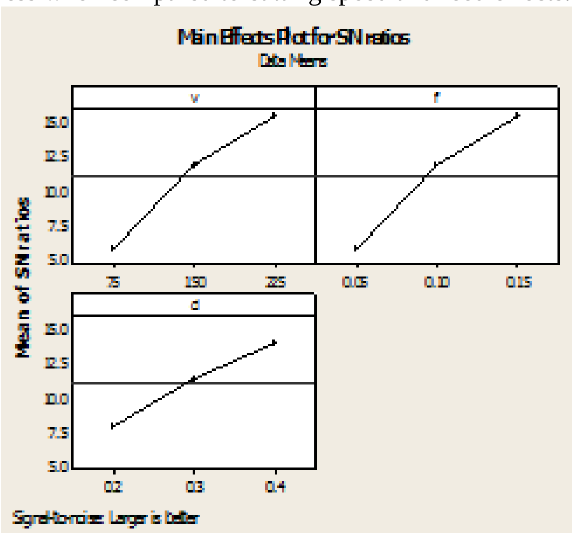

Figure 4.1.1 Main effect plot for S/N ratios of MRR

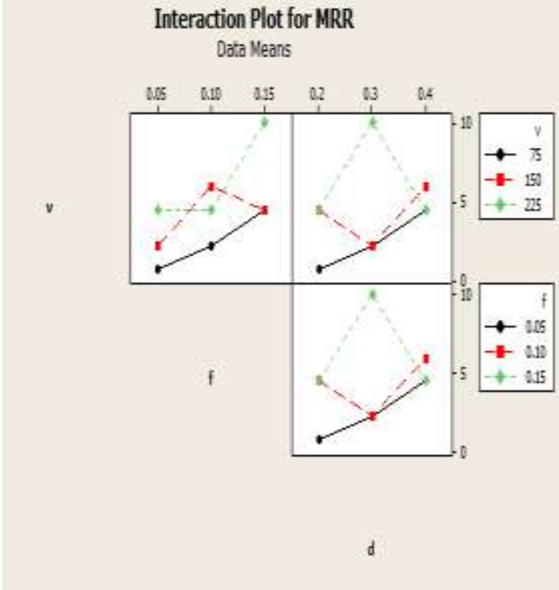

Figure 4.1.2 Interaction plot for MRR

Interactions among the machining parameters for Material Removal Rate were studied from the interaction plot drawn by using MINITAB-16 software. From the fig. 4.1.2 parallel lines represents there is no significant interaction between the machining parameters. Whereas crossed lines represents interaction between the parameters.

Table 8 Mean S/N ratio values of Arithmetic Surface Roughness Average (R_a)

Process parameter	Mean S/N ratio				Rank
	Level-1	Level-2	Level-3	Max-min	
Cutting speed(v)	-10.6792	-7.0673	0.7643	11.4435	1
Feed(f)	-3.2039	-5.1799	-8.5984	5.3946	2
Depth of cut(d)	-5.4176	-6.6058	-4.9588	1.6470	3

Total mean S/N ratio= -5.66

From, Table 8 Main effect plot for Surface Roughness was drawn and shown in fig.4.1.3. From the plot it is observed that the main effect on Surface Roughness is due to cutting speed. We can observe a significant change in Surface Roughness with the change in levels of cutting speed. Whereas Surface Roughness value is first decreased and then increased with the changes in levels of depth of cut. Interaction plot for the Surface Roughness was drawn and shown in fig.4.1.4.

