Simultaneous Optimization of Roughness Parameters using TOPSIS

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Abstract- *The present work is to explore the effect of EDM process parameters on the surface roughness characteristics R_a, R_q and R_z. For the experimentation, twenty seven alternatives of EDM process parameters, Pulse on time (T_{ON}), Pulse off time (T_{OFF}), Wire Tension (WT) and Wire Feed (WF) were considered as per the Taguchi's standard L27 Orthogonal Array. The Roughness characteristics of Arithmetic average (R_a), Geometric average (or) RMS value (R_q) and Ten point height average (R_z) were considered as the experimental responses. Multi-criterion decision making method, TOPSIS has been employed for the optimization of responses simultaneously. From the TOPSIS and main effect plots for Signal-to-Noise ratios of the relative closeness coefficient (C_i^+), the optimal combination of the multi responses was found at twenty second alternative, i.e. Pulse on time (T_{ON}): 131µs, Pulse off time (T_{OFF}): 58µs, Wire Tension (WT): 2 Kgf and Wire Feed (WF): 4 m/sec. Analysis of variance (ANOVA) was applied using the MINITAB-16 software to know the influence of EDM process parameters on the relative closeness coefficient (C_i^+). From the results of ANOVA, it is clear that, Wire Feed (WF) has high influence (F = 30.38) and Pulse off time (T_{OFF}) has low influence (F = 1.00) in affecting the multi-responses.*

Key words- *Arithmetic Average Roughness (R_a), Geometric Average Roughness (R_q), Ten Point Height Average Roughness (R_z), TOPSIS and ANOVA.*

I. INTRODUCTION

Electro Discharge Machining (EDM) is an un-conventional machining process which has the ability to machine hard, difficult-to-machine materials and the parts with complex internal shapes by using precisely controlled sparks. EDM process has wide applications in aerospace, nuclear and automotive industries to machine precise, complex and irregular shapes. The Surface Roughness characteristics R_a, R_q and R_z are very significant parameters from contact stiffness, fatigue strength and surface wear point of view of machined parts. Arithmetic average roughness or central line average (CLA) is defined as the average values of ordinates from the mean line and its value can be measured using $R_a = \frac{1}{n}\sum_{i=1}^{n}|Y_i|$ where, Y_i is the deviation value, n is the total number of deviations. Geometric average roughness or Root mean square value (RMS) is defined as the square root of the arithmetic mean of the values of the squares of the ordinates of the surface measured from a mean line and it can be measured using $R_q = \sqrt{\frac{1}{n}\sum_{i=1}^{n} Y_i^2}$. Similarly, Ten point height average roughness (R_z) is defined as the average difference between the five highest peaks and five lower valleys of the surface texture within the sampling length, it can be measured using $R_z = \frac{1}{5}\sum_{i=1}^{5} R_{pi} - R_{vi}$, where, R_{pi} and R_{vi} are the Ith highest peak and lowest valleys respectively.

The Multi-criteria decision making method, TOPSIS was developed by Hwang and Yoon in 1980. It has high industrial applications and used for solving the various decision-making problems. The basic concept of this method is that the selected alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution in any geometrical sense. The TOPSIS method assumes that each criterion has a tendency of monotonically increasing or decreasing utility. Therefore, it is easy to define the positive ideal and negative-ideal solutions. The Euclidean distance approach was proposed to evaluate the relative closeness of the alternatives to the ideal solution. Thus, the preference order of the alternatives can be derived from a series of comparisons of these relative distances. The TOPSIS method first converts the various criteria, dimensions into non-dimensional criteria. Generally A^+ indicates the most preferable alternative or the ideal solution. Similarly, alternative A^- indicates the least preferable alternative or the negative ideal solution. The relative importance or weight of a criterion indicates the priority assigned to the criterion by the decision-maker while ranking the alternatives in a Multi criteria Decision-Making (MCDM) environment. The Entropy Method estimates the weights of the various criteria from the given payoff matrix and is independent of the views of the decision-maker. This method is particularly useful to explore contrasts between sets of data. These sets of data can be mapped as a set of alternative solutions in the payoff matrix where each alternative solution is evaluated in terms of its outcome. The philosophy of this method is based on the amount of information available and its relationship with the importance of the criterion. If the entropy value is high, the uncertainty contained in the criterion vector is high, diversification of the information is low and correspondingly the criterion is less important. This method is advantageous as it reduces the burden of the decision-maker for large sized problems.

