Application of TQL and AHP for the Optimization of Multiple Performance Characteristics

B.Krishna Prafulla*, Rajulapati Ganesh, Ch.Maheswara Rao
Assistant Professor, Department of Mechanical Engineering, ANITS, VSP-531162, A.P., India
B.E., Department of Mechanical Engineering, ANITS, VSP-531162, A.P., India
Assistant Professor, Department of Mechanical Engineering, ANITS, VSP-531162, A.P., India
bkprafulla@gmail.com

Abstract

In the present work the influence of turning process parameters on the multiple performance characteristics were studied using a multi-objective optimization technique called Taguchi Quality Loss (TQL) method. The experiments were conducted on EN19 steel by taking speed, feed and depth of cut at three different levels (L9 OA) using Conventional lathe. For assigning the weights to the responses Analytical Hierarchy Process (AHP) has been employed. Finally the optimization results were verified with the Taguchi and Regression Analysis and the significance of process parameters was tested by Analysis of Variance (ANOVA).

Keywords: Material Removal Rate (MRR), Surface Roughness (R_a and R_z), Taguchi Total Quality Loss Method, ANOVA and Regression Analysis.

1. Introduction

In any machining processes, Material removal rate and surface roughness serves as the two deciding performance attributes for production rate and quality aspects respectively. Surface roughness is measured as a deflection from the mean line. It is a critical quality attribute of machined parts as it affects the appearance, wear resistance, ductility, tensile and fatigue strengths etc. There are numerous factors which influence the roughness characteristics like cutting parameters (speed, feed and depth of cut), tool nomenclature and work piece properties. From the ancient days, the researchers were working for setting of process parameters which provides optimal results for more than one characteristic at a time. But, in real practices achieving of one attribute may affects the other. To overcome this taguchi has developed a new design called orthogonal array which covers the entire parametric space with a very less number of experiments and there by reduces the total experimentation cost and time effectively. In the present work, Taguchi's total quality loss method has been employed for analyzing the multiple responses and the significant test is conducted with the help of Analysis of variance.

2. Experimental Details

The specimens of EN19 steel in cylindrical form are machined on conventional lathe. The chemical and mechanical properties of EN19 steel are given in the tables 1 and 2. For conducting the experiments; speed, feed and depth of cut are considered as process parameters at three different levels as given in table 3. Taguchi's standard L9 Orthogonal array shown in table 4 has been followed for conducting the experiments.

Table 1. Chemical Properties of EN19 Steel

C	Si	Mn	Cr	Mo	S	P
0.36-0.44	0.1-0.35	0.70-1	0.9-1.20	0.25-0.35	0.035 max	0.040 max

Table 2. Mechanical Properties of EN19 Steel

Density (gm/cm3)	UTS (N/mm^2)	Yield strength (N/mm^2)	Elongation (%)	Hardness (BHN)
7.7	850-1000	680	13	248-302

Table 3. Cutting Parameters and Their Levels

Parameter	Level-1	Level-2	Level-3
Speed (m/min)	100	175	250
Feed (mm/rev)	0.1	0.15	0.2
Depth of cut (mm)	0.4	0.6	0.8

Table 4. L9 OA with Actual Experiments

S.No.	s (rpm)	f (mm/rev)	d (mm)
1	100	0.1	0.4
2	100	0.15	0.6
3	100	0.2	0.8
4	175	0.1	0.6
5	175	0.15	0.8
6	175	0.2	0.4
7	250	0.1	0.8
8	250	0.15	0.4
9	250	0.2	0.6

3. Methodology

In recent days the manufacturers are interested in achieving the several performance characteristics at a time rather to achieve one. Though many multi objective optimization methods are avail, Taguchi quality loss (L_{ij}) method has been employed for the present work as it involves in very less computational procedure and the results were highly accurate as compared with other. The procedural steps are as follows:

Step1: Taguchi quality loss (L_{ij}) for the responses.
$L_{ij} = Y_{ij}^2$ for lower the better (LB)…………….Eq.(1)
$L_{ij} = 1/Y_{ij}^2$ for higher the better (HB)…………Eq.(2)
Step2: Normalization of the responses.
$N_{ij} = L_{ij}/L^*$..Eq.(3)
Where, $L^* = \max L_{ij}$
Step 3: Calculation of total loss function.
$T_{ij} = (1/n) \sum_{i=1}^{n} W_i N_{ij}$…………………………..Eq.(4)
Where,
W is weights of the responses such that $\sum W_i = 1$
Step 4: Finding the optimum parametric levels and their significances using Taguchi and ANOVA.