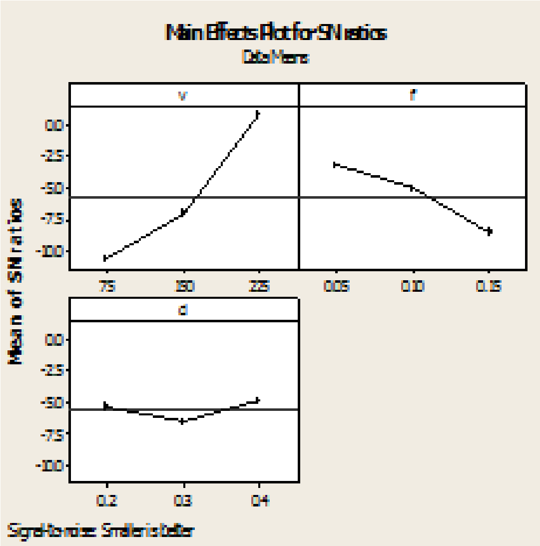

Figure 4.1.3 Main effect plot for S/N ratio of R_a

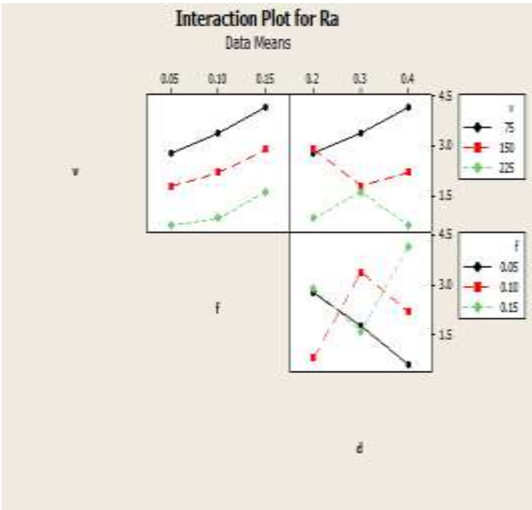

Figure 4.1.4 Interaction plot for R_a

Table 9 Optimum conditions using Taguchi method

S. No.	Parameter	Units	MRR		R_a	
			Best level	Value	Best level	Value
1	Speed(v)	m/min	3	225	3	225
2	Feed(f)	mm/rev	3	0.15	1	0.05
3	Depth of cut(d)	mm	3	0.4	3	0.4

4.2 Regression Analysis

Regression models for the responses were prepared by using the MINITAB-16 software and given below. The models prepared were more accurate and adequate because of their high value of Coefficient of determination (R^2) and Adjusted R^2 values.

MRR = -6+0.0258 v + 38.7 f + 8.75 d

S=0.128817; R-sq=85.7%; R-sq (adj) = 77.1%

R_a = 3.31 – 0.0164 v + 11.7 f + 0.833 d

S=0.135810; R-sq= 99.2%; R-sq (adj) = 98.7 %

Table 10 Regression analysis for Material Removal Rate (MRR)

Predictor	Coefficient	SE Coefficient	T	P
Constant	-6.000	2.210	-2.71	0.042
Cutting speed(v)	0.025833	0.007012	3.68	0.014
Feed(f)	38.75	10.52	3.68	0.014
Depth of cut(d)	8.750	5.259	1.66	0.157

S=0.128817; R-sq=85.7%; R-sq (adj) = 77.1%

Table 11 Regression analysis for Arithmetic Surface Roughness Average (R_a)

Predictor	Coefficient	SE Coefficient	T	P
Constant	3.3056	0.2330	14.1844	0.000
Cutting speed(v)	-0.016444	0.00073	-22.2445	0.000
Feed(f)	11.667	1.109	10.5211	0.000
Depth of cut(d)	0.8333	0.5544	1.5030	0.193

S=0.135810; R-sq= 99.2%; R-sq (adj) = 98.7 %

Regression analysis was done for both Material Removal Rate and Surface Roughness and given in the tables 10 and 11. From the tables it is found that the regression models for the responses were accurate and adequate because of their low variance (0.128817 for MRR, 0.135810 for R_a) and high R^2 (85.7% for MRR, 99.2% for R_a) and Adjusted R^2 (77.1% for MRR, 98.7 % for Ra) values.

4.3 ANOVA Results

Analysis of variance used to find the significance of machining parameters on responses. ANOVA for Material Removal Rate was given in the Table 12. From the table for MRR it is clear that cutting speed has high significance (F= 13.5734, P=0.014231<0.05) and depth of cut has low significance (F= 2.7684, P = 0.157029>0.05).

Table 12 Analysis of variance for MRR

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	3	49.6406	49.6406	16.5469	9.9718	0.014977
v	1	22.5234	22.5234	22.5234	13.5734	0.014231
f	1	22.5234	22.5234	22.5234	13.5734	0.014231
d	1	4.5937	4.5937	4.5937	2.7684	0.157029
Error	5	8.2969	8.2969	1.6594		
Total	8	57.9375				

ANOVA assumptions of Normality, Constant variance and independence were checked with residual plots drawn by using MINITAB-16 software. Residual plots for Material Removal Rate were drawn and shown in fig. 4.3.1, 4.3.2 and 4.3.3.