In the present work, an investigation has been done to explore the effect of EDM process parameters like Pulse on time (T_{ON}), Pulse off time (T_{OFF}), Wire tension (WT) and Wire feed (WF) on the Surface Roughness characteristics (R_a, R_q and R_z). A series of experiments were conducted on EN8 steel using EDM as per the Taguchi's L27 Orthogonal Array. The multi-criteria decision making method, TOPSIS has been adopted for the simultaneous optimization of the responses. The effect of EDM process parameters on the multi-responses were studied using the Main effect plots drawn for the relative closeness coefficient (C_i^+) values using the MINITAB-16 software. ANOVA has been applied to know the influence of EDM process parameters on the Relative closeness coefficient (C_i^+) values.

II. EXPERIMENTAL SETUP

In the present work, the work pieces of a medium carbon steel EN8 have been machined using CNC EDM (ULTRACUT, ELPULS 50f). Twenty seven alternatives of EDM process parameters, Pulse on time (T_{ON}), Pulse off time (T_{OFF}), Wire tension (WT) and Wire feed (WF) were used for the analysis of multiple responses as per the Taguchi's standard L27 Orthogonal Array. The Experimental alternatives of EDM process parameters were given in the table 1.

Table 1. Experimental alternatives

Run No. (Alternatives)	T_{ON}	T_{OFF}	WT	WF
A-1	115	53	2	4
A-2	115	53	3	5
A-3	115	53	4	6
A-4	115	58	2	5
A-5	115	58	3	6
A-6	115	58	4	4
A-7	115	63	2	6
A-8	115	63	3	4
A-9	115	63	4	5
A-10	123	53	2	5
A-11	123	53	3	6
A-12	123	53	4	4
A-13	123	58	2	6
A-14	123	58	3	4
A-15	123	58	4	5
A-16	123	63	2	4
A-17	123	63	3	5
A-18	123	63	4	6
A-19	131	53	2	6
A-20	131	53	3	4
A-21	131	53	4	5
A-22	131	58	2	4
A-23	131	58	3	5
A-24	131	58	4	6
A-25	131	63	2	5
A-26	131	63	3	6
A-27	131	63	4	4

III. METHODOLOGY

TOPSIS decision making method is a technique introduced by Yoon and Hwang. It is a worldwide accepted approach to finding the best alternative that is closest to the ideal solution. The basic principle in this method is that chosen alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS). The TOPSIS procedure is as follows.

Step1: Determination of weights corresponds to each response (w_i)
Step2: Determination of the Normalized decision making matrix (r_{ij})
Step3: Construction of a weighted normalized decision matrix (V_{ij})
Step4: Determination of Positive ideal solution (PIS) and Negative ideal solutions (NIS)
Step5: Determination of the separation values from the PIS and NIS
Step6: Determination of the relative closeness to the ideal solutions and corresponding Signal to noise (S/N) ratios
Step7: Rank the alternatives in descending order of C_i^+.

IV. RESULTS AND DISCUSSIONS

The criteria values of Arithmetic average Roughness (R_a), Geometric average Roughness (R_q) and Ten point height average Roughness (R_z) measured for the twenty seven alternatives using SJ-301 gauge (Mitutoyo) were given in the table 2.

Table 2. Experimental results

Run No. (Alternatives)	Criteria		
	R_a	R_q	R_z
A-1	2.5	2.7	9.9
A-2	5.1	4.4	21.5
A-3	7.2	6.8	26.3
A-4	4.3	4.8	18.0
A-5	6.1	5.8	23.9
A-6	3.0	3.7	13.1
A-7	7.1	6.0	27.8
A-8	4.2	4.1	15.9
A-9	5.2	5.8	22.1
A-10	3.7	2.7	15.1
A-11	7.5	7.0	28.9
A-12	3.2	3.6	13.0
A-13	4.3	4.1	16.4
A-14	3.2	2.5	11.9
A-15	5.7	5.3	21.1
A-16	2.8	2.5	10.7
A-17	4.2	5.1	17.1
A-18	6.9	5.7	28.3
A-19	5.5	5.3	19.3
A-20	3.5	3.1	13.7
A-21	4.9	5.1	19.2
A-22	2.3	2.0	9.4
A-23	3.8	3.3	15.8
A-24	6.3	6.0	23.4
A-25	4.2	4.7	16.5
A-26	5.1	4.3	21.7
A-27	3.7	3.6	13.6

Step1. Calculation of weights using Entropy method

The normalized values of criteria's were given in the table 3.