4. Results and Discussions

The output responses of the material removal rate and surface roughness characteristics were given in the table 5. The AHP results obtained are mentioned in the table 6 and the weights are obtained as W_{MRR} = 0.751, W_{Ra} = 0.178 and W_{Rz} = 0.07 respectively.

Table 5. Experimental Results

S.No.	MRR (Cm^3/min)	R_a (µm)	R_z (µm)
1	4	4.03	13.71
2	9	5.12	15.06
3	16	6.57	21.27
4	10.5	3.93	12.84
5	21	4.83	15.80
6	14	5.87	19.57
7	20	3.21	13.31
8	15	3.96	14.36
9	30	5.91	18.36

Table 6. AHP Results

	MRR	R_a	R_z	e
MRR	1	5	9	0.751
R_a	0.2	1	3	0.178
R_z	0.11	0.33	1	0.07

λ_{max} = 3.029, CR = 0.03

The taguchi quality loss values for the individual responses of material removal rate and surface roughness were calculated using the Higher-the-better and Lower-the-better characteristics as given in equations 1 and 2 and the results were shown in the table 7.

Table 7. Quality Loss (L_{ij}) Values of the Responses

S.No	MRR	R_a	R_z
1	0.0625	16.2409	187.9641
2	0.0123	26.2144	226.8036
3	0.0039	43.1649	452.4129
4	0.0091	15.4449	164.8656
5	0.0023	23.3289	249.64
6	0.0051	34.4569	382.9849
7	0.0025	10.3041	177.1561
8	0.0044	15.6816	206.2096
9	0.0011	34.9281	337.0896

The quality loss values obtained were normalized using the equation 3 to reduce the variability and are given in the table 8. From the normalized values the total quality loss (T_{ij}) values were calculated using equation 4 and the corresponding Signal-to-Noise (S/N) ratios were given in the table 9.

Table 8. Normalized (N_{ij}) Values of Responses

S.No.	MRR	R_a	R_z
1	1	0.3763	0.4155
2	0.1975	0.6073	0.5013
3	0.0625	1	1
4	0.1451	0.3578	0.3644
5	0.0363	0.5405	0.5518
6	0.0816	0.7983	0.8465
7	0.0400	0.2387	0.3916
8	0.0711	0.3633	0.4558
9	0.0178	0.8092	0.7451

Table 9. Total Quality Loss function and S/N of T_{ij}

S.No.	T_{ij}	S/N of T_{ij}
1	0.2824	10.9842
2	0.0972	20.2485
3	0.0983	20.1478
4	0.0661	23.6009
5	0.0540	25.3481
6	0.0876	21.1547
7	0.0333	29.5475
8	0.0500	26.0219
9	0.0698	23.1170

Taguchi analysis was employed for the total quality loss values obtained in table 9 and the effect of cutting parameters on the multi response was observed. From the results of table 10, the main effects plot was drawn and shown in the figure 1. From the figure, it is clear that the speed is the most affecting factor on the total quality loss (T_{ij}) followed by depth of cut and feed respectively. The optimum levels of cutting parameters are found at 100 m/min, 0.15 mm/rev and 0.4 mm.

Table 10. Response Table for Signal to Noise Ratios

Level	S	f	D
1	0.15928	0.12724	0.13997
2	0.06921	0.06707	0.07770
3	0.05105	0.08524	0.06188
Delta	0.10823	0.06018	0.07808
Rank	1	3	2