The normality can be checked with Normal probability plot. If the distribution of residuals is normal, then the plot will resembles a straight line i.e. maximum values of residuals will lies on (or) nearer to straight line. Constant variance, assumption can be checked with residual versus fitted values plot. The condition is that, there should be a random pattern of residuals on both sides of Zero and should not show any recognizable pattern. Independence assumption checked by drawing the residuals versus order plot. A positive correlation or a negative correlation means the assumption is violated. If the plot does not reveal any pattern, the independence assumption was assumed to be satisfied.

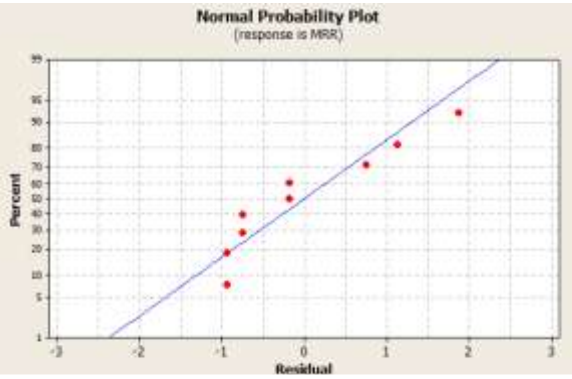

Figure 4.3.1 Normal probability plot for MRR

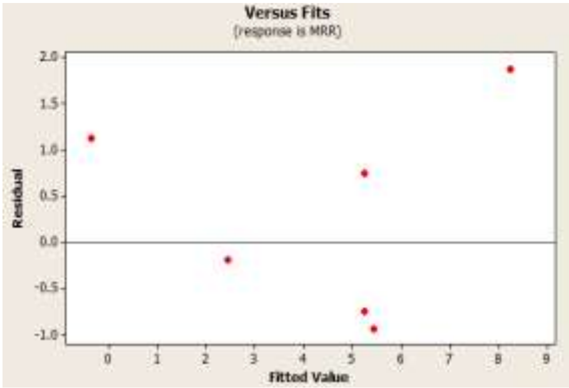

Figure 4.3.2 Residual versus fitted value plot for MRR

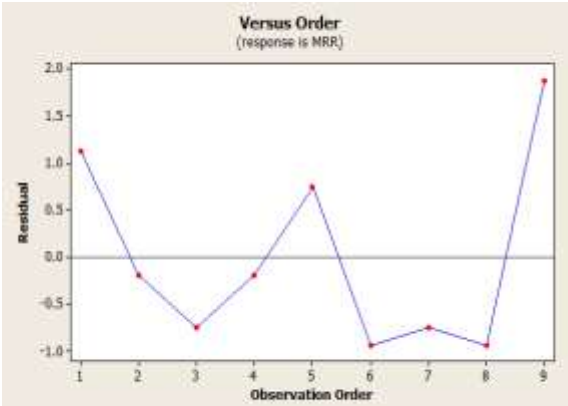

Figure 4.3.3 Residual versus order plot for MRR

ANOVA for Surface Roughness was given in the Table 13. From the table for Ra it is clear that cutting speed has high significance (F= 494.819, P=0.0000<0.05) and depth of cut has low significance (F= 2.259, P = 0.193156>0.05).

Table 13 Analysis of variance (ANOVA) for Arithmetic Surface Roughness Average (R_a)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	3	11.21	11.21	3.73667	202.590	0.000012
v	1	9.1267	9.1267	9.12667	494.819	0.000003
f	1	2.0417	2.0417	2.04167	110.693	0.000134
d	1	0.0417	0.0417	0.04167	2.259	0.193156
Error	5	0.0922	0.0922	0.01844		
Total	8	11.3022				

ANOVA assumptions of Normality, Constant variance and independence were checked with residual plots drawn by using MINITAB-16 software. The Normal probability, Residuals versus fitted values and Residuals versus order plots for Surface Roughness were drawn and shown in fig. 4.3.4, 4.3.5 and 4.3.6. From the plots of Surface Roughness it is clear that the residual analysis does not indicate any model inadequacy.