Table 3. Normalized values of criteria

Run No. (Alternatives)	R_a	R_q	R_z
A-1	0.01992	0.0225	0.02005
A-2	0.04063	0.03666	0.04355
A-3	0.05737	0.05666	0.05328
A-4	0.03426	0.04	0.03646
A-5	0.04860	0.04833	0.04841
A-6	0.02390	0.03083	0.02653
A-7	0.05657	0.05	0.05632
A-8	0.03346	0.03416	0.03221

A-9	0.04143	0.04833	0.04477
A-10	0.02948	0.0225	0.03059
A-11	0.05976	0.05833	0.05854
A-12	0.02549	0.03	0.02633
A-13	0.03426	0.03416	0.03322
A-14	0.02549	0.02083	0.02410
A-15	0.04541	0.04416	0.04274
A-16	0.02231	0.02083	0.02167
A-17	0.03346	0.0425	0.03464
A-18	0.05498	0.0475	0.05733
A-19	0.04382	0.04416	0.03910
A-20	0.02788	0.02583	0.02775
A-21	0.03904	0.0425	0.03889
A-22	0.01832	0.01666	0.01904
A-23	0.03027	0.0275	0.03200
A-24	0.05019	0.05	0.04740
A-25	0.03346	0.03916	0.03342
A-26	0.04063	0.03583	0.04396
A-27	0.02948	0.03	0.02755

The output entropy and weights for the criteria's were calculated and the values were given in the table 4.

Table 4. Weights of criteria's from entropy method

Criteria	R_a	R_q	R_z
W_j	0.04167	1.02250	-0.06416

Step2. The Normalized decision making matrix (r_{ij}) values were given in the table 5.

Table 5. Normalized Decision Matrix (r_{ij})

Run No. (Alternatives)	R_a	R_q	R_z
A-1	0.09869	0.11182	0.09964
A-2	0.20133	0.18223	0.21639
A-3	0.28423	0.28162	0.26471
A-4	0.16975	0.19879	0.18117
A-5	0.24081	0.24021	0.24055
A-6	0.11843	0.15323	0.13185
A-7	0.28029	0.24849	0.27980
A-8	0.16580	0.16980	0.16003
A-9	0.20528	0.24021	0.22243
A-10	0.14606	0.11182	0.15198
A-11	0.29608	0.28991	0.29088
A-12	0.12632	0.14909	0.13084
A-13	0.16975	0.16980	0.16506
A-14	0.12632	0.10353	0.11977
A-15	0.22502	0.21950	0.21237
A-16	0.11053	0.10353	0.10769
A-17	0.16580	0.21122	0.17211
A-18	0.27239	0.23607	0.28484
A-19	0.21712	0.21950	0.19425
A-20	0.13817	0.12838	0.13789
A-21	0.19344	0.21122	0.19324
A-22	0.09079	0.08283	0.09461
A-23	0.15001	0.13667	0.15902
A-24	0.24870	0.24849	0.23552
A-25	0.16580	0.19465	0.16607
A-26	0.20133	0.17808	0.21841
A-27	0.14606	0.14909	0.13688

Step3. The weighted normalized decision matrix (V_{ij}) values were given in the table 6.

Table 6. Weighted normalized decision matrix (V_{ij})

Run No. (Alternatives)	R_a	R_q	R_z
A-1	0.004112	0.11433	-0.006392
A-2	0.008389	0.18633	-0.01388

A-3	0.01184	0.28795	-0.01698
A-4	0.00707	0.20326	-0.01162
A-5	0.01003	0.24561	-0.01543
A-6	0.004934	0.15667	-0.008459
A-7	0.01167	0.25408	-0.01795
A-8	0.006908	0.17362	-0.01026
A-9	0.008554	0.24561	-0.01427
A-10	0.006086	0.11433	-0.00975
A-11	0.01233	0.29643	-0.01866
A-12	0.005263	0.15244	-0.00839
A-13	0.007073	0.17362	-0.01059
A-14	0.005263	0.10585	-0.007684
A-15	0.009376	0.22443	-0.01362
A-16	0.004605	0.10585	-0.006909
A-17	0.006908	0.21597	-0.01104
A-18	0.01135	0.24138	-0.01827
A-19	0.009047	0.22443	-0.01246
A-20	0.005757	0.13126	-0.00884
A-21	0.008060	0.21597	-0.01239
A-22	0.003783	0.08469	-0.00607
A-23	0.00625	0.13974	-0.01020
A-24	0.006908	0.25408	-0.01511
A-25	0.006908	0.19902	-0.01065
A-26	0.008389	0.18208	-0.01401
A-27	0.006086	0.15244	-0.00878