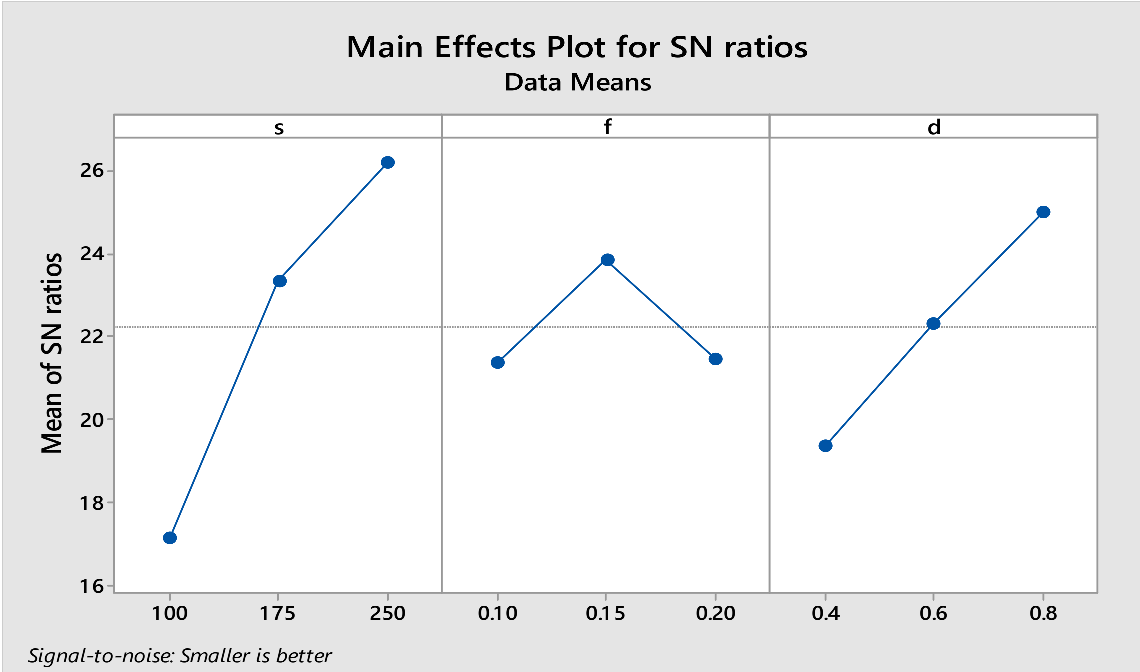

Figure 1. Main Effect Plot for S/N ratios of T_{ij}

4.1. Regression Analysis

The regression analysis has been conducted to predict the multi response value at the optimum levels of the cutting parameters. The relation between the cutting parameters and the multi response value (T_{ij}) is as given below.

The regression equation is

T_{ij} = 0.400 - 0.000722 s - 0.420 f - 0.195 d

Table 11 shows the regression analysis of total quality loss (T_{ij}). From the results of ANOVA shown in the table 12 it is clear that the model is best fit with the cutting parameters.

Table 11. Regression Analysis

Predictor	Coef	SE Coef	T	P
Constant	0.400	0.109	3.67	0.014
s	-0.000722	0.000296	-2.44	0.059
f	-0.420	0.444	-0.95	0.387
d	-0.195	0.111	-1.76	0.139

Table 12. Analysis of Variance

Source	DF	Adj SS	Adj MS	F	P
Regression	3	0.029362	0.009787	3.32	0.115
S	1	0.017571	0.017571	5.95	0.059
F	1	0.002647	0.002647	0.90	0.387
D	1	0.009145	0.009145	3.10	0.139
Error	5	0.014760	0.002952		
Total	8	0.044122			