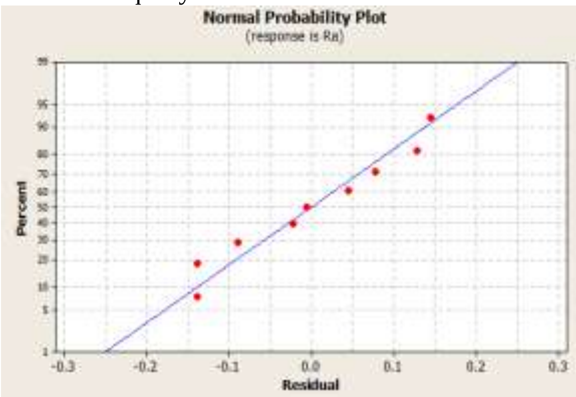

Figure 4.3.4 Normal probability plot for R_a

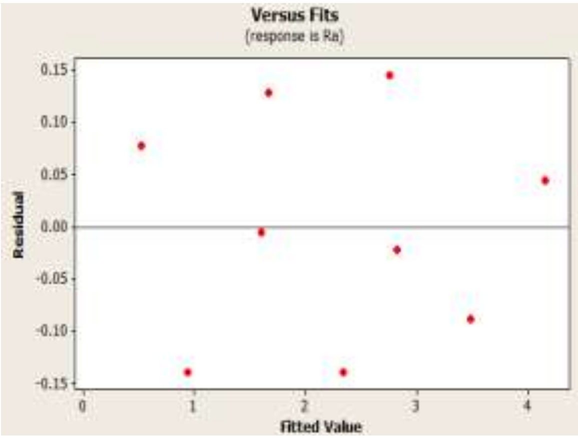

Figure 4.3.5 Residual versus fitted value plot for R_a

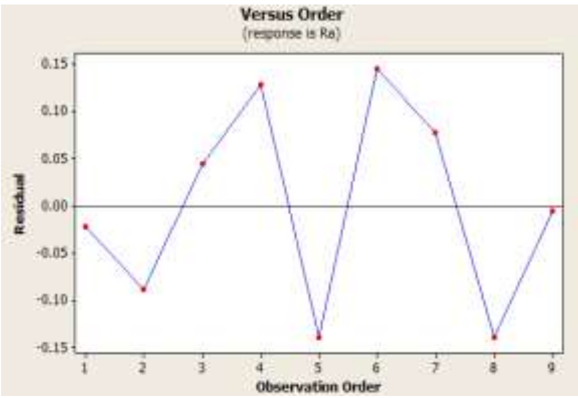

Figure 4.3.6 Residual versus order plot for R_a

4.4 Comparison between Experimental and Predicted Values of Responses

For the comparison of experimental and predicted values of responses, predicted values were calculated from the Regression models and given in table 14. From the results it is found that both experimental and predicted values are very close to each other. Thus the models developed using regression analysis can be utilized for accurate prediction of the responses. %Errors between experimental and predicted values of responses were given in the table 15. From the comparison graph for %errors of responses shown in fig.4.4.1, it is clear that most of the error values were within a range of ±0.20.

Table 14 Experimental and Predicted values of Responses

Run no.	Experimental Results (Actual)		Regression model results (Predicted)	
	MRR	R_a	MRR	R_a
1	0.75	2.8	0.38	2.83
2	2.25	3.4	2.43	3.5
3	4.5	4.2	5.24	4.17
4	2.25	1.8	2.43	1.68
5	6	2.2	5.24	2.35
6	4.5	2.9	5.42	2.77
7	4.5	0.6	5.24	0.54
8	4.5	0.8	5.42	0.96
9	10.125	1.6	8.23	1.62

Table 15 %Errors between Experimental and Predicted values of Responses

Run No	% of Error ((Actual-Predicted)/(Actual))*100	
	MRR	R_a
1	15.06	-1.13
2	-8.00	-2.94
3	-16.44	0.76
4	-8.00	6.39
5	12.67	-6.96
6	-20.56	4.43
7	-16.44	10.30
8	-20.56	-19.57
9	18.67	-1.56

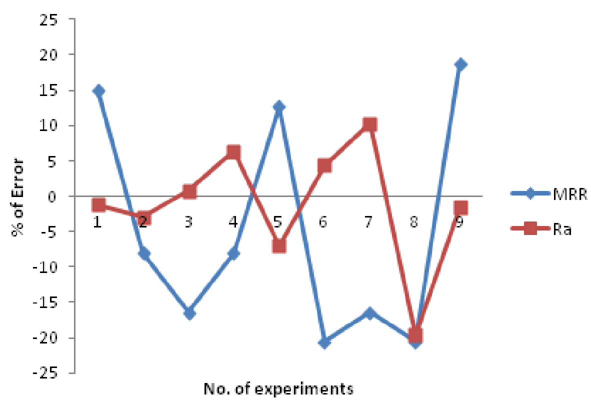

Figure 4.4.1 Comparison graph for % errors of Responses

V. CONCLUSIONS

Based on the experimental and predicted results obtained by Taguchi and Regression methods, the following conclusions can be drawn:

1. The Optimal combination of process parameters for obtaining high Material Removal Rate values at 225 m/min cutting speed, 0.15 mm/rev feed and 0.4 mm depth of cut.
2. The optimal combination of process parameters for obtaining low Surface Roughness values at 225 m/min cutting speed, 0.05 mm/rev feed and 0.4 mm depth of cut.
3. From ANOVA results it is clear that cutting speed is the most dominant parameter that has high influence on both MRR and R_a followed by feed and depth of cut has very low influence.
4. Regression models prepared were used for prediction of responses. The % errors between experimental and predicted values were within a range of ±0.20.

REFERENES

[1] Harish Kumar., mohd. Abbas., Dr. Aas Mohammad, Hasan Zakir Jafri., "optimization of cutting parameters in CNC turning"; *IJERA; ISSN:2248-9622; Vol.3, Issue3*, 2013, pp.331-334.

[2] M.Kaladhar et.al. "Determination of Optimal Process parameters during turning of AISI304 Austenitic Stainless Steel using Taguchi method and ANOVA", *International Journal of Lean Thinking, Volume 3, Issue 1*, 2012.

[3] IIhan Asilturk., Harun Akkus., "Determining the effect of cutting parameters on surface roughness in hard turning using the Taguchi method"; *Elsvier Journal, Measurement 44*, pp.1697-1704,2011.

[4] Sunil J Raykar, D.M.Daddona, Davorin Kramar; "Analysis of surface topology in dry machining of EN-8 steel" *Elsvier journal, procedia material science 6* (2014) 931-938.

[5] M.Nalbant, H.Gokkayya & G.Sur, "application of taguchi method in the optimization of cutting parameters for surface roughness in turning", *Elsevier Journal, Measurement 44*, pp. 1379-1385, 2007.

[6] Upinder Kumar Yadav., Deepak Narang., Pankaj Sharma Attri., "Experimental Investigation and optimization of machining parameters for surface roughness in CNC turning by Taguchi method"; *IJERA; ISSN:2248-9622; Vol.2, Issue4*, 2012, pp.2060-2065.

[7] H.K.Dave et.al. "Effect of machining conditions on MRR and Surface Roughness during CNC Turning of different materials using TiN Coated Cutting Tools by Taguchi method", *International Journal of Industrial Engineering Computations 3*, pp. 925-930, 2012.

[8] Harish singh & Pradeep kumar, "optimizing feed force for turned parts through the Taguchi technique", *Sadana vol.31, part 6*, pp. 671-681, 2006.

[9] Gaurav Bartarya, S.K.Choudhury; "Effect of cutting parameters on cutting force and surface roughness during finish hard turning AISI52100 grade steel", *Elsvier journal, procedia CIRP 1* (2012) 651-656.

[10] Gokulachandran.J, Mohandas. K; "Application of regression and fuzzy logic method for prediction of tool life"; *Elsvier journal, procedia engineering 38* (2012) 3900-3912.

[11] Chou,Y.K., and Song, H. "Tool nose radius effects on surface finish in hard turning", *Journal of materials processing technology, 148(2)*, 2004, 259-268.

[12] N.E. Edwin Paul, P. Marimuthu, R.Venkatesh Babu; "Machining parameter setting for facing EN 8 steel with TNMG Insert"; *American International Journal of Research in Science and Technology, Engineering & Mathematics, 3(1)*,pp.87-92,2013.

[13] Gopalaswamy B.M., Mondal B. And Ghosh S., "Taguchi method and ANOVA: An approach for process parameters optimization of hard machining while machining hardened steel", *Journal of Scientific and Industrial Research, vol.68*, pp.686-695, 2009.

[14] Mahapatra, S.S. et al. "Parametric analysis and Optimization of cutting parameters for turning operations based on Taguchi method", *Proceedings of the International Conference on global Manufacturing and Innovation, Coimbatore, India*, 2006; 1-8.

[15] Thamizhmanii, S., Saparudin, S., and Hasan, S. "Analysis of Surface Roughness by turning process using Taguchi method". *Journal of Achievements in Materials and Manufacturing, vol. 20(1-2)*, pp. 503-506, 2007.

[16] Jitendra varma, PankajAgarwal& Lokesh Bajpai, "Turning parameter optimization for surface roughness of ASTM A242 type-1 alloy steel by taguchi method", *International Journal of Advances in Engineering & Technology*, March 2012.