Step4. The Positive ideal solution (PIS) and Negative ideal solutions (NIS) values were given in the table 7.

Table 7. PIS & NIS Values

PIS	0.00378	0.08469	-0.01866
NIS	0.01233	0.29643	-0.00607

Step5. The separation values from the PIS and NIS were given in the table 8.

Table 8. Distance measures

Run No. (Alternatives)	S_i^+	S_i^-
A-1	0.03205	0.18228
A-2	0.10185	0.11044
A-3	0.20342	0.01382
A-4	0.11882	0.09348
A-5	0.16107	0.05172
A-6	0.07270	0.13997
A-7	0.16957	0.04398
A-8	0.08938	0.12300
A-9	0.16105	0.05161
A-10	0.03103	0.18224
A-11	0.21191	0.01259
A-12	0.06854	0.14418
A-13	0.08935	0.12300
A-14	0.02388	0.19071
A-15	0.13994	0.07245
A-16	0.02421	0.19073
A-17	0.13153	0.08079
A-18	0.15687	0.05639
A-19	0.13997	0.07235
A-20	0.04763	0.16532
A-21	0.13149	0.0808
A-22	0.01259	0.21191
A-23	0.05575	0.15686
A-24	0.16945	0.04364
A-25	0.11465	0.09766
A-26	0.09760	0.11469
A-27	0.06850	0.14415

Step6. The relative closeness coefficient values (C_i^+) to the ideal solutions were given in the table 9. The ranking of alternatives was given in the descending order of C_i^+ values.

Table 9. Relative closeness coefficient (C_i^+)

Run No. (Alternatives)	C_i^+	S/N of C_i^+	Rank
A-1	0.85046	-1.4069	5
A-2	0.52023	-5.6761	14
A-3	0.06361	-23.9295	26
A-4	0.44032	-7.1246	16
A-5	0.24305	-12.2861	22
A-6	0.65815	-3.6335	10
A-7	0.20594	-13.7252	24
A-8	0.57915	-4.7442	12
A-9	0.24268	-12.2993	23
A-10	0.85450	-1.3658	4
A-11	0.05608	-25.0238	27
A-12	0.67779	-3.3781	9
A-13	0.57923	-4.7430	11
A-14	0.88871	-1.0248	2
A-15	0.34111	-9.3421	19
A-16	0.88736	-1.0380	3
A-17	0.38051	-8.3927	18
A-18	0.26441	-11.5544	21
A-19	0.34075	-9.3513	20
A-20	0.77633	-2.1991	6
A-21	0.38061	-8.3904	17
A-22	0.94391	-0.5014	1
A-23	0.73778	-2.6415	7
A-24	0.20479	-13.7738	25
A-25	0.45998	-6.7452	15
A-26	0.54025	-5.3481	13
A-27	0.67787	-3.3771	8

The main effect plots were drawn for the Signal-to-Noise ratios of the relative closeness coefficient (C_i^+) by using the MINITAB-16 software and shown in the Fig.1. The main effect plot represents the changes in the response with an increase in the levels of process parameters. From the plot we can observe that the effect due to wire feed is high on the C_i^+ value.