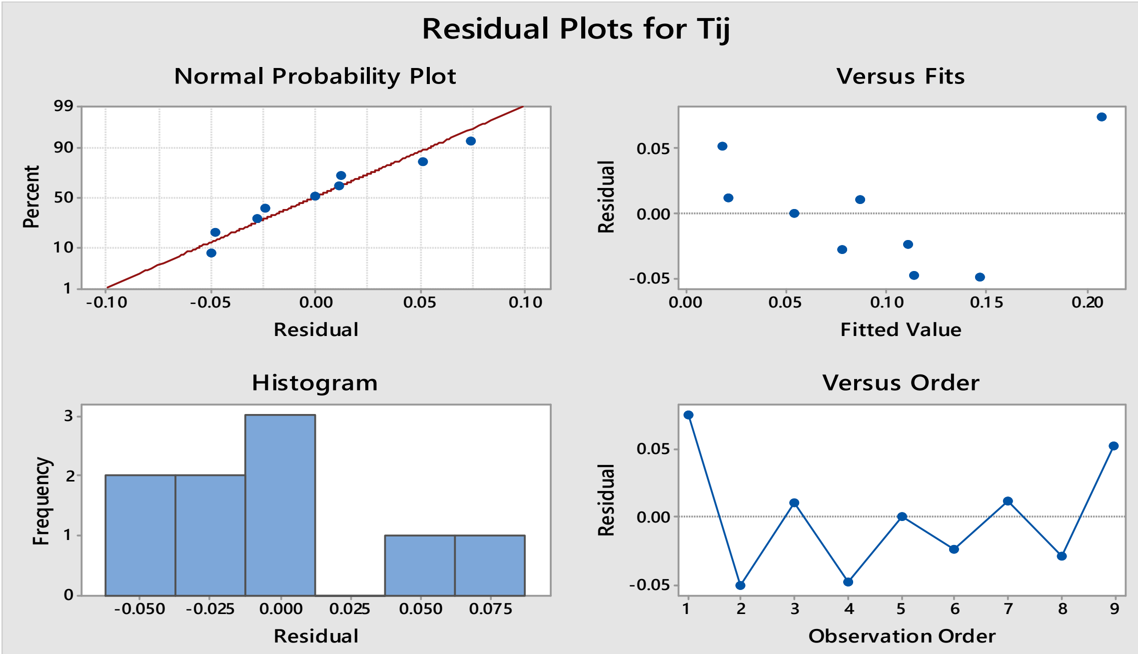

Figure 2. Residual Plots for T_{ij}

Figure 2 shows, the residual plots of T_{ij} and it is showing that the residuals are following the normal distribution and the model is not following any regular pattern hence the model is more accurate and adequate. Contour plots for the total quality loss (T_{ij}) against the process parameters were drawn and shown in the figures 3-5. From the contour plots, it is clear that the optimal regions for achieving the maximum material removal rate and minimum roughness characteristics simultaneously are found at low levels of speed and depth of cut and at moderate levels of feed respectively.