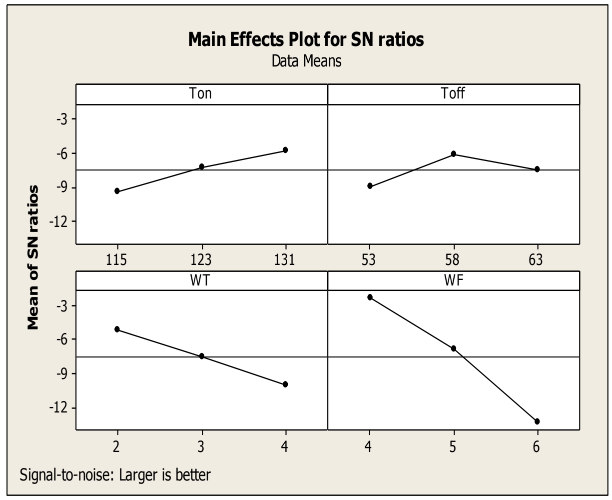

Fig 1: Main effect plot for S/N ratios of C_i^+

Analysis of variance (ANOVA) has been done to find the influence of process parameters on the response. ANOVA results of the relative closeness coefficient (C_i^+) were given in the table 10. From the results, it is clear that the Wire feed (WF) has high influence (F = 30.38) and Pulse off time (T_{OFF}) has low influence (F = 1.00) in affecting the relative closeness coefficient (C_i^+) value. The residual plots for C_i^+ values were drawn and shown in the Fig.2. From the residual plot, it is observed that the residuals are following a normal distribution and do not represent any particular pattern.

Table 10. ANOVA for C_i^+

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TON	2	0.10630	0.10630	0.05315	2.92	0.080
TOFF	2	0.03648	0.03648	0.01824	1.00	0.387
WT	2	0.23634	0.23634	0.11817	6.49	0.008
WF	2	1.10566	1.10566	0.55283	30.38	0.000
Error	18	0.32757	0.32757	0.01820		
Total	26	1.81235				

S = 0.134901; R^2 = 81.93%; R^2(Adj) = 73.89%

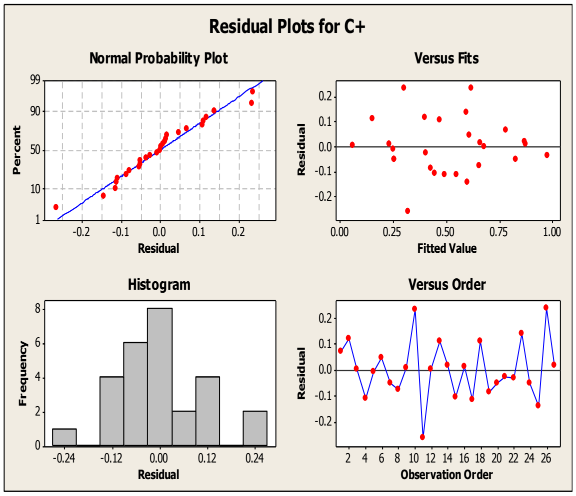

Fig 2: Residual plots for C_i^+

V. CONCLUSIONS

- From the TOPSIS and main effect plots for Signal-to-Noise ratios of the relative closeness coefficient (C_i^+), the optimal combination was found at
  Pulse on time (T_{ON}): 131µs
  Pulse off time (T_{OFF}): 58µs
  Wire Tension (WT): 2 Kgf
  Wire Feed (WF): 4 m/sec.
- From the ANOVA results, it is found that the Wire feed (WF) has high influence and Pulse off time (T_{OFF}) has low influence in affecting the relative closeness coefficient (C_i^+) value.
- From the residual plots for the relative closeness coefficient (C_i^+), it is clear that the residual are following a normal distribution.

REFERENCES

[1] M. K. 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, pp.492, 2013.

[2] Ch. Maheswara Rao and K.V. Subbaiah, "Effect and Optimization of EDM Process Parameters on Surface Roughness for EN41 Steel", *International Journal of Hybrid Information Technology*, Vol. 9(5), pp. 343-358, 2016.

[3] B. Kuriachen, J. Kunju Paul and J. Mathew, "Modelling of Wire Electrical Discharge Machining Parameters Using Titanium Alloy (Ti-6Al-4v)", *International Journal of Emerging Technology and Advanced Engineering*, vol.2, no.4, pp.377-381, 2012.

[4] 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, pp. 503-506, 2007.

[5] Ch. Maheswara Rao, K.V. Subbaiah, K. Sowjanya and K. Anusha, "Influence of Speed, Feed and Depth of Cut on Multiple Responses in CNC Turning", *International Journal of Advanced Science and Technology*, Vol. 92, pp. 59-76, 2016.

[6] P.S. Rao, K. Ramji and B. Satyanarayana, "Effect of WEDM Conditions on Surface Roughness: A Parametric Optimisation Using Taguchi Method", *International Journal of Advanced Engineering Sciences and Technologies*, vol. 6, pp. 041 – 048, 2011.

[7] Ch. Maheswara Rao and K. Venkatasubbaiah, "Optimization of Surface Roughness in CNC Turning Using Taguchi Method and ANOVA", *International Journal of Advanced Science and Technology*, Vol.93, pp.1-14, 2016.

[8] F. Han and J. Jiang, "Influence of Machining Parameters on Surface Roughness in Finish Cut of WEDM", The *International Journal of Advanced Manufacturing Technology*, vol. 34, Issue 5-6, pp. 538-546, 2007.

[9] M.A. Abo-Sinna and A.H. Amer, "Extensions of TOPSIS for Multi-Objective Large Scale Nonlinear Programming Problems", *Applied Mathematics and Computation 162*, pp.243-256, 2005.

[10] G.R. Jahanshahloo, F. Hosseinzadeh Lotfi and M.Lzadikhah, "An Algorithmic Method to Extend TOPSIS for Decision Making Problems with Interval Data", *Applied Mathematics and Computations*, 2005.

[11] M. Behzadian, S. Otaghsara, M. Yazdani and J. Ignatius, "A State-of-the-Art Survey of TOPSIS Applications", *Expert Systems with Applications, 39(17)*, pp. 13051-13069, 2012.

[12] Ch. Maheswara Rao and K.V. Subbaiah, "Application of WSM, WPM and TOPSIS Methods for the Optimization of Multiple Responses", *International Journal of Hybrid Information Technology*, vol. 9(10), pp. 59-72, 2016.

[13] Ch. Maheswara Rao and K.V. Subbaiah, "Application of MCDM Approach-TOPSIS for the Multi-Objective Optimization Problem", *International Journal of Grid and Distributed Computing*, Vol. 9(10), pp. 17-32, 2016.

[14] Y.Ic, "An Experimental Design Approach Using TOPSIS Method for the Selection of Computer-Integrated Manufacturing Technologies", *Robotics and Computer-Integrated Manufacturing*, vol.28(2), pp.245-256, 2012.

[15] S.H. Zanakis, A. Solomon, N. Wishart and S. Dublish, "Multi-Attribute Decision Making: A Simulation Comparison of Select Methods", *European Journal of Operational Research*, vol. 107, no.3, pp. 507-529, 1998.

[16] K.L. Wen, T.C. Chang and M.L. You, "The Grey Entropy and its Application in Weighting Analysis", *IEEE International Conference on Systems, Man and Cybernetics*, vol. 2, pp. 1842-1844, 1998.

[17] S.Ding and Z. Shi, "Studies on Incident Pattern Recognition Based on Information Entropy", *Journal of Information Science*, vol. 31, no. 6, 2005.

[18] M. Durairaj, D. Sudharsun and N. Swamynathan, "Surface Roughness Optimization in Wire Cut EDM Taguchi Method", *Proceedings of the National Conference on Fascinating Advancements in Mechanical Engineering*, pp.176, 2013.

[19] 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-1, no. 4, pp.1268, 2011.

[20] M. Nalbant, H. Gokkayya and G. Sur, "Application of Taguchi Method in the Optimization of Cutting for Surface Roughness in Turning", *Elsevier Journal, Measurement, vol. 44*, pp. 1379-1385, 2007.

[21] A. Vishal Parashar, J.L Rehman, Bhagoria and Y.M Puri, "Investigation and Optimization of Surface for Wire Cut Electro Discharge Machining of SS 304 Using Taguchi

Method", *International Journal of Engineering*, pp. 257-267, 2009.

[22] M.KAladhar, K. Venkata Subbaiah and C. Srinivasa Rao, "Determination of Optimal Process During Turning of AISI 304 Austenitic Stainless Steel Using Taguchi Method and ANOVA", *International Journal of Lean Thinking*, vol.3, Issue.1, 2012.

[23] Ch. Maheswara Rao, K.V. Subbaiah and Ch. Suresh, "Prediction of Optimal Designs for Material Removal Rate and Surface Roughness Characteristics", *International Journal of Lean Thinking*, Volume 7, Issue 2, pp. 24-46, 2016.

[24] B.M. Gopala Swamy, B. Mondal and S. Ghosh, "Taguchi Method and ANOVA: An Approach for Optimization of Hard Machining While Machining Hardened Steel", *Journal of Scientific and Industrial Research*, vol.68, pp. 686-695, 2009.