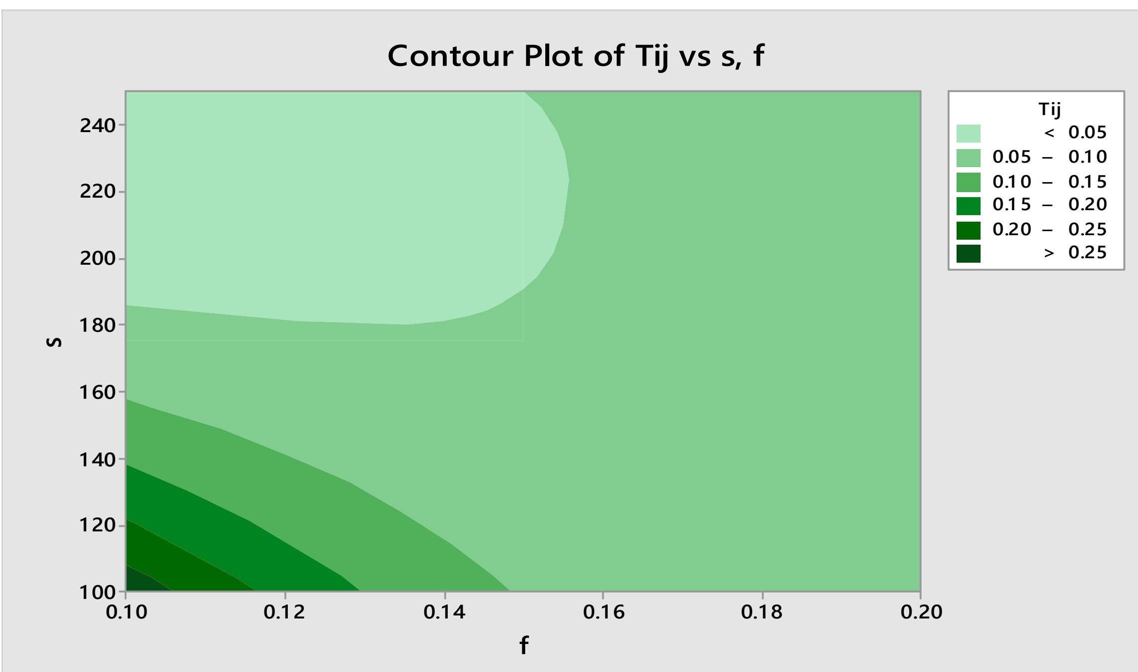

Figure 3. Contour Plot of T_{ij} Vs s,f

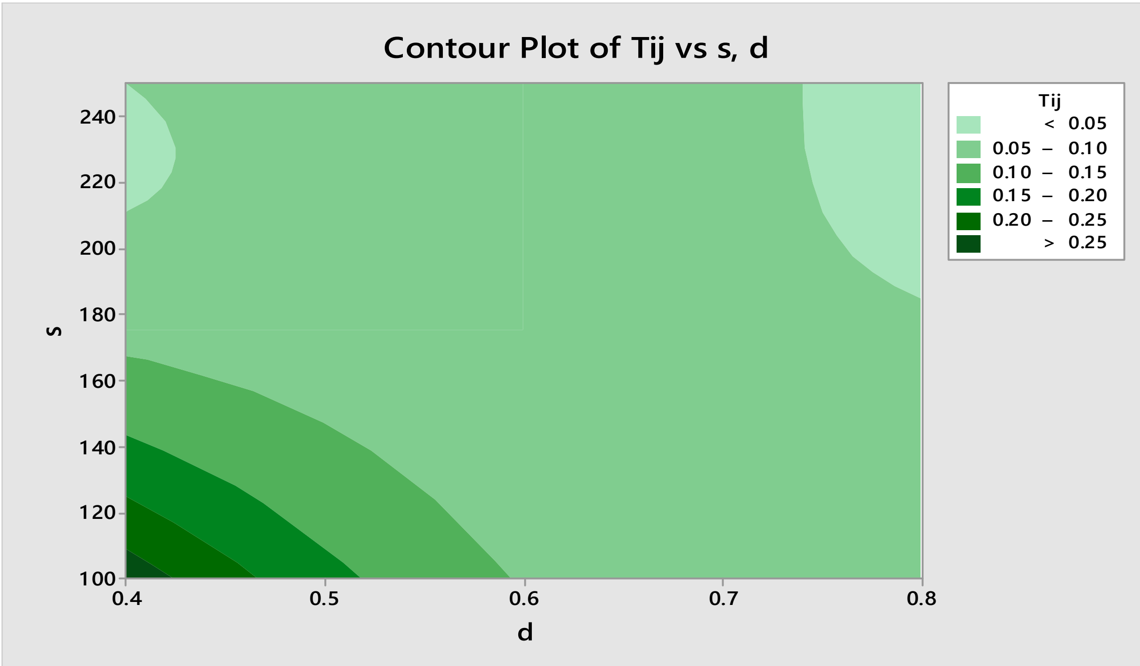

Figure 4. Contour Plot of T_{ij} Vs s,d

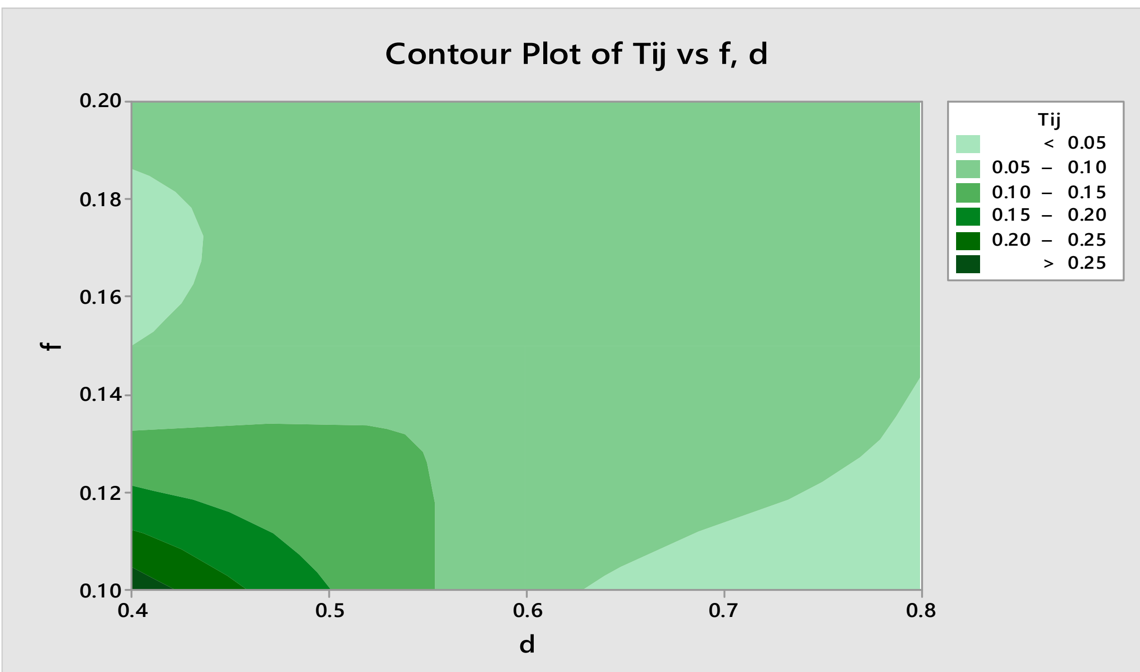

Figure 5. Contour Plot of T_{ij} Vs f,d

5. Conclusions

- The optimal combination for achieving the maximum material removal rate and minimum surface roughness is obtained at 100 m/min of speed, 0.15 mm/rev of feed and 0.4 mm of depth of cut respectively.
- The results of ANOVA concluded that speed is the most influencing parameter in affecting the multi response and followed by depth of cut and feed.
- The regression model prepared for the multi response values is best fit and is more accurate in prediction of the response.
- The proposed method can be effectively used for all industrial multi objective problems and involves in less computations compared to other multi objective optimization methods.

References

[1] M. Kumar Sorabh and N. Nirmal, “A Literature Review on Optimization of Machining Parameters in Wire EDM”, International Journal of Latest Research in Science and Technology, vol. 2, no. 1, (2013), pp. 492.

[2] V. Muthu Kumar, A. Suresh Babu, R. Venkata Swamy and M. Raajenthiren, “Optimization of the WEDM Parameters on Machining Incoloy 800 Super Alloy with Multiple Quality Characteristics”, International Journal of Science and Technology, vol. 2, no. 6, (2010), pp. 1538.

[3] S. J. Raykar, D. M. Daddona and D. Kramar, “Analysis of Surface Topology in Dry Machining of EN-8 steel”, Elsvier Journal, Procedia Material Science, vol. 6, (2014), pp. 931-938.

[4] H. Kumar, M. Abbas, Aas Mohammad and H. Zakir Jafri, “Optimization of Cutting Parameters in CNC turning”, IJERA, ISSN: 2248-9622, vol. 3, no. 3, (2013), pp. 331-334.

[5] H. Singh and P. Kumar, “Optimizing Feed Force for Turned Parts Through the Taguchi Technique”, Sadana, vol. 31, no. 6, (2006), pp. 671-681.

[6] S. S. Chaudhari, S. S. Khedka and N. B. Borkar, “Optimization of Process Parameters Using Taguchi Method Approach with Minimum Quantity Lubrication for Turning”, International Journal of Engineering Research and Applications, vol. 4, (2011), pp. 1268.

[7] D. Selvaraj and P. Chandarmohan, “Optimization of Surface Roughness of AISI304 Austenitic Stainless Steel in Dry Turning Operation Using Taguchi Design Method”, Journal of Engineering Science and Technology, vol. 5, no. 3, (2010), pp. 293-301.

[8] K. Kanlayasiri and S. Boonmung, ‘‘Effects of Wire- EDM Machining Variables on Surface Roughness of Newly Developed DC 53 Die Steel: Design of Experiments and Regression Model’’, Journal of Materials Processing Technology, vol. 192-193, (2007), pp. 459-464.

[9] Ch. Maheswara Rao, K. Venkata Subbaiah and K. Sowjanya, “Influence of Speed, Feed and Depth of cut on Multiple Responses in CNC Turning”, International Journal of Advanced Science and Technology, Vol-92, 2016, pp.59-76.

[10] J. Varma, P. Agarwal and L. Bajpai, “Turning Parameter Optimization for Surface Roughness of ASTM A242 type-1 Alloy Steel by Taguchi Method”, International Journal of Advances in Engineering & Technology, (2012) March.

[11] N. E. Edwin Paul, P. Marimuthu and 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, vol. 3, no. 1, (2013), pp. 87-92.

[12] Ch. Maheswara Rao and K. Venkata Subbaiah, “Optimization of Surface Roughness in CNC Turning Using Taguchi method and ANOVA”, International Journal of Advanced Science and Technology, Vol-93, 2016, pp.1-14.

[13] S. Thamizhmanii, S. Saparudin and S. Hasan, “Analysis of Surface Roughness by Turning Process Using Taguchi Method”, Journal of Achievements in Materials and Manufacturing, vol. 20, no. 1-2, (2007), pp. 503-506.

[14] I. Asilturk and H. Akkus, “Determining the Effect of Cutting Parameters on Surface Roughness in Hard Turning Using Taguchi Method”, Measurement, vol. 44, (2011), pp. 1697-1704.

[15] B. M. Gopalaswamy, B. Mondal and S. Ghosh, “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, (2009), pp. 686-695.

[16] Ch. Maheswara Rao, K. Venkatasubbaiah and K. Jagadeeswara Rao, “Experimental Investigation of Surface Roughness Characteristics Ra, Rq and Rz”, International Journal of Hybrid Information Technology, vol.9, no.7, 2016, pp.373-388.